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STORAGE OF POTATOES: EFFECTS OF ETHYLENE AND 1-MCP ON POTATO TUBER QUALITY AND BIOCHEMISTRY

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STORAGE OF POTATOES: EFFECTS OF ETHYLENE AND 1-MCP ON POTATO TUBER QUALITY AND BIOCHEMISTRY

Supervisor: Professor Leon A. Terry

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ABSTRACT

Potatoes are widely consumed in UK and many other countries. There is a continuous demand for potatoes all year around both from consumers and retailers such that several postharvest technologies are being used to meet this demand. Sprouting is the main phenomenon affecting both the quality and marketability of potatoes during long term storage. Several sprout suppressants are widely used (e.g. maleic hydrazide and chloropropham, but there are concerns over their toxicity such that alternatives have been sought. Continuous exposure of potato tubers to ethylene (usually 10 μL L^{-1}) during storage was approved by the Chemicals Regulation Directorate since 2003. Even though potatoes have been regarded as non climacteric, this study aimed to examine the effect of different ethylene regimes in combination with or without 1-methylcyclopropene on physiological, biochemical and mechanical characteristics of a selection of important UK cultivars. In 2008-2009, ten potato cultivars were examined for their response to four different ethylene regimes during storage. Storage time and ethylene treatments had a cultivar specific effect on all the measured parameters (sprouting, sugars, texture). Ethylene applied after first indication of sprouting was as effective at sprout inhibition as when applied continuously for certain potato cultivars; therefore this could be considered as a more environmentally and economical alternative for sprouting inhibition. In addition, sugar accumulation was retarded when tubers were subjected to ethylene at the first indication of sprouting compared to those treated with continuous ethylene. In 2009-2010, four potato cultivars were studied and the effect of 1-MCP either before or after ethylene treatment on sprouting, respiration rate, endogenous ethylene production and texture was investigated. 1-MCP is believed

to interact with ethylene receptors and therefore prevent or retard ethylene dependent responses. 1-MCP seemed to effectively block ethylene binding sites when applied before storage of tubers in ethylene resulting in less tuber sugar accumulation. In 2010-2011, the effect and timings of 1-MCP and ethylene treatments on sprouting, tuber respiration, endogenous ethylene production and sugars on two potato cultivars was studied. 1-MCP effectively suppressed the action of ethylene in terms of the increase in the respiration rate or ethylene production and sugar accumulation. Selected potato samples were also analysed quantitavely for an array of phytohormone using a newly developed UPLC QToF MS method. This method had the advantage of quantifying simultaneously a significant number of plant growth regulators that are present in potato (ABA and its metabolites, cytokinins and gibberellins).

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Last but not least, I would like to thank my parents and Sister and all my friends for believing in me and supporting me throughout these years.

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LIST OF ABBREVIATIONS

AAO3	Aldehyde oxidase
ABA	Abscisic acid
ABA-GE	Abscisic acid glucose ester
ACC	1-aminocyclopropane- 1-carboxylic acid
ANOVA	Analysis of Variance
AU	Australia
A_0	Surface area of the probe
BL	Baseline
BOC	British Oxygen Company
Ca	Calcium
cat.	category
ca.	circa
CA	Controlled Atmosphere
cf.	compare
CRD	Chemical Regulations Directorate
CIPC	Chloropropham
CO_2	Carbon dioxide
CTRL	control (air)
CV	cultivar
CZ	Czech Republic
cv.	cultivar
DHZ	dihydrozeatin

DHZR	dihydrozeatin riboside
DPA	dihydrophaseic acid
DW	dry weight
d	deuterated
E_{ap}	apparent elasticity
ELISA	Enzyme-linked immunosorbent assay
EPA	Environmental Protection Agency
epi-DPA	epimer- dihydrophaseic acid
ETHY	ethylene
et al.	and others
FID	Flame Ionization Detector
FW	fresh weight
g	gram
GAs	gibberellins
GA_1	Gibberellin 1
GA_4	Gibberellin 4
GC	Gas Chromatography
h	hour
HPLC	High Performance Liquid Chromatography
HPP	Hydrogen Peroxide Plus
IAA	Indole-3-acetic acid
IARC	International Agency for Research on Cancer
i.e.	for example

IL	Ilinois
IPA	Isopentenyladenosine
JA	Jasmonic acid
Kg	kilogram
kPa	kilopascal
L.	Linnaeus
L	litre
LC-MS/MS	Liquid Chromatography – Mass Spectrometry/Mass Spectrometry
Lincs.	Lincolnshire
LSD	Least Significant Difference
Ltd.	Limited
l_0	thickness of the sample slice
M	Molarity
MCP	1-Methylcyclopropene
MeJA	Methyl jasmonate
mg	milligram
min.	minute
mm	millimetre
mM	milimolar
mmol	millimole
μL	microlitre
MRM	Multiple Reaction Monitoring
MS	Mass Spectrometry
m/z	mass to charge ratio

n	number
N	Newton
ng	nanogram
NH_4OH	Ammonium Hydroxide
no.	number
NSY	neoxanthin synthase
NY	New York
N_2	nitrogen
OH	Hydroxide
Out	Outturn
O_2	Oxygene
PA	phaseic acid
PCA	Principal Component analysis
PGRs	Plant Growth Regulators
PLS-DA	Partial Least Square Discriminant Analysis
PTFE	Polytetrafluoroethylene
P1	period 1
Q-TOF	Quadrupole time-of-flight mass spectrometer
RfD	Reference dose
RH	Relative Humidity
RT	retention time
SAM	S-adenosylmethionine
SBCSR	Sutton Bridge Crop Storage Research
SCRI	Scottish Crop Research Institute

s-ABA	S- Abscisic acid
TOF	time of flight
Treat.	treatment
T1	time 1
UK	United Kingdom
USA	United States of America
V	volt
v/v	volume/volume
VDE	Violaxanthin de-epoxidase
viz.	namely
Z	zeatin
ZEP	Zeaxanthin epoxidase
ZR	zeatin riboside
1-MCP	1-Methylcyclopropene
1,4-DMN	1,4-dimethylnaphthalene
2iP	Isopentenyladenine
^{o}C	Celsius degrees

CHAPTER ONE
GENERAL INTRODUCTION

1.1 Project Background

Potato (*Solanum tuberosum* L.) is one of the most important crops worldwide and has a high nutritional value. Potatoes are widely consumed in UK and many other countries. Successful potato storage can be achieved by effective sprout control of the tubers, which is important for both the pre-packing and processing markets (Briddon, 2006). Thus, complete inhibition of sprouting is an indicator of good quality of the tubers. Storage of tubers at low temperatures and the application of sprout suppressants, such as maleic hydrazide and chlorpropham are common ways of suppressing sprouting incidence (Prange *et al.*, 1998). However, low temperature promotes the conversion of starch to sugars, leading to subsequent tuber sweetening. During processing of potatoes at high temperatures (e.g. frying), acrylamide is formed via the Maillard reaction, leading to potato tissue darkening, causing an undesirable appearance and taste to the consumers (Blenkinsop *et al*, 2002b). Acrylamide is genotoxic and a potential carcinogen for humans (de Wilde *et al.*, 2006). It is classified in group 2A by the IARC (International Agency for Research on Cancer, 2002). Given the general public resistance to postharvest chemical treatments and concerns over CIPC alternative methods of sprout control are being sought.

Even though potatoes are non-climacteric, ethylene application can successfully extend potato tuber storage by suppressing sprouting incidence. In 2003, the Chemical Regulations Directorate (CRD) in the UK approved the use of a 50 μL L^{-1} ethylene during long term storage; however only 10 μL L^{-1} is commonly used (Briddon, 2006). Prange *et al.* (2005) have reported the effective sprout inhibition in 'Russet Burbank' potatoes when they

were continuously exposed to 4 μL L^{-1} ethylene. Additionally, they reported that the use of ethylene at concentrations of 40-400 μL L^{-1}resulted in better sprout inhibition and also had a positive effect in reducing sugar accumulation of the same cultivar. This suggests that there may be different metabolic pathways that control ethylene-induced sweetening and sprout inhibition (Daniels-Lake *et al.*, 2007).

1.2 Aim and objectives

1.2.1 Aim

The aim of this project was to further elucidate the physiological, biochemical and rheological effects of ethylene (and in combination with 1-MCP) on potato during storage using detailed chemometric analysis.

1.2.2 Objectives

- To profile the effect of ethylene treatment on sprout suppression and allied temporal changes in both taste- and health-related compounds and texture during storage
- To assess the efficacy of ethylene and 1-MCP treatment, timing of application, method of application (*viz.* no ethylene, initial ethylene, continuous ethylene and ramped ethylene and also 1-MCP application before or after ethylene storage)
- To profile the effect of ethylene treatment on temporal changes in plant growth regulators
- To provide guidelines to storage practitioners on potentially more efficacious use of ethylene to prolong potato storage whilst maintaining product quality for both the fresh and processing markets

1.3 Thesis structure

This thesis is comprised of nine chapters. The Literature Review is presented in Chapter 2. Materials and Methods used in this study are shown in Chapter 3. Experiments 1-3 that were conducted in years 2008-2009 are included in Chapter 4. Chapter 5 is constituted by experiments 4-7 that were conducted in years 2009-2010, while Chapter 6 represents the experiment 8 that was performed in years 2010-2011. Phytohormones analysis in selected potato samples during years 2008-2011 is included in Chapter 7. General discussion and conclusions of this project are presented in Chapter 8. References are provided in Chapter 9. Appendices A, B, C and D include all ANOVA tables that correspond to Chapters 4, 5, 6 and 7 respectively. Appendix E shows the report that was produced by Sutton Bridge Crop Storage Research Unit (SBCSR) on the relative dormancy break evaluation. Appendix F includes a report on project R298 (SBCSR) which was also conducted during year 2008-2009. Appendix G includes all abstracts of papers that were presented at International Conferences, as described below.

Results from this work have already been presented at the following International Conferences:

- **Sofia G. Foukaraki**, Gemma A. Chope and Leon A. Terry. Differential effect of ethylene treatments on non-structural carbohydrate composition of six UK-grown potato cultivars. 7*th international Postharvest Symposium, Kuala Lumpur, Malaysia, 25-29 June 2012* (oral presentation)

- José Juan Ordaz Ortiz, **Sofia G. Foukaraki** and Leon A. Terry. A new liquid chromatography tandem ultra-high definition accurate mass spectrometry for the simultaneous quantitation of nine plant hormones in fruits and vegetables. 7*th international Postharvest Symposium, Kuala Lumpur, Malaysia, 25-29 June 2012* (oral presentation)

- **Sofia G. Foukaraki**, Gemma A. Chope and Leon A. Terry. 1-MCP application before continuous ethylene storage suppresses sugar accumulation in the UK-grown potato cv. Marfona. 4th Postharvest Unlimited 2011, Leavenworth, WA, USA, 23-26 May 2011 (oral presentation)

- **Sofia G. Foukaraki**, Gemma A. Chope and Leon A. Terry. Ethylene exposure after dormancy break is as effective in controlling sprout growth as continuous ethylene for some UK-grown potato cultivars. *28th International Horticultural Congress, Lisbon, Portugal, 22-27 August 2010* (oral presentation)

- **Sofia G. Foukaraki**, Gemma A. Chope and Leon A. Terry. Effect of transition between ethylene and air storage on two potato varieties. *8th International Symposium on the Plant Hormone Ethylene, Cornell University, Ithaca, New York, USA, 21-25 June 2009* (oral presentation)

- **Sofia G. Foukaraki**, Gemma A. Chope and Leon A. Terry. Differential effect of ethylene on sugars in UK-grown potato cultivars during storage. *6th International Postharvest Symposium, Antalya, Turkey 8-12 April, 2009* (poster presentation)

1.4 Declaration

Eye movement and dormancy break evaluation assessments (Chapter Three, Sections 3.3, 3.4 and Appendix E) were carried out in SBCSR by Graeme Stroud in all three years of the study. All experiments took place in the storage facilities at SBCSR (Chapter Three, Section 3.5). ABA extraction (Chapter Three, Section 3.9.3, sub-Section 3.9.3.1) was carried out by the author; however analysis using LC/MS-MS was conducted by Dr. Gemma A. Chope of the Plant Science Laboratory, Cranfield University. Phytohormone extraction and quantification (Chapter Three, Section 3.9.3, sub-Section 3.9.3.2) was conducted by the author under the supervision of Dr. José Juan Ordaz Ortiz of Plant Science Laboratory, Cranfield University. All other work described in this thesis was carried out by the author.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Potato (*Solanum tuberosum* L.) belongs to the family Solanaceae, along with other species such as tomato, tobacco, pepper, and more (Salunkhe and Kadam, 1998). Potato is the fourth largest crop worldwide after maize, wheat and rice, with an annual production of more than 206 million tonnes (FAOSTAT, 2009). It is highly valued as it provides an excellent source of nutrients and vitamins (Suttle, 2008a).

Managing potato tuber dormancy is of considerable importance for both the pre-packing and processing markets, as well as for the seed industry (Wiltshire and Cobb, 1996). Sprouting is a major cause of loss during storage, since it reduces the number of marketable potatoes. Tuber fresh weight decreases when water evaporates from sprout surfaces (Afek *et al.*, 2000). Storing potatoes at low temperatures (2 to 4°C) and the application of sprout suppressants are effective methods of prolonging potato storage life (Rastovski, 1987; Khanbari and Thompson, 1996; Prange *et al.*, 1998). However, low temperatures can cause non-structural carbohydrate conversion, with a subsequent increase in tuber sweetness (Ross and Davies, 1992). During frying of potatoes, acrylamide is formed via the Maillard reaction, leading to darker coloured potato chips. This is undesirable for consumers, due to the appearance and allied bitter taste of the potatoes (Blenkinsop *et al.*, 2002b).

Potatoes can be divided into four groups: first early, second early, the early main crop and the late maincrop (Burton, 1989). First early potatoes (e.g. cvs. Duke of York and Premiere) are planted from January - March for consumption in May to July. The second earlies (e.g. cvs. Estima and Marfona) are planted between February and May and harvested from July to October. The early main crop potatoes (e.g. cvs. Desiree, King Edward and Maris Piper) are planted between March and May and harvested from September to October. Both second early and mains are available in supermarket stores throughout the year. Planting of late potatoes such as cv. Russett Burbank occurs between middle of July and early August. There is a year-round demand for consumption, because potatoes are a staple food in the UK diet, therefore the regulation of potato tuber dormancy and sprout suppression is of major importance in this long-storage crop (Sonnewald, 2001). However, despite the nutritional properties of potatoes, they are not included in the UK Government's "Five A Day" campaign for improved public health (Terry, 2008).

2.2 The potato life cycle

The potato tuber is a modified stem that grows underground on a stolon. The eye-shaped depressions on the potato tuber are actually the dormant buds, which give rise to new shoots. Usually tubers are oval in shape, but differences can occur according to cultivar (Rastovski and van Es, 1978). When the buds of the potato tuber are unable to grow under favourable conditions, they are considered to be dormant (Coleman, 1987). Potato tubers are naturally dormant for 1 to 15 weeks (Wiltshire and Cobb, 1996). The dormancy of potatoes is of great importance and a long dormancy period is desirable, since the potato crop can be subjected to long-term storage (Alexopoulos *et*

al., 2007). When this period of dormancy ends, sprout growth can only be suppressed by artificial means, such as low temperature storage (Rastovski, 1978; Wiltshire and Cobb, 1996). Dormancy release is a process during which the buds grow and develop gradually (Coleman, 1987). For the potato industry, an extended dormancy period is preferred, when potatoes are going to be processed. A long-lasting dormancy period is not needed when tubers are going to be used as seed (Suttle, 2008b).

The potato life cycle in the field has been divided into seven stages *viz*. seed germination and emergence, tuber dormancy, tuber sprouting, emergence and shoot expansion, flowering, tuber development, and senescence (Jefferies and Lawson, 1991). In stage 1, seed germination and emergence, the dry seed is taken as the point where plants derive from true seed. In stage 2, tuber dormancy is considered to be the state of the tuber when no sprouting will take place even under favourable conditions. In the third stage, tuber sprouting is where the eyes break dormancy and produce sprouts. In the fourth stage, at tuber emergence and shoot expansion, potato plants are already planted in the ground and their shoots expand. The fifth stage of flowering follows after shoot expansion, while tuber development is the most important step in the potato cycle, where the initiation and development of the tubers takes place. Tuber development stage is of great importance, in terms of harvesting a commercially accepted product of appropriate size. In the stage of senescence, the canopy goes through a phase of maturation. During this phase, maleic-hydrazide is sometime applied before yellowing, in order for the tuber size to be controlled and achieve a reduction of sprouting during storage (Jefferies and Lawson, 1991). In the store, potato life cycle is divided into 4 stages, *viz*. stage 1, at the time of harvest; stage 2, the dormancy period; stage 3, when tubers break dormancy and stage 4, at the time of sprouting (Claasens and Vreugdenhill,

2000). Potatoes destined for storage first undergo a curing process, where they are held at 10-15°C for 2 weeks, which allows surface drying, periderm formation and wound healing (Wiltshire and Cobb, 1996). After this period of curing, the potatoes are typically brought down to a storage temperature by 0.5°C per day (Adrian Briddon, SBCSR, personal communication).

2.3 Postharvest factors affecting dormancy and sprout growth

The dormancy period is highly dependent on variety, but can also be modified according to storage conditions (Coleman, 1987). Dormancy release in storage leads to sprouting; an unacceptable condition, especially when potatoes are going to be processed (Suttle, 2000). The duration of tuber dormancy also depends on the environmental conditions that exist during tuber development on the mother plant (Burton, 1989).

Plant dormancy can be further subdivided into three distrinct types: endodormancy, paradormancy and ecodormancy (Lang *et al.*, 1987). During the period of these different types, the structure of the meristem is affected by internal physiological factors (endodormancy), external physiological factors (paradormancy) or external environmental factors (ecodormancy). After the tuber formation, the eyes are endodormant and will not sprout. During storage, tubers begin to sprout (endodormancy ends). At this stage, one sprout is usually the dominant one that inhibits the growth of the paradormant eyes. When tubers are stored at 3°C, they will not sprout and they remain at the stage of ecodormancy (Suttle, 2007).

2.3.1 Storage temperature

Storage temperature plays a vital role in defining storage duration. Accordingly, dormancy release and subsequent sprout suppression depends upon storage temperature. Immediately after harvest tubers are placed in store rooms at 10-15°C to cure. The curing process results in healing of wounds, as well as the thickening of the periderm (Salunkhe and Kadam, 1998). After curing, potatoes are stored at low temperatures to inhibit sprouting and therefore extend storage life of the tubers. Storage of potatoes at low temperatures (2-5°C) results in degradation of starch to sugars (Ross and Davies, 1992). High sugar concentrations and the presence of high acrylamide concentrations (when potatoes are cooked at high temperatures of 150-190°C) leads to a dark brown colour of the potatoes during frying (de Wilde *et al.*, 2005). Low temperature storage of potatoes can also increase the accumulation of toxic compounds, such as glycoalkaloids, especially when tubers are exposed to light (Griffiths *et al.*, 1998). When potatoes cv. Russett Burbank were stored at 20°C, dormancy was released and sprout growth began after 35 to 50 days of storage. However, dormancy was released after 50 to 80 days of storage when potatoes were stored at 3°C, but subsequent sprouting occurred only after transfer to 20°C (Suttle, 1995). Also, temperatures of 10°C may delay dormancy breakage and sprout development, but tubers typically need to be treated with disease control chemicals and a sprout suppressant (Burton, 1989).

2.3.2 Controlled atmosphere

The study of the ideal controlled atmosphere (CA) conditions for the storage of potatoes is of importance, since the dormancy can be regulated using this technique. Dormancy of potato cvs. Bliss Triumph and Irish Cobbler was broken after exposure to

CA conditions of 40-60 kPa CO_2 and 20 kPa O_2 continuously for 3-7 days at 25°C (Thornton, 1933). Later, Thornton (1939) hypothesized that a higher concentration of O_2 (20-80 kPa) could cause dormancy release, but this hypothesis was rejected by other scientists (Sawyer and Smith, 1955). Khanbari and Thompson (1996) have also studied the effect of different gaseous combinations to control sprouting. Record, Saturna and Hermes varieties that were stored in 9.4 kPa CO_2 and 3.6 kPa O_2 for 25 weeks, did not sprout and also maintained lower water loss and healthier skin. Subsequent storage of the same cultivars at 5°C for additionally 20 weeks was also successful in inhibiting sprouting. More research is needed on understanding the effects of CA and elevated CO_2 on different potato varieties and the influence of different gas mixtures (especially endogenously produced CO_2) on taste and flavour.

2.3.3 Chemical treatments

A number of chemical compounds have been introduced to reduce or inhibit sprout growth in potatoes. The effects of chlorpropham (CIPC) and ethylene have been extensively studied (Blenkinsop *et al.,* 2002a). Other chemical compounds that have also been used but not extensively are hydrogen peroxide plus (HPP) and 1,4-dimethylnaphthalene (1,4-DMN). Afek etal. (2000) achieved complete sprout suppression of cv. Desiree potatoes when treated with HPP for 10 h and then stored for 6 months at 10±1°C. 1,4-DMN can be applied as a vapour and is recommended at a rate of 20 μL L^{-1}. However, its use as a sprout suppressant needs more investigation to examine whether it is environmentally safe (Oteef, 2008). The effects of CIPC and ethylene are discussed below.

2.3.3.1 Chlorpropham (CIPC)

Chlorpropham (isopropyl N-(3-chlorophenyl) carbamate) was introduced in 1951 by Witman and Newman as a herbicide (Balaji *et al.*, 2006) and is widely used for managing potato storage. Usually, CIPC is used as a fog applied to potato tubers once or twice during storage. Care should be taken to not exceed Environmental Protection Agency (EPA) residue values (Blenkinsop *et al.*, 2002a). According to the EPA, the daily exposure to humans (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime is expressed as oral Reference Dose (RfD) and for chlropropham this is defined as 2×10^{-1} mg Kg^{-1} day^{-1} (EPA, 2008). Application of CIPC may also negatively affect the reducing sugar concentration and colour quality of potatoes when they are processed for frying (Burton *et al.*, 1992). However, CIPC that was applied as a continuous concentration of 36 mg L^{-1} on the potatoes stored in darkness at 10-12°C and 95% RH showed no significant difference in chip colour quality or tuber sugar concentrations (Blenkinsop *et al.*, 2002a). CIPC has been the world's leading sprout suppressant for potatoes and the only effective solution for storing crops for prolonged periods. The Potato Council in association with Glasgow University have launched a stewardship action plan on CIPC, in order to inform farmers about limitations that exist for this pesticide.

2.3.3.2 Ethylene and 1-MCP

The biosynthetic pathway of ethylene was firstly described by Yang and Hoffmann (1984) (Figure 2.1). This shows that methionine is firstly converted to S-adenosylmethionine (SAM) and then 1-aminocyclopropane-1-carboxylic acid (ACC) is formed by ACC synthase. ACC is subsequently converted to ethylene through the ACC

oxidase enzyme (Bradford, 2008). Most research had been focused on the role of ethylene on climacteric systems. There is a paucity of research on establishing the effect and role that ethylene has in non-climacteric crop systems.

Ethylene was initially reported to have a dormancy breaking effect on potatoes in 1925 by Rosa, but later there were investigations suggesting the opposite effect of sprout suppression could be achieved (Briddon, 2006). Rylski *et al.* (1974) effectively explained these reverse effects. After 72 h of short term storage and exposure to 0.02-20 μL ethylene L^{-1}, dormancy break was induced in cv. Russett Burbank potatoes. However the effects were more intense than in cv. White Rose, where continuous ethylene exposure at 2 μL ethylene L^{-1} completely inhibited sprouting. Therefore, there is a consensus that short-term exposure to ethylene promoted dormancy release, whilst long-term exposure prolonged sprout suppression. However, the mechanism for this differential response is unknown.

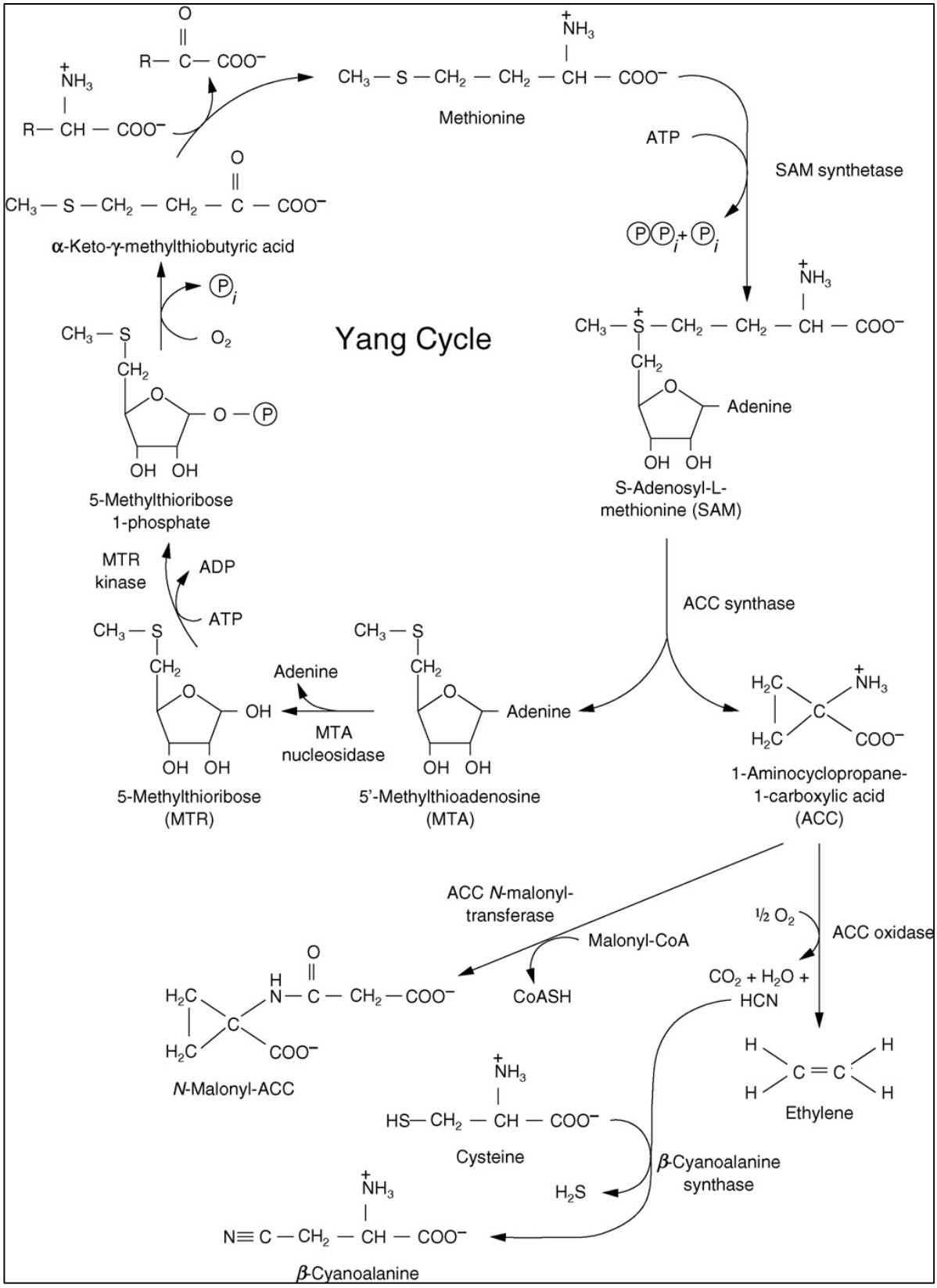

Figure 2.1. The Yang Cycle and formation of ethylene and other products from ACC (after Bradford, 2008)

Ethylene as a commercial sprout suppressant was introduced by Greenvale-AP (UK) in 2001. In 2003, approval of ethylene use was given in the UK by the Chemicals Regulation Directorate (CRD), and until 2006, the approved ethylene concentration was 10 μL L^{-1}, a level at which, when combined with low temperatures, gives satisfactory sprout suppresion (Briddon, 2006). A revised approval of ethylene was reported in 2006, increasing the concentration to 50 mg L^{-1} for seed potatoes. In 2008, the Biofresh Company was the first to be awarded a UK Pesticide Safety Directorate license to use ethylene in potato sprouting systems and this excluded CIPC and other pesticides from storage treatments. Two systems are currently commercially available in UK; the Biofresh (http://www.bio-fresh.com/index) and the Restain (www.restrain.eu.com) system. The Biofresh system introduces pure ethylene from cylinders of this gas and is either integrated into the store's fan/refrigeration control system or to an auxiliary fan and allows the introduction of ethylene only when the fans are operating. The Restrain system uses an electrochemical cell for sensing ethylene and the gas is generated from an ethanol based fuel that is held in the storage tank. The difference between the two systems is that the Biofresh requires permanent installation and can control more than one store at the same time, while the Restrain is absolutely portable and can only be used for a single storage unit.

Ethylene is used to inhibit sprout growth in stored potatoes, but during subsequent processing, fry colour darkening can occur in some cvs. (e.g. Russett Burbank) (Daniels-Lake *et al.*,2005). Ethylene has also been reported to cause deterioration in texture and flavour of the cvs. Maris Piper, Marfona and King Edward (Briddon, 2006). Maris Piper and King Edward showed a more "waxy" flavour, but Marfona resulted in a more "nutty" flavour when stored at 3.5°C (Briddon, 2006). Ethylene increases tuber

respiration rate and promotes conversion of starch to sugars, thus potentially increasing the sugar concentration of Russett Burbank potatoes (Day *et al.*, 1978; Prange *et al.*, 1998). Potatoes produce ethylene at very low concentrations (0.1 μL^{-1} Kg^{-1} h^{-1} at 20°C) and their sensitivity to ethylene is thought to be low (Chope and Terry, 2008). Effective sprout suppression was achieved in potatoes cv. Russett Burbank continuously exposed to 4 μL L^{-1} ethylene for 23-33 weeks (Prange *et al.*, 2005). However, 40-400 μL L^{-1} ethylene had better sprout inhibition in potatoes cv. Russett Burbank, as well reduced darkening after frying compared to a lower concentration of ethylene at 4 μL L^{-1} at 20 and 25 weeks (Daniels-Lake *et al.*, 2005). This suggests that there are different metabolic pathways controlling ethylene-induced sweetening and sprout inhibition (Daniels-Lake *et al.*, 2007). However, the effects of different ethylene concentrations and timing of application should be examined to better understand the effect on sugar metabolism and sprout inhibition. The role of ethylene in mediating potato sprouting and dormancy is not yet known.

1-Methylcyclopropene (1-MCP) has anti-ethylene effects and is thought to block the ethylene binding sites in plant cells (Blankenship and Dole, 2003; Prange and DeLong, 2003; Watkins, 2006). 1-MCP gas treatment has been widely used on a great range of fruits, vegetables and ornamentals and has been shown to reduce the effects of ethylene on them (Blankenship and Dole, 2003). Depending on the species, 1-MCP may have different effects on respiration, ethylene production, volatile production and sugars (Blankenship and Dole, 2003). Fry colour darkening was avoided in potatoes cv. Shepody stored at 9°C, when treated with 4 μL L^{-1} ethylene and 0.9 μL L^{-1} 1-MCP monthly or bimonthly (Prange *et al.*, 2005). Therefore, 1-MCP appeared to reduce sugar accumulation in potato tubers, while ethylene caused the opposite. However,

these findings contradict results reported by Chope *et al.* (2007) on onions. When onion cv. SS1 bulbs were treated with 1 μL L^{-1} 1-MCP and stored at 12°C, a higher sugar concentration was maintained, probably due to reduced carbohydrate catabolism (Chope *et al.,* 2007). This contradiction may be a result of the differences between the two crops. Onions grow from the inside of the bulb, but potatoes sprout from the outer surface. Onions accumulate fructans, but potatoes store starch. Considering these differences between onions and potatoes, an explanation is still required to explain these contradictory results. Even if 1-MCP behaves differently compared to ethylene and has the opposite effect when applied, there may be mechanisms under which both of them act synergistically. The contribution of endogenous ethylene should be taken into account and clearly gaps in understanding remain.

2.4 Biochemical changes occurring in potato tubers during storage and sprouting

The concentrations of many biochemical substances change during storage, including carbohydrates, plant growth regulators and many compounds related to health and taste such as glycoalkaloids and phenolics.

2.4.1 Plant Growth Regulators (PGRs)

Plant hormones have been found to play an important role in potato tuber dormancy (Hemberg, 1985; Coleman, 1987; Wilshire and Cobb, 1996; Claassens and Vreugdenhil, 2000; Galuszka *et al.,* 2008). Auxins do not have an influence on dormancy, but appear to inhibit sprout growth (Hemberg, 1985). Gibberellins (GAs)

and cytokinins promote growth, whereas abscisic acid (ABA) and ethylene can inhibit sprouting (Sonnewald, 2001). Jasmonates have been found to have a significant role in potato tuber dormancy also, but most of the research is focused on their effects *in-vitro*. The role of plant growth regulators on potato tuber dormancy and sprout suppression are discussed below, while ethylene was discussed in Section 1.3.3.2.

2.4.1.1 Gibberellins

Dormancy release may be achieved by the application of exogenous gibberellins (GAs) during tuber growth on the mother plant (van Ittersum and Scholte, 1993), but Alexopoulos *et al.* (2006) have shown that it depends on the plant growth stage and the potato tuber development at the time of GA_3 application. Potato cv. Chacasina F1 tubers were cut at the point of detachment of the stolon and then the cut surface was treated with a solution of 10 mg L^{-1} GA_3 and 10 mg L^{-1} of the cytokinin benzyl adenine (BA, 6-benzylaminopurine) ten days after harvest and stored in the dark at 5±1, 10±1 and 20±1°C and 85±5 % RH (Alexopoulos *et al.*, 2007). The application of GA_3 alone or in combination with BA caused faster release of dormancy in tubers stored at 10 and 20°C, but not at 5°C. The weight loss and the respiratory activity of the tubers were also increased at 10 and 20°C (Alexopoulos *et al.*, 2007). The effect of temperature played a key role in defining storage life, since under higher temperatures the synergistic effect of GA_3 and BA induced dormancy breaking. Gibberellins have been shown to play an important role in tuber dormancy, but more research is needed to understand their effect and any possible interaction with ethylene and other PGRs.

2.4.1.2 Abscisic acid

According to the biosynthetic pathway of ABA (Figure 2.2), violaxanthin is synthesised through the catalysis of zeaxanthin epoxidase (ZEP), while the opposite reaction occurs in chloroplasts under high light conditions and the catalysis takes place through violaxanthin de-epoxidase (VDE). Two cis-isomers of both violaxanthin and neoxanthin are formed through neoxanthin synthase (NSY) and an isomerase enzyme. Xanthosin is converted to abscisic aldehyde by ABA2 hydrogenase and then is oxidised into ABA by an abscisic acid aldehyde oxidase (AAO3) (Figure 2.2). ABA catabolism (Figure 2.3) is mainly divided into two different types of reaction, hydroxylation and conjugation. The 8'-hydroxylation is actually the major regulatory step in physiological events controlled by ABA, while PA (phaseic acid) and DPA (dihydrophaseic acid) are the most widespread and abundant catabolites (Zeevaart and Creelman, 1988; Cutler and Krochko, 1999). On the other hand, ABA glucosyl ester (ABA-GE) is the most widespread conjugate in the ABA conjugation.

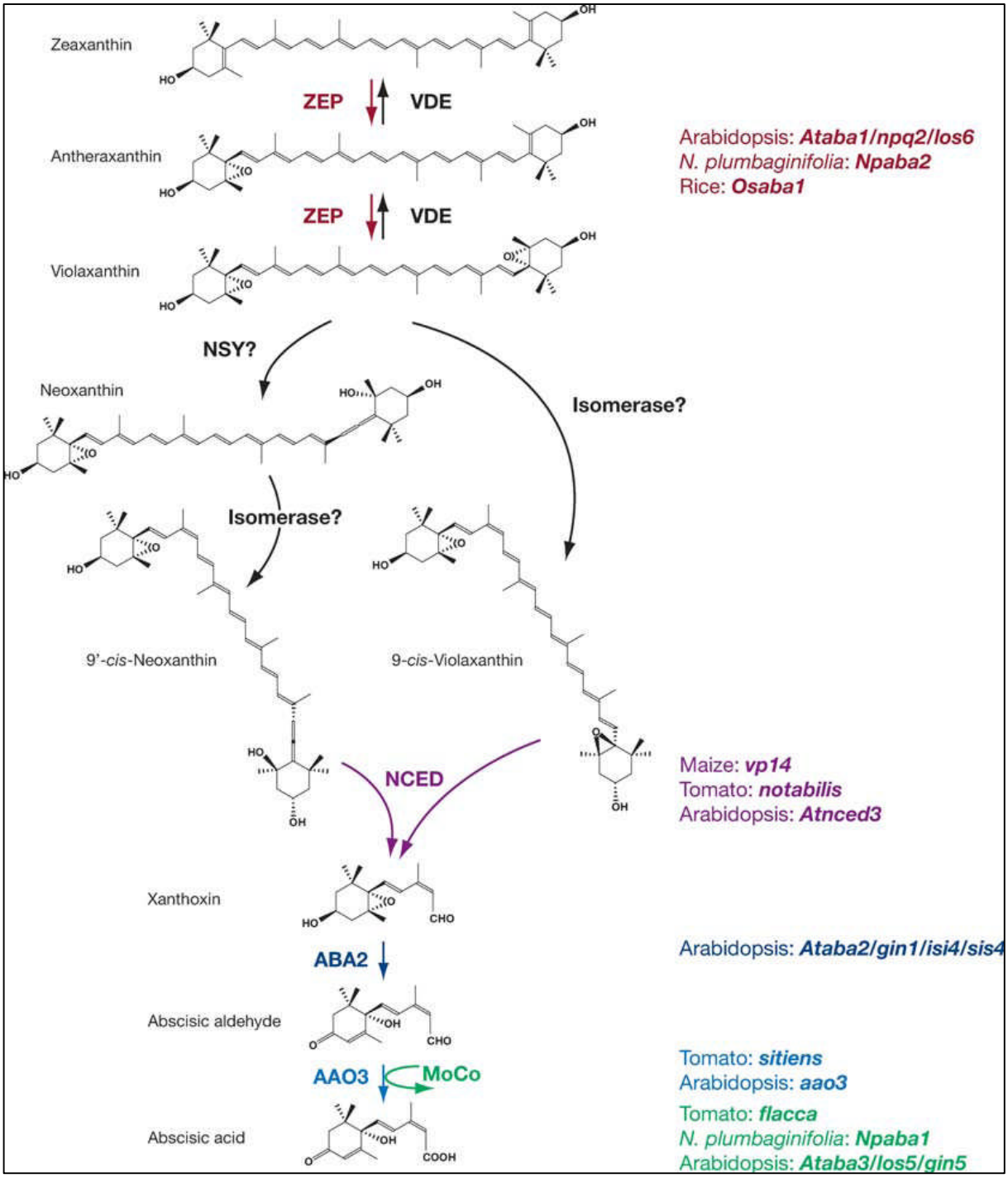

Figure 2.2 ABA biosynthetic pathway (after Nambara and Marion-Poll, 2005)

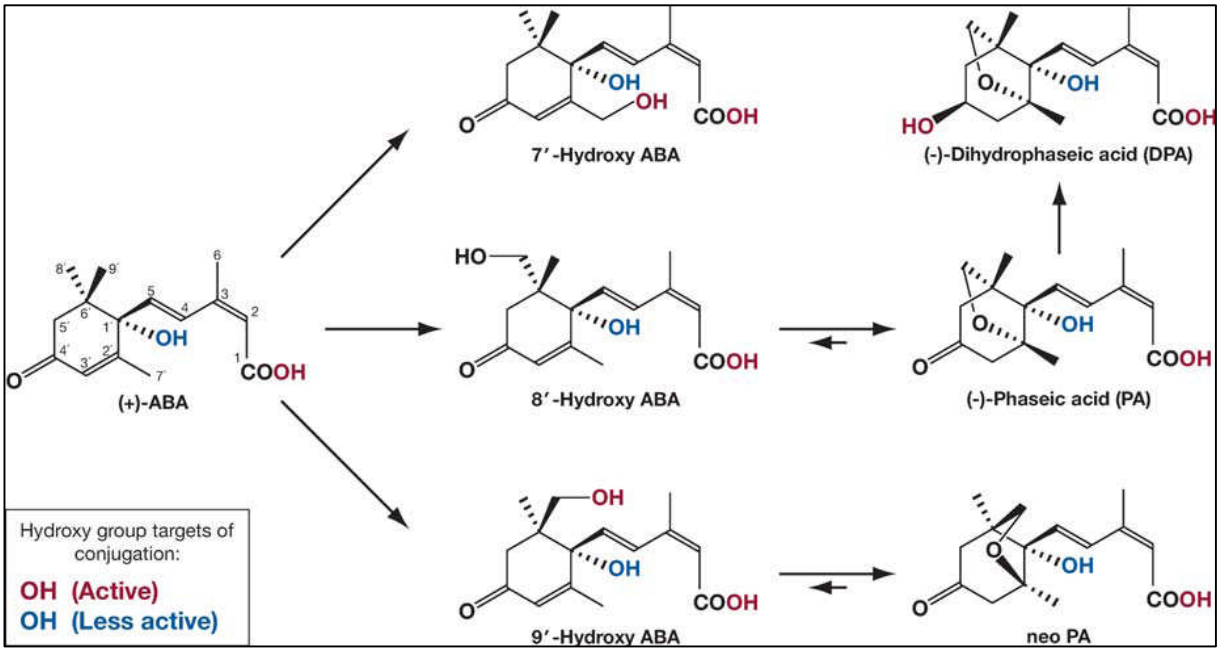

Figure 2.3 ABA catabolic pathways (after Nambara and Marion-Poll, 2005)

Many scientists have demonstrated a connection between ABA, dormancy and sprout suppression in potatoes (Suttle and Hultstrand, 1994; Destefano-Beltrán *et al.*, 2006a, b). At the time of harvest, potato tuber ABA concentration was high, but subsequently decreased (concentrations not reported) during storage for cvs. Alwara, Semena, Ivetta, Adretta, Eersteling and Pana (Biemelt *et al.*, 2000). Similar results were also reported by Chope *et al.* (2006) for specific onion cultivars. Sonnewald (2001) reported that the decline in ABA concentration coincided with dormancy release, and ABA levels decreased below a threshold level (again the concentration was not reported) before tuber sprouting occurred. This contradicts the findings of Suttle (1995), who demonstrated that although ABA concentration decreased during storage of potatoes, there was no threshold level below which sprouting could not occur. However, according to Suttle (1995), regardless of the temperature (whether tubers

were stored at 20 or 3°C), the ABA levels declined during storage. More specifically, the endogenous ABA concentration (measured by reversed phase HPLC) of potatoes cv. Russett Burbank stored at 3°C for 35 days was higher compared to tubers that were transferred from 3 to 20°C and also those that were stored only in 20°C. Summarizing the findings above, although sprouting was delayed with time, low temperature conditions caused higher ABA levels. Biemelt *et al.* (2000) demonstrated that ABA concentration in different potato varieties (that were quantified with an ELISA test) gradually declined during a 24-week storage period in darkness at room temperature, but found no correlation between ABA concentration and sprouting. Exceptions to the above findings also exist compared to earlier findings, especially when the experiments are conducted under different circumstances and analyses is performed using different methods. According to Coleman and King (1984), dormancy release occurred at 10°C, but ABA levels measured with a GC-MS actually increased at lowest temperatures of 2°C during a 11-month period of experiments. The effect of absence or presence of light in combination with storage temperatures could possibly be a key factor and give a good explanation of these differences in ABA content in potatoes. Therefore, the role of ABA in potato tuber dormancy remains unclear. Further research is required to better understand the role of ABA during potato dormancy and sprouting.

Coleman (1998) also studied the effects of O_2 and CO_2 on the concentration of ethylene on abscisic acid (ABA) in potato cv. Russett Burbank tubers during dormancy release and sprout growth. ABA levels decreased within 24 h, when potatoes were treated with a mixture of the following gases: 60 kPa CO_2 – 20 kPa O_2 – 20 kPa N_2 at 3°C and 13°C during storage. The application of ethylene also decreased ABA levels in potato tubers within the same period of time suggesting a close association between

these two hormones. However, a smaller decrease in ABA levels was achieved by application of ethylene and a gas mixture of 20 kPa CO_2 – 40 kPa O_2 – 40 kPa N_2 at 13 °C storage but not at 3°C (Coleman, 1998).

The analysis of ABA metabolites would be of interest, since many of these are either potential candidate markers, or have already been implicated to be important in dormancy and/or sprout suppression in potato (Destefano-Beltrán *et al.*, 2006; Suttle, 1998; 2001; 2004; Suttle and Banowetz, 2000) and other vegetable crops (Chope and Terry, 2008). Phaseic acid (PA) and dihydrophaseic acid (DPA) are involved in ABA metabolism process. ABA is metabolized to PA, via hydroxyabscisic acid (7'OH-ABA) and afterwards to DPA and its epimer *epi*-DPA (Hirai and Koshimizu, 1983; Schwarz *et al.*, 2003; Galuszka *et al.*, 2008). Suttle (1995) studied the metabolism of ABA to PA and DPA in a short-term study (≤ 7 days) in potato cv. Russett Burbank tubers stored at 3 and 20°C. When the potato tubers were stored at 20°C, then ABA was mostly metabolized to DPA, but for tubers stored at 3°C, a transient accumulation of PA and DPA was apparent only after 7 days of storage.

2.4.1.3 Cytokinins

Cytokinins belong to the growth promoting group of hormones and are rapidly metabolized in plant tissues to a wide variety of products (Suttle, 2001). Suttle (1998) and Suttle and Banowetz (2000) have identified the presence of at least nine cytokinins in potato tuber tissues using an ELISA test. The cytokinins identified included isopentyl-, *trans*-zeatin- and *cis*-zeatin-type cytokinins. Exogenous [^{14}C]- *cis*-zeatin was converted to cis-zeatin riboside, trans-zeatin riboside and adenine derivatives after

injection (Suttle and Banowetz, 2000). Recent studies by Suttle (2004) suggested that endogenous cytokinins are tuber dormancy regulators, while exogenous cytokinins can prematurely terminate tuber dormancy and promote sprout growth. The dormancy breaking action of cytokinins was first reported by Hemberg (1970) using the naturally occurring cytokinin zeatin and the synthetic analog kinetin. More recent findings include research by Suttle (2008b), where treatment of potato cv. Russett Burbank minitubers, stored at 20°C and 95% RH for 2 weeks, with synthetic phenylurea and nitroguanidine cytokinins resulted in premature termination of dormancy. At harvest, tubers were insensitive to exogenous cytokinins, and the sensitivity to exogenous cytokinins increased during storage until the termination of dormancy. Potato cv. Russett Burbank is a long storing variety and has been extensively studied in USA. Differences in the role of cytokinins may exist between long- and short-storing cultivars, so further investigation of plant growth regulators would be of interest.

2.4.1.4 Auxins

Application of auxins to plant species usually results in an increase of endogenous ethylene production (Sterling and Hall, 1997). Auxins are believed to have a stimulating effect on ethylene production, which inhibits stolon elongation (Vreugdenhill and Struik, 1989). An increase in phenols has also been observed in potato cvs. Katahdin and Kennebec which were sprayed with 10^{-5} M auxin at the beginning of flowering (Chandra and Mondy, 1981). The contribution of auxins during dormancy and sprout inhibition is not extensively studied and more research is needed to reveal possible interactions with other plant growth regulators including ethylene.

2.4.1.5 Jasmonates

Jasmonates are a group of naturally occurring plant growth regulators and jasmonic acid (JA) is the major representative of them (Sembdner and Parthier, 1993). JA and MeJA are derived from tri-unsaturated fatty acids [alpha-linolenic acid (18:3) or 7Z, 10Z, 13Z-hexadecatrienoic acid (16:3)] through the octadecanoid pathway (Liechti and Farmer, 2006). Generally, JA biosynthesis starts with linolenic acid and proceeds through a number of stages involving lipoxidation, cyclisation and β- oxidation (Creelman and Mullet, 1997). Abdala *et al.* (1996) have reported that JA exists in all the organs of the potato plant. JA can induce tuberization (Koda *et al.*, 1991) and also influence a range of developmental processes, with effects similar to those of ABA and ethylene (Arteca, 1996). Takahashi *et al.* (1994) demonstrated that JA induces stolon elongation and swelling in the sub-apical meristem region in potatoes, as a result of cell expansion. JA has also been found to promote the growth of potato plantlets *in-vitro* in combination with cytokinins (Dermastia *et al.*, 1994). The contribution of JA in regulation of dormancy is possible, since this takes place during tuberization.

2.4.2 Health and taste related compounds

Potatoes are prized for their unique taste, texture and flavour. There is a great variation between potato varieties worldwide, as well as a wide diversity of cooking methods. Secondary metabolites originating from plants have been widely used in recent years, especially in the pharmaceutical industry (Parr *et al.*, 2005). Potatoes contain many phenolic compounds, which have a wide range of health-promoting properties, including compounds with antioxidant activity. Among these are vitamin C

(ascorbic acid), folic acid, chlorogenic acid, flavonoids, and kukoamines. Rodriquez de Sotillo *et al.* (1994) identified the following phenolic compounds in potato tubers: chlorogenic, gallic, protocatechuic and caffeic acids. Ascorbic acid has been studied by many scientists and has been reported to play a significant role in human health and nutrition (Han *et al.*, 2004). Ascorbic acid (vitamin C) in potatoes ranges from 8-30 mg 100^{-1} FW (Davey *et al.*, 2000). Regarding its antioxidant activity, ascorbic acid acts against oxidative stress (Finlay *et al.*, 2003) and is also involved in cell division and growth (Navas and Gomez-Diaz, 1995). Chlorogenic acid is one of the principal phenolic compounds found in potatoes and contributes to *ca*. 90% of the total phenolic compound present (Dao and Friedman, 1992) and has been associated with the fry colour darkening of potatoes (Griffiths *et al.*, 1998). Potatoes are a good source of vitamin C (contain 14.6 mg 100 mg^{-1} boiled potatoes) and are believed to prevent cardiovascular disease, lower cholesterol levels, lower blood pressure, as well to fight symptoms of all sorts of diseases from diabetes to osteoporosis (Jha *et al.*, 1995). Folic acid (26 μg 100 mg^{-1} boiled potatoes) is essential during pregnancy (Delgado, 2008). Kukoamines contain an important and potential bioactive conjugate, kukoamine A, which has been found to have health benefits (Parr *et al.*, 2005; Burns, 2010). Kukoamines may also help to lower blood pressure and had previously only been found in the Chinese medicinal plant *Lycium chinense* (Funayama *et al.*, 1980).

The taste of potatoes can be affected by the concentration of glycoalkaloids. Glycoalkaloids are naturally occurring, nitrogen-containing plant steroids (Friedman, 2004) and are toxic at concentrations > 20 mg 100 g^{-1} FW (Sinden, 1987). In potatoes, more than 95% of the total glycoalkaloids is composed of α-chaconine and α-solanine (Mondy and Ponnampalam, 1985; Friedman and McDonald, 1997). Low concentrations

of potentially toxic glycoalkaloids such as α-solanine have been reported to improve potato flavour (Högy and Fangmeier, 2009), but when the concentration of glycoalkaloids reach 15 mg 100 g^{-1} FW, a bitter taste can be perceived (Mondy *et al.*, 1978). In addition to glycoalkaloids, potatoes also contain calystegine A_3 and B_2, which are biologically active, non-tropane compounds that are found predominantly in the peel and are variety dependant (Friedman, 2004). Glycoalkaloids play an important role as plant defence compounds (Rodriquez-Saona, 1999), but have also been reported to cause symptoms of illness in people and animals (Thomson and Sporns, 1995).

Sweetness of potatoes is governed by sugar concentration. Sucrose, glucose and fructose are the major sugars in a potato tuber (Spychalla and Desborough, 1990). High levels of these sugars result in potatoes becoming unsuitable for processing, e.g. frying because they react with free amino acids and produce an undesirable dark colour (Spychalla and Desborough, 1990), as a result of the Maillard reaction (Mottram *et al.*, 2002; Stadler *et al.*, 2002). Acrylamide is formed through the Maillard reaction, which takes place when sugars react with asparagine during high temperature processes of potatoes (Viklund *et al.*, 2008). The concentration of sugars in a potato tuber changes during storage. Storage of potatoes at low temperatures (e.g. 4-7°C) results in greater accumulation of sugars and therefore to a cold-induced sweetening (Burton, 1989). However, low temperature storage inhibits high respiration rates and sprouting, as well as decreases water loss. Starch is a major source of energy in a variety of diets worldwide and the main component of potato tubers. Under high temperatures during processing of potatoes (frying or boiling), starch is caramelized and is converted to sucrose, glucose and fructose, leading to a high accumulation of these sugars in the potato tuber (de Wilde *et al.*, 2005).

The cooking quality and flavour of potatoes is of great importance for the consumers. Recent research by the Scottish Crop Research Institute (SCRI) has revealed that flavour of the potato is the second most important characteristic for the consumers. More research is needed to reveal any possible interaction between health and taste-related compounds and PGRs. For this reason, work on fresh potatoes should also be linked with work of cooked potatoes, so that a comparative study would take place.

2.5 Conclusions

The expression of potato tuber dormancy is generally well described, but not for all cultivars. Comparison of potato varieties differing in the length of their tuber dormancy should allow identification of biochemical and physiological processes responsible for the break of dormancy. However, specific hormonal changes that take place during dormancy and sprout suppression, and which are affected by ethylene have not yet been profiled. Little work has specifically been centred on measuring the relationship between taste and health-related compounds and plant growth regulators. Furthermore, less work has elucidated the effect of ethylene treatment on temporal changes in potato-derived taste- and health-related compounds during storage. The interaction between ethylene and other plant growth regulators and their effect on different taste and health-related compounds is thus not clear. Identification of the temporal changes in taste related compounds and plant growth regulators could act as reliable biomarkers of dormancy and predictors of sprout suppression under defined conditions.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Overview of work

Eight experiments were conducted in total during three years of study (Table 3.1): Experiments 1-3 (2008-2009, Chapter Four), Experiments 4-7 (2009-2010, Chapter Five) and Experiment 8 (2010-2011, Chapter Six). A total of nine potato (*Solanum tuberosum* L.) cultivars (viz. 'King Edward', 'Maris Piper', 'Marfona', 'Estima', 'Desiree', 'Sylvana', 'Russet Burbank', 'Fianna', 'Saturna') and one potato (*Solanum phureja* Juzepczuk & Bukasov) variety (*viz.* 'Mayan Gold') were evaluated. Potatoes were sourced through Sutton Bridge Crop Storage Research (SBCSR, Lincs., UK) and came from various locations to test the potential ubiquity of the treatments. Thus, supply was beyond the control of the author and the supervisor. The number of tubers used over three years of study was n = 3246 (n = 4 replicates ; 1 tuber per replicate in 2008-2009 and n = 3 replicates; 3 tubers per replicate in 2009-2011). In total, n = 1386 potato samples were used for sugar analysis in flesh (2008-2011) and n = 456 (2008-2009) in peel. Texture was evaluated in n = 2760 potato slices (2008-2009, 2009-2010) giving a total of n = 8280 penetrations. Respiration rate and ethylene production were measured from n = 930 tubers, while 1-MCP in n = 144 tubers (2009-2011). A total amount of n = 720 tubers were also evaluated under shelf life conditions in 2009-2010. Starch analysis was done in 'Marfona' potato samples (n = 52) in 2008-2009. ABA concentration was measured in 'Saturna' potato flesh samples in 2008-2009 (n = 33), while 'Marfona' flesh samples in 2008-2011 (n = 126) were analysed for all phytohormones (Section 3.9.3). Full details on replicates are shown in each Chapter.

Table 3.1 Number of tubers used (per experiment and for shelf life evaluation) and number of samples for measurement of dry weight, sugars, texture, respiration rate, ethylene production, 1-MCP, starch and phytohormones during three years of study (2008-2011)

Measurements	**Experiments**							
	Year 2008-2009			**Year 2009 -2010**				**Year 2010-2011**
	1	2	3	4	5	6	7	8
Tubers	n = 12	n = 132	n = 312	n = 630	n = 558	n = 576	n = 540	n = 486
Dry weight	n = 12	n = 132	n = 312	n = 210	n = 186	n = 192	n = 180	n = 162
Sugars: flesh	n = 12	n = 132	n = 312	n = 210	n = 186	n = 192	n = 180	n = 162
Sugars: peel	n = 12	n = 132	n = 312	-	-	-	-	-
Texture	n = 36	n = 396	n = 936	n = 1890	n = 1674	n = 1728	n = 1620	-
Respiration rate	-	-	-	n = 210	n = 186	n = 192	n = 180	n = 162
Ethylene	-	-	-	n = 210	n = 186	n = 192	n = 180	n = 162
1-MCP	-	-	-	n = 12	n = 12	n = 30	n = 30	n = 60
Shelf life tubers	-	-	-	n = 180	n = 180	n = 180	n = 180	-
ABA (‘Saturna’)	-	n = 33	-	-	-	-	-	-
Starch (‘Marfona’)	-	-	n = 52	-	-	-	-	-
Phytohormones (‘Marfona’)		-	n = 36	-	n = 57	-	-	n = 33

3.2 Plant material and experimental design

3.2.1 Experiments 1-3: Year 2008-2009 (Chapter Four)

Nine potato (*Solanum tuberosum* L.) cultivars *viz.* 'King Edward', 'Maris Piper', 'Marfona', 'Estima', 'Desiree', 'Sylvana', 'Russet Burbank', 'Fianna', 'Saturna' and one potato (*Solanum phureja* Juzepczuk & Bukasov) variety *viz.* 'Mayan Gold' were selected. 'King Edward', 'Maris Piper', 'Marfona', 'Estima' and 'Desiree' tubers constituting the first batch were supplied by Solanum Ltd. (Lincs., UK) and arrived at Sutton Bridge Crop Storage Research (SBCSR, Lincs., UK) on 24th September 2009. The second batch arrived later over several days (6th-10th October 2009) and consisted of potatoes 'Sylvana' (Greenvale AP Ltd., Cambs., UK), 'Russet Burbank' (McCain Foods Ltd., Yorks., UK), 'Fianna' (H Prins Ltd., Cambs., UK), 'Saturna' (G H Chennells Farms Ltd.) and 'Mayan Gold' (Greenvale AP Ltd.). The selected potato cultivars are categorized as maincrop (*viz.* 'Kind Edward', 'Maris Piper', 'Mayan Gold', 'Desiree', 'Russet Burbank', 'Saturna' and 'Fianna'), early maincrop ('Estima'), medium early maincrop ('Sylvana') and second early maincrop ('Marfona') according to the British Potato Variety Database (2009). As soon as possible after arrival, tubers were passed over a grading line to remove loose soil, and rotten, damaged, green and/or undersized (< 45 mm) tubers. Sprout suppressants were not applied to the tubers used in the study. Each experiment conducted in 2008-2009 was a completely randomized design with four replicates per treatment per cultivar (one tuber per replicate). Potatoes were stored for 30 weeks at 6°C under four different ethylene treatment regimes *viz.* continuous ethylene, continuous air, transfer from ethylene to air and transfer from air to ethylene (Figure 3.1, Sampling 5) at the time of first indication of sprouting. The

tubers that were divided into two batches according to their arrival date at SBCSR, underwent a controlled cooling regime from 15°C (arrival temperature), at a rate of 0.5°C reduction per day at ambient relative humidity (RH), to a holding temperature of 6°C, in order to minimize chilling stress and allow time for wound healing. After reaching 6°C, tubers were either stored under continuous ethylene (10 μL ethylene L^{-1}) or air (0 μL ethylene L^{-1}). Ethylene was controlled as described in Section 3.5. When tubers showed first indication of sprouting (10% eye movement assessed in air storage; see Section 3.3), a sub-sample of these two treatments (ethylene and air) was transferred to either ethylene or air stores. The detailed experimental design for Experiments 1-3 is presented in Figure 3.1. The investigation was divided into three experiments according to the sampling points. More specifically, 'King Edward' constituted Experiment 1, where only sampling points 1 and 5 were included, since this variety showed first indication of sprouting before storage in ethylene and air; therefore the transfer between ethylene and air stores did not apply. 'Maris Piper', 'Mayan Gold' and 'Saturna' constituted Experiment 2, where sampling point 2 was absent, as these two cultivars showed first indication of sprouting soon after storage in ethylene and air (at approximately four weeks; before sampling point 2). Experiment 3 included all 5 sampling points for 'Marfona', 'Estima', 'Desiree', 'Sylvana', 'Russet Burbank' and 'Fianna'.

At each sampling, four tubers were selected at random from each treatment/cultivar combination. Sampling points and dates of the experiments are presented in Table 3.2.

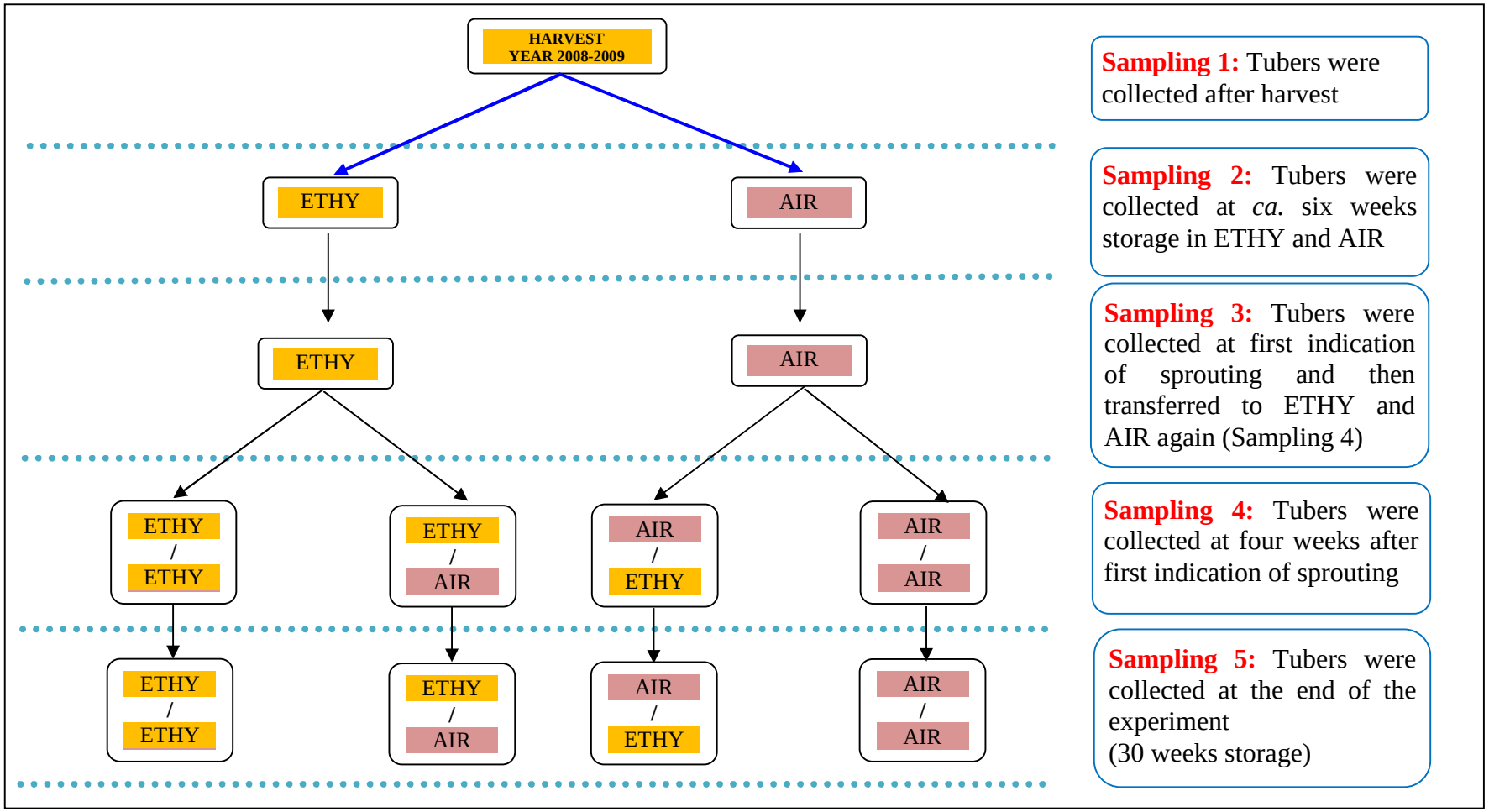

Figure 3.1 Experimental design of Experiments 1-3 (2008-2009; 4 replicates; 1 tuber per replicate)

Table 3.2 Sampling points and dates of Experiments 1-3 (2008-2009)

Potato cultivars	**Sampling points and dates**					
	1		**2**	**3**	**4**	**5**
	After harvest (Day 0)	Tubers stored in ETHY and AIR	At *ca.* six weeks storage in ETHY and AIR	At first indication of sprouting	At four weeks after first indication of sprouting	At the end of the experiment (30 weeks storage)
King Edward	25/09/2008	15/10/2008	*	*	*	13/05/2009
Maris Piper	25/09/2008	15/10/2008	*	30/10/2008	27/11/2008	13/05/2009
Mayan Gold	09/10/ 2008	23/10/2008	*	30/10/2008	27/11/2008	21/05/2009
Saturna	10/10/2008	23/10/2008	*	07/11/2008	05//12/2008	21/05/2009
Marfona	25/09/2008	15/10/2008	01/12/2008	15/01/2009	10/02/2009	13/05/2009
Estima	25/09/2008	15/10/2008	01/12/2008	18/12/2008	18/12/2008	13/05/2009
Desiree	25/09/2008	15/10/2008	01/12/2008	05/12/2008	02/01/2009	13/05/2009
Sylvana	09/10/2008	23/10/2008	01/12/2008	15/01/2009	10/02/2009	21/05/2009
Russet Burbank	09/10/2008	23/10/2008	01/12/2008	28/01/2009	25/02/2009	21/05/2009
Fianna	10/10/2008	23/10/2008	01/12/2008	28/01/2009	25/02/2009	21/05/2009

* No tubers were collected at that sampling point

3.2.2 Experiments 4-7: Year 2009-2010 (Chapter Five)

Four potato (*Solanum tuberosum* L.) cultivars *viz.* 'Marfona' (Wright & Son Ltd; Gedney), 'Estima' (Elveden Farms Ltd), 'Saturna' (R.S. Cockerill Ltd.; York) and 'Russet Burbank' (Greenvale Ltd.) were selected and were stored for 30 weeks at 6°C under twelve different ethylene treatment regimes (Figures 3.2 & 3.3, Sampling 7). Tubers underwent a controlled cooling regime from 10°C (arrival temperature), at a rate of 0.5°C reduction per day at ambient relative humidity (RH), to a holding temperature of 6°C, in order to minimize chilling stress and allow time for wound healing. After reaching 6°C, tubers were either treated with -/+1 μL 1-MCP L^{-1} and then stored in continuous ethylene (10 μL ethylene L^{-1}) or air (0 μL ethylene L^{-1}) (Experiments 4 & 5) or stored in continuous ethylene (10 μL ethylene L^{-1}) or air (0 μL ethylene L^{-1}) firstly and were subsequently exposed to -/+ 1μL 1-MCP L^{-1} when showed first indication of sprouting (Experiments 6 & 7). The investigation was divided into four experiments according to the samplings. At each sampling, three tubers were selected at random from each replicate per treatment/cultivar combination. The experiment was a blocked randomized design with three replicates (3 replicates x 3 tubers per replicate; n = 9 tubers per treatment/cultivar combination). Sampling points and dates of the experiments are presented in Table 3.3. Number of samples analysed is presented in Table 3.1.

Table 3.3 Sampling points and dates in experiments 4-7 (2009-2010)

	Sampling points and dates							
	1	**2**		**3**	**4**	**5**	**6**	**7**
Potato cultivars	After harvest (Day 0)	After the +/-1µL 1-MCP L^{-1} treatment (a)	Tubers stored in ETHY and AIR	At 2 weeks after storage in ETHY and AIR	At first indication of sprouting (b)	At 6 weeks after first indication of sprouting	At 26 weeks storage	At the end of the experiment (30 weeks storage)
Marfona	23/10/2009	10/11/2009	10/11/2009	*	24/11/2009	05/01/2010	12/04/2010	15/05/2010
Estima	16/10/2009	10/11/2009	10/11/2009	24/11/2009	15/12/2009	25/01/2010	12/04/2010	15/05/2010
Saturna	23/10/2009	10/11/2009	10/11/2009	*	24/11/2009	05/01/2010	12/04/2010	15/05/2010
Russet Burbank	04/11/2009	10/11/2009	10/11/2009	24/11/2009	25/01/2010	09/03/2010	12/04/2010	15/05/2010

* No tubers were collected at that sampling point
(a) First -/+1µL 1-MCP L^{-1} treatment done on 09/11/2009
(b) Second +/-1µL 1-MCP L^{-1} treatment done on 23/11/2009 (Marfona and Saturna), 14/12/2009 (Estima) and 24/01/2010 (Russet Burbank).

Experiments 4 &5

'Marfona', 'Estima', 'Saturna' and 'Russett Burbank' potatoes were exposed to -/+ 1 μL 1-MCP L^{-1} for 24 h at 6°C and then stored either under continuous ethylene (10 μL ethylene L^{-1}) or air (0 μL ethylene L^{-1}). At the time of first indication of sprouting (10% eye movement assessed in air), a sub-sample from the ethylene and air treatments was transferred to air and ethylene. 'Estima' and 'Russet Burbank' potatoes constituted Experiment 4 and assessments were made at seven samplings *viz*. (1) after harvest (day 0), (2) after the -/+ 1 μL 1-MCP L^{-1} treatment and before storage in ethylene or air, (3) at two weeks after transfer to ethylene or air, (4) at first indication of sprouting, (5) at six weeks after first indication of sprouting, (6) at 26 weeks storage and (7) at 30 weeks storage (end of experiment). 'Marfona' and 'Saturna' constituted Experiment 5 and were not collected at sampling (3), since they had passed the threshold point of 10% first indication of sprouting before that period of time. The detailed experimental design for Experiments 4 and 5 is presented in Figure 3.2.

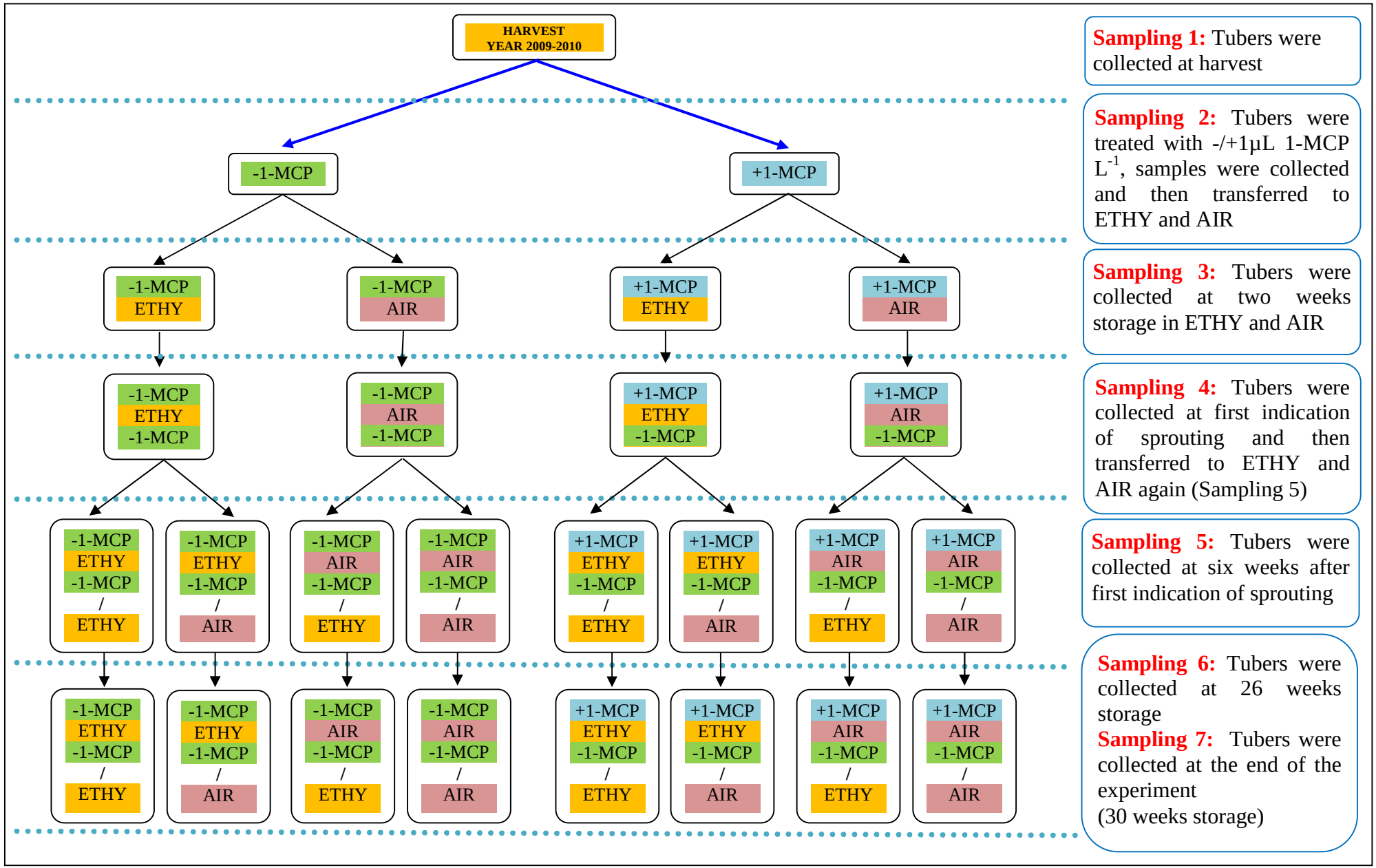

Figure 3.2 Experimental design of Experiments 4 and 5 (2009-2010; n = 3 replicates; 3 tubers per replicate)

Experiments 6 & 7

'Marfona', 'Estima', 'Saturna' and 'Russett Burbank' potatoes were stored under continuous ethylene (10 µL ethylene L^{-1}) or air (0 µL ethylene L^{-1}). At the time of first indication of sprouting (10% eye movement assessed in air), tubers were exposed to -/+1 µL 1-MCP L^{-1} for 24 h at 6°C and then a sub-sample from the ethylene and air treatments was transferred to air and ethylene. 'Estima' and 'Russet Burbank' potatoes constituted Experiment 6 and assessments were made at seven samplings *viz*. (1) after harvest (day 0), (2) before storage in ethylene and air, (3) at two weeks after transfer to ethylene and air, (4) at first indication of sprouting, (5) at six weeks after first indication of sprouting, (6) at 26 weeks storage and (7) at 30 weeks storage (end of experiment). 'Marfona' and 'Saturna' constituted Experiment 7 and were not collected in sampling (3), since they had passed the threshold point of 10% eye movement before that period of time.

The detailed experimental design for Experiments 6 and 7 is presented in Figure 3.3.

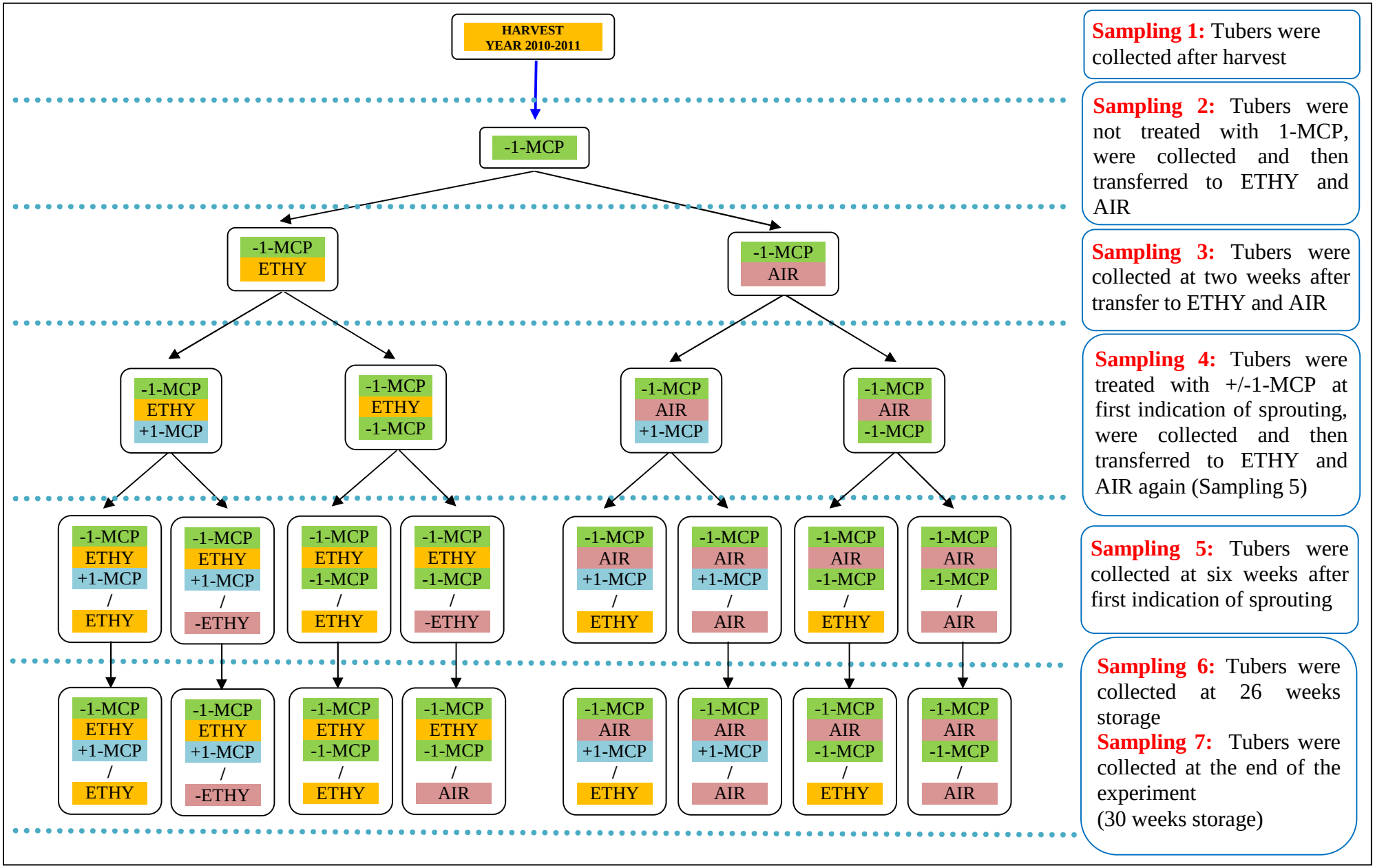

Figure 3.3 Experimental design of Experiments 6 and 7 (2009-2010; n = 3 replicates; 3 tubers per replicate)

3.2.2.1 Shelf life

Tubers from all treatments (see Section 3.2.2; Figures 3.2, 3.3) were collected at sampling point 5 (six weeks after first indication of sprouting) (n = 720 tubers for four potato cultivars, n = 3 replicates; 5 tubers per replicate = 15 tubers per treatment/cultivar combination). For shelf life assessments, tubers were stored in darkness at 20°C for 18 days. Sprouting incidence was recorded every three days.

3.2.3 Experiment 8: Year 2010-2011 (Chapter 6)

Two potato (*Solanum tuberosum* L.) cultivars viz. 'Marfona' and 'Estima' (Wright & Son Ltd; Gedney) were selected and arrived at SBCSR on 12th October 2010. The experiment was a completely randomized design with three replicates (three tubers per replicate; n = 9 tubers). Potatoes were stored for 30 weeks at 6°C under sixteen different ethylene treatment regimes (Figure 3.4, Sampling 4). Tubers underwent a controlled cooling regime from 10°C (arrival temperature), at a rate of 0.5°C reduction per day at ambient relative humidity (RH), to a holding temperature of 6°C, in order to minimize chilling stress and allow time for wound healing. After reaching 6°C, tubers were treated with -/+ 1 μL 1-MCP L^{-1} (first treatment) and then stored in continuous ethylene (10 μL ethylene L^{-1}) or air (0 μL ethylene L^{-1}). At the time of first indication of sprouting, tubers were treated again with -/+ 1 μL 1-MCP L^{-1} (second treatment) and then stored in continuous ethylene (10 μL ethylene L^{-1}) or air (0 μL ethylene L^{-1}). The detailed experimental design for Experiment 8 is presented in Figure 3.4. At each sampling, three tubers were selected at random from each replicate per

treatment/cultivar combination. Assessments were made at 4 samplings for both cultivars *viz*. (1) after harvest, (2) after the first -/+1µL 1-MCP L^{-1} treatment and before storage in ethylene or air, (3) at first indication of sprouting and after the second +/-1µL 1-MCP L^{-1} and (4) at 30 weeks storage (end of experiment).

Sampling points and dates of Experiment 8 are presented in Table 3.4.

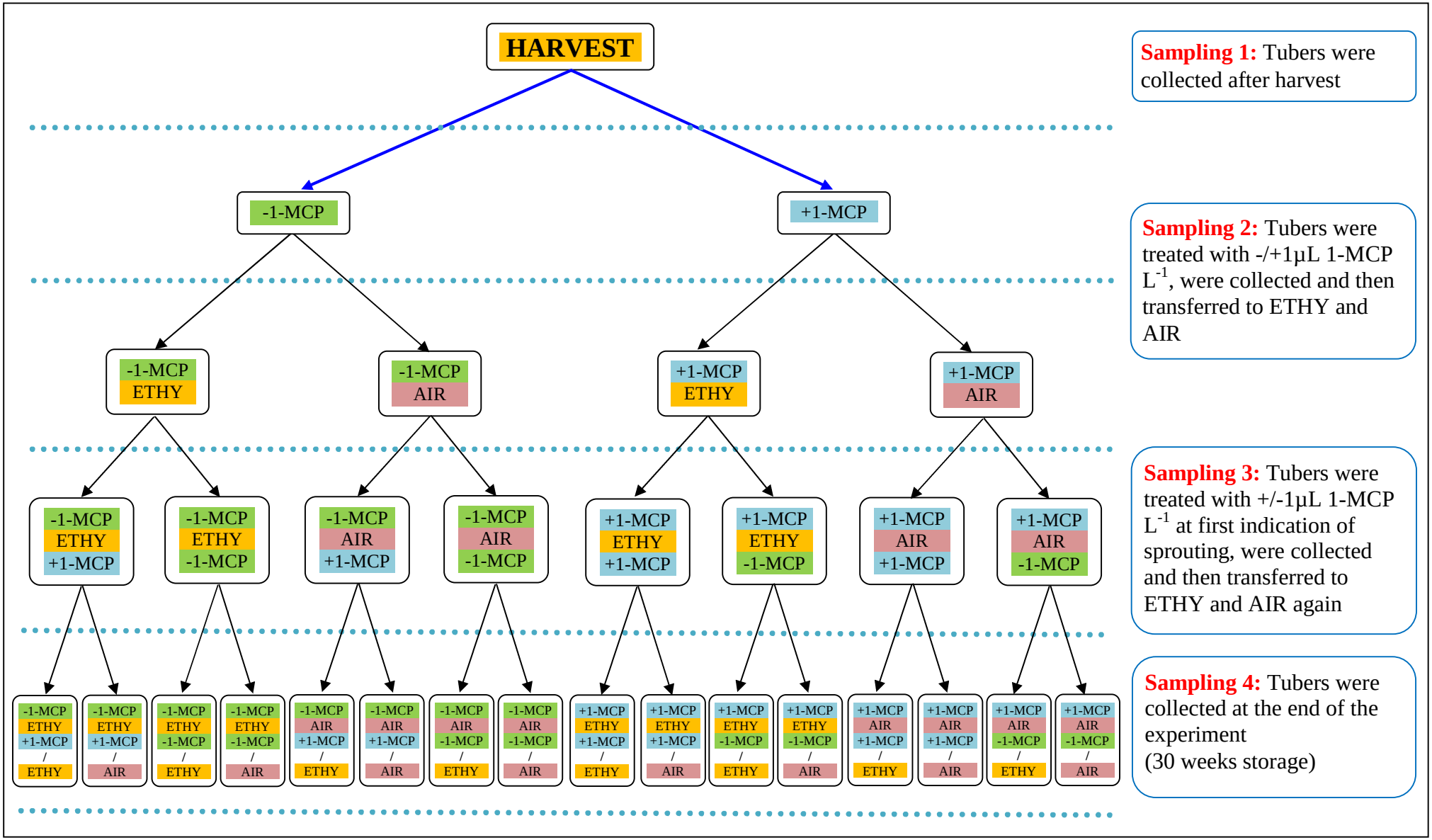

Figure 3.4 Experimental design of Experiment 8 (2010-2011; n = 3 replucates; 3 tubers per replicate)

Table 3.4 Sampling points and dates of Experiment 8 (2010-2011)

Potato cultivars	Sampling points and dates				
	1	**2**		**3**	**4**
	After harvest (Day 0)	After the first +/- 1µL 1-MCP L^{-1} treatment (c)	Tubers stored in ETHY and AIR	At first indication of sprouting (d)	At the end of the experiment (30 weeks storage)
Marfona	13/10/2010	27/10/2010	27/10/2010	20/01/2011	27/04/2011
Estima	13/10/2010	27/10/2010	27/10/2010	06/01/2011	28/04/2011

(c) First -/+ 1µL 1-MCP L^{-1} treatment done on 26/10/2010

(d) Second +/- 1µL 1-MCP L^{-1} treatment done on 19/01/2010 (Marfona) and 05/01/2010 (Estima)

3.3 Eye movement evaluation

The trigger for reciprocal transfer between the ethylene and air stores was when 10% of the air-stored tubers showed white sprout tissue development (first indication of sprouting) (Figure 3.5) and was monitored in whole trays at approximately weekly intervals. Where possible, each tray was only assessed once to minimize handling stress. A pre-treatment sprouting assessment was carried out on four replicate samples of 25 tubers per cultivar within 24 h of arrival at SBCSR. Thereafter, sprouting assessments were carried out on sub-samples of 25 tubers. When a large number of sprouting assessments were due, allocated trays were held at 3°C to halt sprout development until assessments were possible. Eye movement evaluation assessments were conducted at SBCSR.

Figure 3.5 The trigger for reciprocal transfer between the ethylene and air stores was when 10% of the air-stored tubers showed white sprout tissue development (first indication of sprouting)

3.4 Relative Dormancy Break (%) evaluation

Immediately after arriving at SBCSR, one hundred tubers per cultivar were placed in paper sacks and stored at 15°C, 95% RH for dormancy assessment. At approximately weekly intervals, any tuber with sprouts ≥3 mm long was recorded and discarded. This process continued until no tubers remained. Relative dormancy break evaluation assessments were conducted at SBCSR and a report was generated (Appendix E).

3.5 Storage conditions

Tubers of all experiments were put in 10 Kg capacity trays and stored in continuous ethylene (10 μL ethylene L^{-1}) or air (0 μL ethylene L^{-1}) (Figure 3.6). Ethylene was monitored and controlled by an EMU2 TS Ethylene Management Unit (Biofresh Ltd., Newcastle, UK), which sampled and measured the concentration of ethylene gas using a Polytron® 7000 (Dräger, Herts., UK) electro-chemical sensor calibrated specifically for ethylene (Figure 3.6). Sampled air was drawn through a narrow bore tube from the opening of the store air return duct. This unit drove an external control mechanism with solenoid valves to control the introduction of ethylene from a pressurized cylinder with reference to a configurable set-point. An integral data logger recorded the ethylene concentration and was checked daily. The air store was fitted with a Humimax HM2 2000 (Munters Ltd., Cambs., UK) fan that assisted a humidification cell (temperature controlled at 6 ± 0.5°C and relative humidity controlled at 95 ± 5% in the store rooms), whereas the ethylene store was equipped with a compressed air atomiser. No CIPC had ever been used in any stores used in this investigation.

Figure 3.6 Storage of tubers in 10 Kg capacity trays into the specifically modified for ethylene store room

3.6 Respiration measurements

Respiration measurements were done only in Years 2009-2010 and 2010-2011 (Experiments 4-8). Gas samples were received from the 1-MCP treatment chambers 30 min and 24 h after the beginning of the treatment. Three tubers per replicate per cultivar were placed in 3 L glass jars fitted with an air tight septum (Figure 3.7) and gas samples were taken with repeated withdrawal-injection displacements using a 30 mL plastic syringe. The CO_2, ethylene and 1-MCP concentrations were measured using gas chromatography (GC model 8340, DP800 integrator, Carlo Erba Instruments, Herts., UK) with flame ionization detection (FID) for ethylene and 1-MCP and a hot wire detector for CO_2 (Chope *et al.*, 2007). The GC was calibrated using 0.9 μL L^{-1} isobutylene (1 μL L^{-1} isobutylene in nitrogen; Certified Standard from British Oxygen Company (BOC, Surrey, UK) as the 1-MCP standard (Chope *et al.*, 2007), 10.6 μL L^{-1} ethylene (10 μL L^{-1} ethylene in nitrogen; Certified Standard from BOC) and 10.06%

CO_2 (10% CO_2, 2% O_2, 88% N_2; Certified Standard from BOC). Three tubers per replicate were weighed and the rate of ethylene and CO_2 was expressed in mmoles Kg^{-1} h^{-1}.

Figure 3.7 Three tubers per replicate were placed in 3L jars fitted with an air tight septum and gas measurements were taken

3.7 Sample preparation

Potatoes were collected from SBCSR (Lincs., UK) and transported to Cranfield University within 2 h. On arrival, potatoes were carefully washed with tap water and left to air-dry before textural and biochemical analysis. Two equatorial slices (thickness 10 mm each) were cut with a sharp knife from the central portion of each tuber. One slice was used for biochemical analysis and was divided into flesh (~20 g FW) and peel (~5 g FW) before being immediately snap-frozen in liquid nitrogen. Potato slices were carefully peeled using a very sharp knife that allowed skin removal from the uneven surface. Samples were stored at -40°C both before and after lyophilisation (Scanvac, Lynge, Denmark) which took place in the dark at -50°C for 7 days. Fresh and dry weights were recorded before and after lyophilisation, respectively. Sample numbers

that were weighed are presented in Table 3.1. The adjacent slice was used for textural analysis.

3.8 Physiological assessments

3.8.1 Sprouting

The number of sprouts falling into each of three categories according to length (<5 mm, 5-10 mm and >10 mm) were recorded. A different sprouting scale consisting of small and large sprout clusters (30 and 60 mm respectively) was adopted for 'Mayan Gold'.

3.8.1.1 Sprouting during shelf life

Three categories of sprout length were used for potato cvs. Marfona, Estima and Saturna: < 5 mm, 5-10 mm and > 10mm, and twelve categories for potato cv. Russett Burbank (< 5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40, 40-45, 45-50, 50-55 and 55-60 mm) due to the fact that this cv. sprouted more rapidly during the 18-day shelf life in darkness. 'Russett Burbank' was a seed potato variety that was used for the second year's experiment and this may explain the different sprouting behaviour of this variety during storage at 20°C for 18 days.

3.8.2 Texture

Texture analysis was performed on potato slices of Years 2008-2009 and 2009-2010 (Table 3.1) using an Instron (Model 5542, Instron, Norwood, MA) Uniaxial Testing Machine, equipped with a calibrated 500 N load cell according to Meyer and Terry (2008) with slight modifications. The machine was programmed (Bluehill 2,

version 2.11, Instron) such that an 8 mm diameter cylindrical flat probe (Terry *et al.*, 2007) indented the sample to a depth of 4 mm at a cross head speed of 10 mm min^{-1}. Three penetrations were performed on each slice in a form of triangle inside the vascular band and the mean value was calculated. Force (N) and deformation (mm) were recorded using the same Bluehill software. Firmness (N) was represented by the maximum load (N). The apparent elasticity modulus (E_{ap}) (Landahl *et al.*, 2009) was calculated as:

$$E_{ap} = (l_0/A_0) \text{ x } \tan \varphi$$

where l_0 is the actual thickness of the sample slice at the beginning of the test. A_0 is the surface area of the probe calculated as: $A_0 = r^2 \cdot \pi$, and $\tan \varphi$ is the slope (N mm^{-2}) calculated from force (N) and deformation (mm).

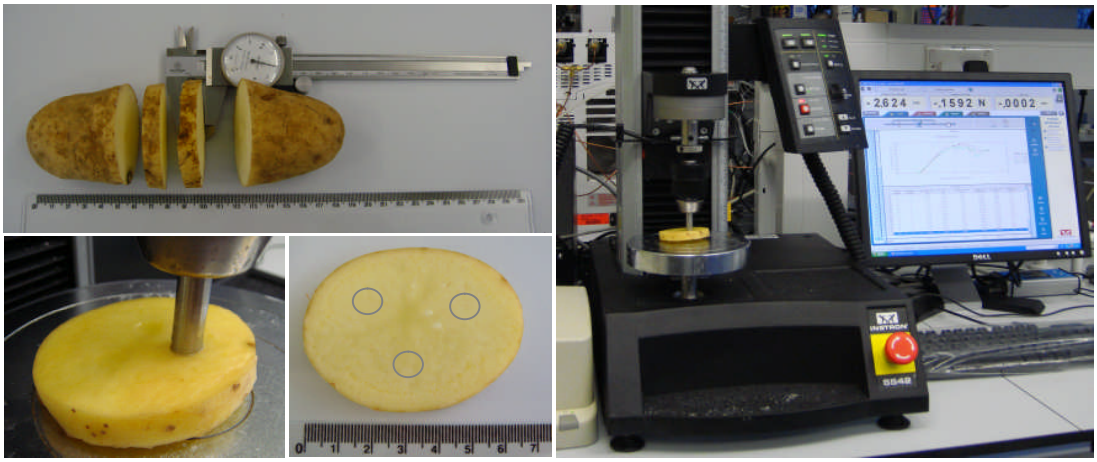

Figure 3.8 Texture analysis was performed on fresh potato slices using Instron (Model 5542, Instron, Norwood, MA)

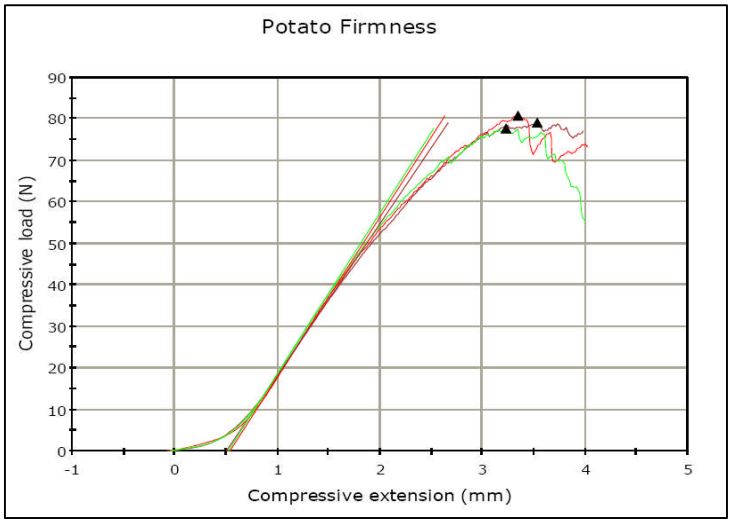

Figure 3.9 Firmness of a fresh potato slice measured at 10 mm min^{-1} to a depth of 2 mm with a cylindrical probe of 8 mm diameter (each colour represents one penetration).

3.9 Biochemical assessments

3.9.1 Extraction and quantification of non-structural carbohydrates

Freeze-dried powdered potato (150 mg) flesh (all experiments, n = 1386) or peel (Chapter Four; Experiments 1-3, n = 456) samples were combined with 3 mL of 62.5:37.5 HPLC grade methanol:water (v/v) and mixed well (Terry *et al.*, 2007). Vials (7 mL polystyrene bijou vials; Sterilin, Staffs., UK) of the slurry were placed in a shaking water bath (Fisons, Leics., UK) at 55°C for 15 min, removed briefly and vortexed (Vortex Genie 2, Scientific Industries, NY) for 20 s every 5 min to prevent layering and then left to cool. Cooled samples were filtered through a 0.2 μm Cronus PTFE syringe driven filter unit (Jaytee Biosciences, Kent, UK) and stored at -40°C until required. Non-structural carbohydrates were then quantified using an Agilent 1200 series HPLC binary pump (Agilent, Berks., UK) equipped with an Agilent refractive index detector G1362A (Giné Bordonaba and Terry, 2009). Extracts were diluted (1:4)

immediately before analysis, and 20 μL was injected into a Rezex RCM monosaccharide Ca^{+} (8%) size exclusion column of 300 mm x 7.8 mm diameter, 8 μm particle size (Phenomenex, CA; Part no. 00H-0130-K0) with a Carbo-Ca^{2+} security guard column of 4 mm x 3 mm diameter (Phenomenex,; Part no. AJ0-4493). The mobile phase was HPLC grade water (filtered through a 0.4 μm filter and degassed using He) at a flow rate of 0.6 mL min^{-1} (Terry *et al.*, 2007; Giné Bordonaba and Terry, 2008). Temperature of the optical unit in the detector was set up at 35ºC and temperature of the column heater at 80°C. The autosampler was cooled at 5 ºC. The presence and abundance of fructose, glucose and sucrose were automatically calculated by comparing sample peak area to standards (0.05-2.5 mg mL^{-1}) using ChemStation Rev. B.02.01 software. Detailed flesh and peel sample numbers that were extracted for sugars are presented in Table 3.1.

3.9.2 Starch

Starch content was measured using a total starch assay kit (Megazyme International Ireland Ltd., Bray, Republic of Ireland) according to the manufacturer's instructions (AOAC method 996.11, 1998; AACC method 76.13, ICC standard method no. 168; Thanaraj *et al.*, 2009). Starch was analysed in flesh of potato cv. Marfona only (n = 52, Chapter Four; Experiment 3; 2008-2009), as this cultivar exhibited large differences in sugars composition according to treatment.

3.9.3 Extraction and quantification of phytohormones in potato

3.9.3.1 Extraction and quantification of ABA in 'Saturna' potatoes in Year 2008-2009

Plant material

'Saturna' potatoes were treated and collected as described in Section 3.2.1. Three replicates per sampling point (n = 33 samples; Tables 3.1 & 3.2, Figure 3.1) were selected randomly, extracted and quantified as follows.

ABA extraction and quantification

Freeze-dried potato flesh powder (500 mg) was weighed out in each glass tube and 5 mL acetone : water (80 : 20, v/v) were added. Then, 20 ng of the deuterated internal standard d_4-ABA was added. The samples were extracted overnight on a shaking vortex at 4°C. Samples were centrifuged (Thermo Scientific, Fischer, UK) at 503 x g for 10 min at room temperature. The supernatant was removed and was re-extracted with 1 mL acetone : water (80 : 20, v/v). The supernatant was placed in ice in a sonicator (VWR ultrasonic cleaner, Batavia, IL) for 10 min and subsequently dried under a stream of N_2 for 75 min. After drying, the sample was re-dissolved in 5 mL formic acid 1M. The acidified extract was loaded onto an Oasis MCX 6cc/150mg, 60μm cartridge (Waters Associates, Milford, MA, cat .no 186000255) as described; the cartridge was conditioned with 5 mL methanol 100%, following equilibration with 5 mL formic acid 1M. The sample was then loaded. The cartridge was washed with 2 mL formic acid 1M and eluted with 2 mL methanol 100%. The methanol fraction was taken to dryness under a stream of N_2 (40ºC) and was re-dissolved in 400 μL methanol 100%.

Samples (10 µl) were injected using a HPLC system comprising an Waters Alliance 2695 separation module equipped with a 2.1 mm x 100 mm diameter and 3.5 µm particle size Eclipse XDB C18 column (Agilent, CA, USA, part no. 961753-902), with a 2.1 mm x 12.5 mm diameter, 5 µm Zorbax XDB-C8 guard column (Agilent, CA, USA, part no. 821125-926). The mobile phase was a ternary system comprising methanol (A), deionised water (B) and 5% glacial acetic acid in water (C). The gradient was of increasing methanol content, 10 – 60% - 15 min, 60 – 99.2% - 15 min, 99.2 – 10% - 2 min, 10% 3 min, constant glacial acetic acid concentration of 7 mM (pH 3.4) at a flow rate of 0.200 ml min^{-1}. The column temperature was set at 25˚C. The MS was a quadrupole tandem mass spectrometer (Micromass) fitted with an electrospray ion source. The cone voltage was 30 and 25 V for ABA and d_4-ABA respectively, the collision energy was set at 9 eV and ions were detected in multiple reaction monitoring mode (Table 3.5).

Table 3.5 The ionisation mode, characteristic product to precursor ion transition, and retention time for ABA and its deuterated internal standard.

Ionisation mode	Compound	Transition	RT (min)	Internal standard	Transition	RT (min)
Negative	ABA	263 >153	18.10	d_4-ABA	267 > 156	18.07

The concentration of ABA was quantified in relation to its internal standard using the calibration curve generated. For the calibration curve, the area beneath the MRM product ion peak was determined for the analyte and IS in a dilution series. The response was calculated according to the formula:

Response = Analyte product ion peak area * (IS concentration/IS product ion peak area), where IS concentration is the known amount of the internal standard added. Calibration curves were created by plotting the known concentration of each unlabeled

compound against the calculated response for each standard solution in the dilution series.

3.9.3.2 Extraction and quantification of various phytohormones in 'Marfona' potatoes during three years of study (2008-2011)

Plant material

'Marfona' potatoes were treated as described in Sections 3.2.1 - 3.2.3 and collected at the sampling points presented in Figure 3.10 (extensive description of each sampling point is shown in Figures 3.1, 3.2 & 3.4). Three replicates per sampling point (n = 126 in total, Table 3.1) were extracted and quantified as follows.

Extraction of phytohormones

The extraction of specific phytohormones (Tables 3.6 and 3.7) was done as described by Giannarelli *et al.* (2010) with slight modifications. Freeze-dried potato flesh (150 mg) (n = 126; Table 3.7, Figure 3.10) was weighed out in a 15 mL polypropylene tube (17 x 19 mm, Fischer, UK) and 20 ng of the deuterated internal standard mix [d_4-ABA, d_5-ABA-GE, d_3-PA, d_4-7'-OH-ABA, d_3-DPA (National Research Council of Canada, SK, Canada); d_2-GA_1, d_2-GA_4 (The Australia National University, Australia, AU) and d_6-IPA, d_6-2iP, d_3-DHZR, d_3-DHZ, d_5-IAA (OlChemlm Ltd., Chech Republic, CZ); Tables 3.6 and 3.7] was added to the samples, which were then subjected to cold extraction (-20°C) using 5 mL of Bieleski modified methanol : water : formic acid mixture (75 : 20 : 5, v/v) for 12h (Dobrev and Kamínek, 2002).

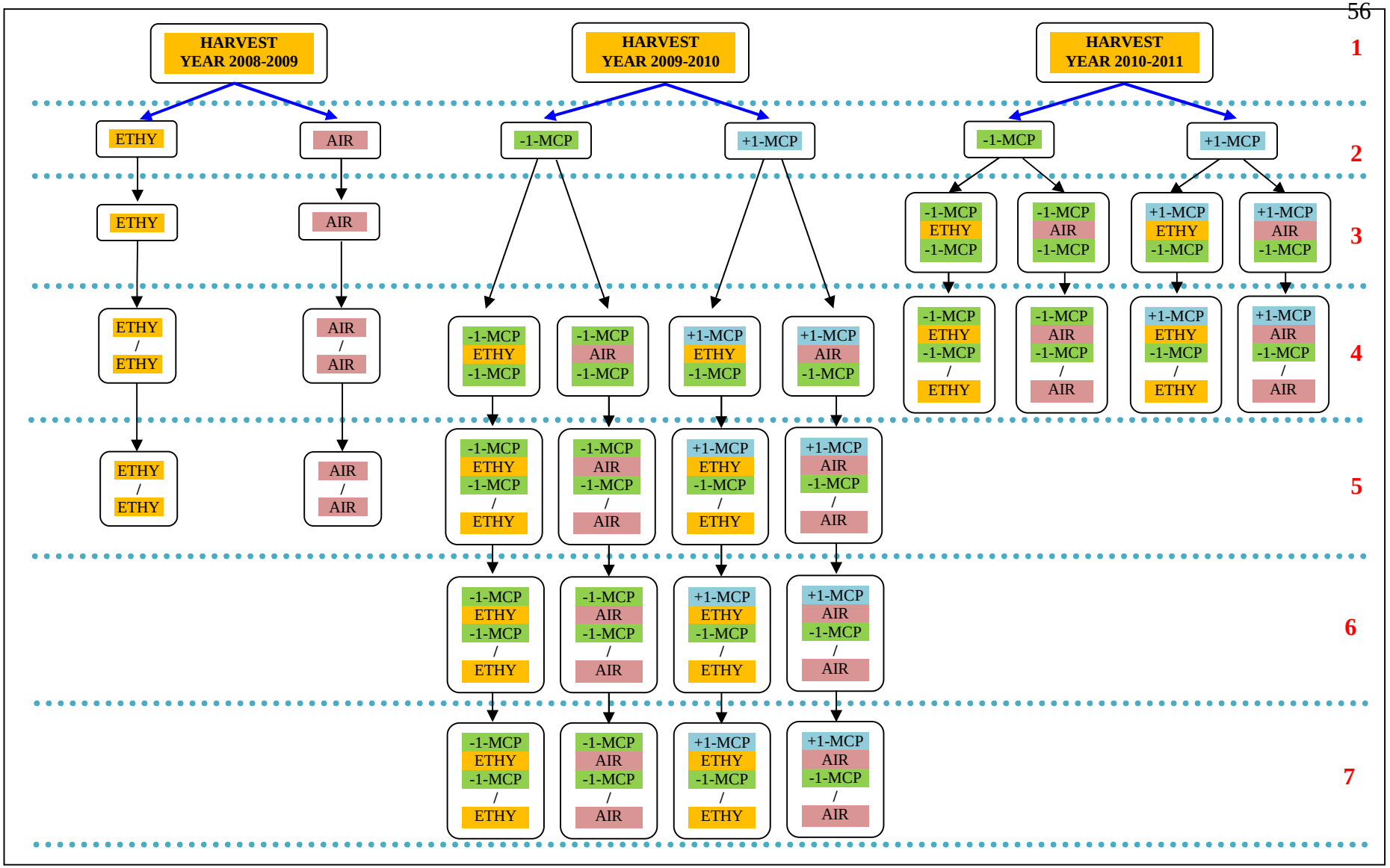

Figure 3.10 Sampling points (1-7) of 'Marfona' potato samples used for detection of various phytohorrmones in 2008-2009 (n = 36), 2009-2010 (n =57) and 2010-2011 (n = 33)

Bieleski solvent allowed the enzymatic degradation of phytohormones to be blocked without extracting large quantities of lipids (Lightfoot *et al.,* 1997). After 12 h, samples were centrifuged at 685 x g for 15 min at 4°C. The supernatant was removed and kept. The samples were re-extracted by adding 2 mL of methanol : water : formic acid mixture (75 : 20 : 5, v/v) and then centrifuged again at 685 x g for 15 min at 4°C. The supernatant was removed again and kept. Supernatants of both fractions were reunified into one fraction. A 3cc/500mg, 37-55μm Sep-Pak Plus C18 cartridge (Waters Associates, Milford, MA, cat. no: 186004619) that retains lipids and pigments was conditioned with 5 mL methanol 100% and equilibrated with 5 mL formic acid 1M. Each sample was then loaded, kept and freeze-dried in darkness (covered with aluminium foil to avoid photodegradation) overnight. Each freeze-dried sample was re-constituted with 1 mL formic acid 1M and loaded into an 6cc/150mg, 60μm Oasis MCX cartridge (Waters Associates, Milford, MA, cat. no: 186000255) which had firstly been conditioned with 5 mL methanol 100% and then equilibrated with 5 mL formic acid 1M; the sample was kept. The Oasis MCX cartridge was able to retain cytokinins by a cationic exchange mechanism, because they are positively ionised at acid pH, to retain s-ABA and IAA by the RP mechanism (Giannarelli *et al.,* 2010). The latter were eluted with 2 mL methanol 100% and the fraction was kept. Finally, 2 mL NH_4OH 0.35M in 60% methanol were added, both fractions were mixed together and freeze-dried in darkness as described before. Each sample was re-dissolved in 400 μL methanol 100% and filtered through a 0.2 μm syringe filter (Jaytee Biosciences Ltd., Kent, UK, part no: SF-J101322). Samples were stored at -40°C in brown glass vials until injection. The whole extraction procedure was done under low light conditions to avoid photodegradation of the samples.

Quantification of phytohormones

Samples (5 μL) were analysed using an Agilent 1290 Infinity LC System comprising an Infinity 1290 thermostatted column compartment (TCC) operated at 30°C, chromatographic separation was performed using a ZORBAX RRHD Eclipse Plus C18 column (2.1 x 100 mm 1.8 μm, Agilent, USA) . The mobile phase was a binary system comprising 0.1% formic acid in deionised water (A) and 0.1% formic acid in ACN (B). The gradient was of increasing acetonitrile concentration, 10-15% 2 min, 15-50% - 10 min, 100% - 3 min, equilibrated to initial condition for 4 min at a flow rate of 0.25 ml min^{-1}. The MS and MS/MS experiments were performed on an Agilent 6540 Ultra High Definition Accurate Mass Q-TOF LC-MS System equipped with a Agilent Jet stream ESI source. For either negative and positive mode the following settings were applied: Nebulizer gas temperature (N_2) 200 °C at a flow rate of 8 L/min, sheath gas temperature (N_2) 350 °C at a flow rate of 11 L/min, capillary voltage ±4000, nozzle voltage 500 V, fragmentor 175 V. Full scan data acquisition was performed on the range of 100-1000 m/z, at acquisition rate of 3 spectra/s, in both profile and centroid mode, using a cycle time of 0.333 s. Mass correction was performed using the Agilent TOF reference solution kit containing the m/z 119.03632 and m/z 966.000725 ion masses in negative mode, and the m/z 121.050873 and m/z 922.009798 ion masses in positive mode. In product ion scan experiments (MS/MS) products ions were produced by collision induced dissociation (CID) of selected precursor ions using targeted MS/MS experiments, with collision energy optimized per each compound (Tables 3.6 and 3.7) and an isolation window of 4 m/z (medium) for all compounds. Data acquisition was performed on the mass range of 100-1000 m/z with an acquisition rate of 6 spectra/s. Ions were detected in negative and positive mode.

Table 3.6 ABA and its metabolites and gibberellins (standards and their internal standards) that were used for the calibration curve and were detected in negative mode

ABA and metabolites	Mass	m/z (calculated by LC/MS ($M-H^-$) Precursor ion	Chemical Formula	Transition mz/ Product ion	RT (min) (peak)	Collision energy
Standards						
ABA	264.1362	263.1289	$C_{15}H_{20}O_4$	153.0921	8.284	10
ABA-GE	426.1890	425.1817	$C_{21}H_{30}O_9$	263.1292	5.758	12
PA	280.1311	279.1238	$C_{15}H_{20}O_5$	139.0760	6.242	14
7'-OH-ABA	280.1311	279.1238	$C_{15}H_{20}O_5$	151.0751	6.732	15
DPA	282.1467	281.1394	$C_{15}H_{22}O_5$	237.1496	4.149	17
Internal Standards						
d_4-ABA	268.1613	267.1540	$C_{15}H_{16}O_4D_4$	156.1113	8.255	10
d_5-ABA-GE	431.2204	430.2131	$C_{21}H_{25}O_9D_5$	268.1591	5.792	12
d_3-PA	283.1499	282.1426	$C_{15}H_{17}O_5D_3$	142.0959	6.282	14
d_4-7'-OH-ABA	284.1562	283.1489	$C_{15}H_{16}O_5D_4$	154.0946	6.754	15
d_3-DPA	285.1656	284.1583	$C_{15}H_{19}O_5D_3$	174.1365	4.194	17
Gibberellins						
Standards						
GA_1	348.1573	347.1500	$C_{19}H_{24}O_6$	273.113	5.678	25
GA_4	332.1624	331.1551	$C_{19}H_{24}O_5$	213.1286	11.452	25
Internal Standards						
d_2-GA_1	350.1698	349.1626	$C_{19}H_{22}O_6D_2$	275.1263	5.604	25
d_2-GA_4	334.1749	333.1677	$C_{19}H_{22}O_5D_2$	215.1800	11.435	25

Table 3.7 Cytokinins and auxins (standards and their internal standards) that were used for the calibration curve and were detected in positive mode.

Cytokinins	**Mass**	**m/z (calculated by LC/MS (M+H)+ Precursor ion**	**Chemical Formula**	**Transition mz/ Product ion**	**RT (min) (peak)**	**Collision energy**
Standards						
IPA	335.1594	336.1666	$C_{15}H_{21}N_5O_4$	204.1247	2.680	10
2iP	203.1171	204.1244	$C_{10}H_{13}N_5$	136.061	2.725	15
ZR	351.1543	352.1615	$C_{15}H_{21}N_5O_5$	220.1194	2.071	17
Z	219.1120	220.1193	$C_{10}H_{13}N_5O$	136.0617	1.232	15
Internal Standards						
d_6-IPA	341.1970	342.2043	$C_{15}H_{15}N_5O_4D_6$	210.1622	2.702	10
d_6-2iP	209.1548	210.1620	$C_{10}H_7N_5D_6$	137.0682	2.464	15
d_3-DHZR	356.1887	357.1960	$C_{15}H_{20}N_5O_5D_3$	225.1542	2.088	17
d_3-DHZ	224.1465	225.1538	$C_{10}H_{12}N_5OD_3$	136.0617	1.203	15
Auxin						
Standard						
IAA	175.0633	176.0706	$C_{10}H_9NO_5$	130.0665	3.351	10
Internal Standard						
d_5-IAA	180.0947	181.1020	$C_{10}H_4NO_5D_5$	135.0959	3.368	10

3.10 Statistical and multivariate analysis

Statistical analysis was performed using Genstat for Windows Version 12 VSN International Ltd. (Herts., UK). Analysis of variance was used to demonstrate the main effects of cultivar, treatment and time and the interactions between these factors to a probability of $P<0.05$ unless otherwise stated. The analysis was carried out considering the first time point as a common baseline to which the remaining points were compared and dummy variables were used to ensure the ANOVA captured the design of each experiment (Appendices A, B, C and D; Tables A.1, B.1; B.33; C.1). Least significant difference values (LSD $P_{0.05}$) were calculated for mean separation. Correlation coefficients (r) were calculated between mean data sets for starch results for 'Marfona' potatoes (see Chapter Four, Experiment 3).

Multivariate analysis was performed with Partial Least Square Discriminant Analysis (PLS-DA) and Principal Component Analysis (PCA) using The Unscrambler, Version 8.9 software (Camo Software, AS, Norway). The PLS-DA was used to classify observations from the results of PLS regression on indicator variables (Chevallier *et al.*, 2006). Logarithms were used, so that all data were normally distributed and a full cross validation was performed; data were centred and variables were weighted by dividing by the standard deviation. PCA is an unsupervisied technique and involves a mathematical procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. Total explained variance per principal component, loading plots and score plots showing treatment factors were used for interpretation.

CHAPTER FOUR

EFFECT OF THE TRANSITION BETWEEN ETHYLENE AND AIR STORAGE ON THE POSTHARVEST QUALITY OF TEN UK-GROWN POTATO CULTIVARS

4.1 Introduction

Long term storage of potato tubers allows year round availability of the crop but is limited by sprouting. Continuous exposure to ethylene during storage has been demonstrated to prolong storage life of potato by suppressing sprouting, yet there is a dearth of information on the effects of various ethylene treatments on cultivars other than 'Russet Burbank', and indeed on whether continuous ethylene treatment is needed for all genotypes. 'King Edward', 'Maris Piper', 'Saturna', 'Mayan Gold', 'Marfona', 'Estima', 'Desiree', 'Sylvana', 'Russet Burbank' and 'Fianna' potatoes were stored under four ethylene treatments (*viz.* continuous ethylene (10 μL L^{-1}), continuous air, transfer from air to ethylene after first indication of sprouting and vice versa) for thirty weeks. All potato cultivars previously mentioned belong to different groups according to their cropping season and thus is was hypothesised that they would probably respond differently to the ethylene treatment. This study has been divided into three experiments according to the number of sampling points (further details in Section 3.2.1).

4.2 Materials and methods

Sample preparation for Chapter 4 was described in Section 3.7. The measurement and analysis of dry matter content, texture, sprouting and sugar analysis were described in Chapter 3: Materials and Methods.

4.3 Experiment 1

Effect of exogenous ethylene application on dry matter, sugars, texture and sprouting of potato cv. King Edward

4.3.1 Dry matter content in flesh and peel

Dry weight content in flesh and peel of 'King Edward' tubers did not significantly change under any of the treatments (Tables 4.1).

Table 4.1 Dry weight content (g DW 100 g^{-1} FW) in flesh and peel of 'King Edward' potatoes (Appendix A, Tables A.2; A.3).

Experiment 1		g DW 100g^{-1} FW	
King Edward		Flesh	Peel
After harvest (Day 0)		23.53	19.92
At the end of the experiment	AIR/AIR	24.61	20.90
(30 weeks storage)	ETHY/ETHY	23.60	19.63
LSD ($P_{0.05}$)		1.907	2.026
$P_{0.05}$		0.400	0.374

4.3.2 Sugar analysis in flesh and peel

Flesh glucose and fructose concentration in ethylene-treated and air-treated tubers of 'King Edward' significantly increased between day 0 and 30 weeks of storage; this pattern was also observed for sucrose and glucose in peel. However, there was no significant difference between fructose concentration in peel of ethylene-treated and air-treated tubers of 'King Edward' in flesh at 30 weeks of storage, but fructose was significantly higher in the peel of ethylene-treated tubers (10.30 mg g^{-1} DW) vs. air-treated ones (4.50 mg g^{-1} DW) at the same time point (Table 4.2).

4.3.3 Texture measurements

No significant differences between treatments were recorded either under continuous air (AIR/AIR) or continuous ethylene (ETHY/ETHY) for both firmness and elasticity of the tubers under 30 weeks storage (Figure 4.1)

4.3.4 Sprouting

A significantly lower number of sprouts were recorded on ethylene-treated (ETHY/ETHY) tubers of potato cv. King Edward, compared to air-treated (AIR/AIR) ones after 30 weeks of storage. Sprouts at the length of < 5mm were the most abundant on both air-treated and ethylene-treated tubers, but the proportion was significantly higher in the ethylene-treated tubers (Table 4.3).

Table 4.2 Fructose, glucose, sucrose (mg g^{-1} DW) in flesh and peel of potato cv. King Edward (Appendix A, Tables A.4-A.9).

Experiment 1		Flesh			Peel		
Potato cv. King Edward		Fructose	Glucose	Sucrose	Fructose	Glucose	Sucrose
After harvest (Day 0)		6.46	0.96	6.57	8.70	0.98	6.66
At the end of the experiment	AIR/AIR	9.79	8.31	11.05	4.50	6.88	13.36
(30 weeks storage)	ETHY/ETHY	12.02	11.59	12.59	10.30	9.08	16.53
LSD ($P_{0.05}$)		2.756	5.254	4.963	5.560	2.550	4.567
$P_{0.05}$		0.004	0.004	0.054	0.104	<0.001	0.003

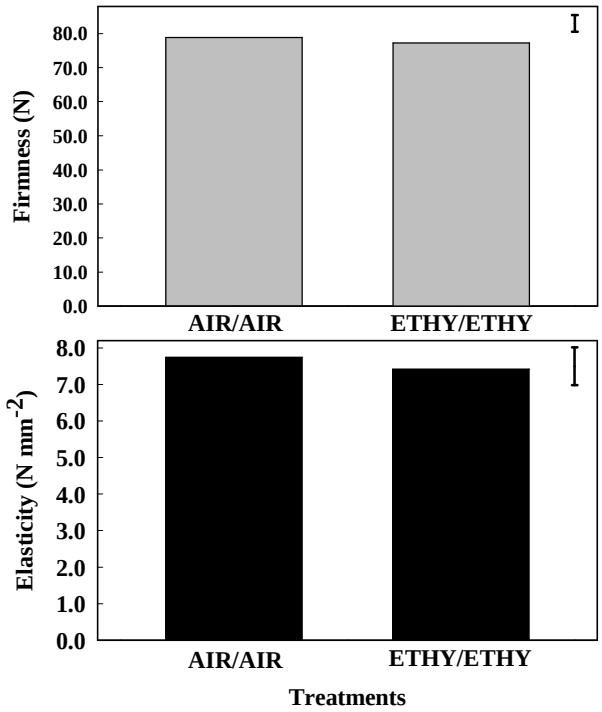

Figure 4.1 Firmness (N) and elasticity (N mm^{-2}) of potato cv. King Edward measured after storage for 30 weeks in continuous air (AIR/AIR) or in continuous ethylene (ETHY/ETHY). Individual treatment data are means; n=12. $LSD_{0.05}$ value is for comparison of individual treatment means (Appendix A; Tables A.10; A.11).

Table 4.3 Sprouting assessment for potato cv. King Edward measured at the end of the experiment (30 weeks) in air (CTRL/CTRL) and in ethylene (ETHY/ETHY). Individual treatment data are means; n=4. $LSD_{0.05}$ value is for comparison of individual treatment means (Appendix A, Tables A.12-A.15 & Plate A.1).

% of sprouts/size	Treatments		$LSD_{0.05}$
	AIR/AIR	ETHY/ETHY	
< 5 mm	59.0	97.2	19.3
5-10 mm	31.2	2.8	10.0
>10 mm	9.7	0.0	19.5
Total number of sprouts	19.2	10.2	5.6

4.4 Experiment 2

Effect of exogenous ethylene application on dry matter, sugars, texture and sprouting of potato cvs. Maris Piper and Saturna and potato variety Mayan Gold

4.4.1 Dry matter content in flesh and peel

Dry weight content significantly decreased between at the time of first indication of sprouting plus 4 weeks and the end of the experiment for potato cv. Maris Piper tubers that were transferred from air to ethylene (Figure 4.2). In potato cv. Mayan Gold, dry weight content was significantly increased between the beginning of storage and the time of first indication of sprouting in air-treated tubers. Significantly higher dry weight was recorded in air-treated tubers of potato cv. Mayan Gold compared to ethylene-treated ones at the end of the experiment. For potato cv. Saturna dry weight of ethylene-treated tubers was significantly higher compared to air-treated ones at the time of first indication of sprouting. In contrast, at the end of the experiment, significantly higher dry weight content was recorded for the air-treated tubers compared to ethylene-treated ones for potato cv. Saturna.

No significant differences were recorded between any of the treatments regarding dry weight content in peel of potato cvs. Maris Piper, Mayan Gold and Saturna (Figure 4.2).

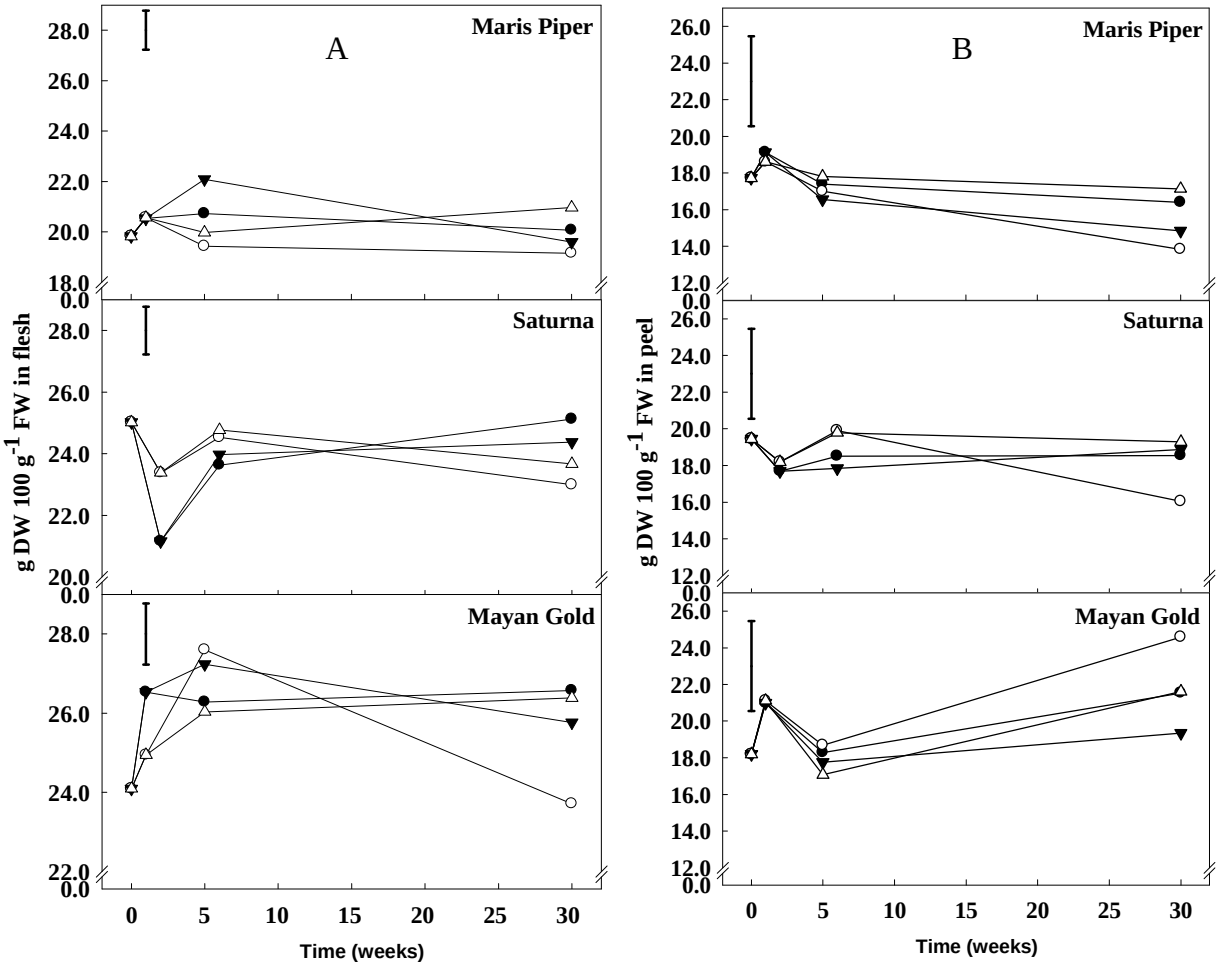

Figure 4.2 Dry weight content (g DW 100 g^{-1} FW) in flesh (A) and peel (B) of potato cvs. Maris Piper and Saturna and potato variety Mayan Gold measured after harvest (day 0), at first indication of sprouting, at 4 weeks after first indication of sprouting and at the end of the experiment (30 weeks). (●) continuous air; (○) continuous ethylene; (▼) transfer from air to ethylene; (△) transfer from ethylene to air. Individual treatment data are means; n=4. LSD bars (P<0.05) are shown (Appendix A, Tables A.16; A.17).

4.4.2 Sugar analysis in flesh and peel

Flesh sucrose and peel glucose and fructose levels in 'Maris Piper' and 'Mayan Gold' tubers was up to 3-fold higher in ethylene-treated than air-treated tubers at the time of first indication of sprouting (one week after storage in air and ethylene) (Figure 4). However, there was no significant effect of ethylene treatment on flesh glucose and fructose, or peel sucrose concentrations in tubers of any cultivar at this time point. Four

weeks after first indication of sprouting, 'Maris Piper' tubers that were continuously treated with ethylene and those transferred from air to ethylene and vice versa had about 2-fold higher flesh and peel glucose and fructose content compared to air-treated ones. By the end of storage, there were no significant differences in glucose flesh and peel content between treatments for 'Maris Piper' and 'Mayan Gold' tubers. In contrast, higher flesh sucrose was observed in ethylene-treated (23.08 mg g^{-1} DW) than air-treated (15.34 mg g^{-1} DW) 'Mayan Gold' tubers, whereas significantly lower flesh fructose content was measured in 'Maris Piper' air-treated (14.00 mg g^{-1} DW) tubers, than those transferred from air to ethylene (23.48 mg g^{-1} DW) at the same time point. There was no effect of treatment on peel sucrose and fructose content of 'Mayan Gold' tubers by the end of storage. In contrast, *ca.* 2-fold higher peel sucrose (13.20 mg g^{-1} DW) and fructose (12.81 mg g^{-1} DW) content was shown in 'Maris Piper' tubers transferred from air to ethylene than vice versa (6.53 and 6.57 mg g^{-1} DW respectively) at the same time point (Figures 4.3 and 4.4). Ethylene-treated 'Saturna' tubers had about 3-fold higher flesh sucrose content (36.50 mg g^{-1} DW) than air-treated ones (13.41 mg g^{-1} DW) at six weeks after storage in ethylene and in air (Figure 4.3). At the time of first indication of sprouting, there were significant differences between ethylene-treated (18.43 mg g^{-1} DW) and air-treated (11.80 mg g^{-1} DW) tubers regarding sucrose content in 'Saturna' tubers only (Figure 4.3).

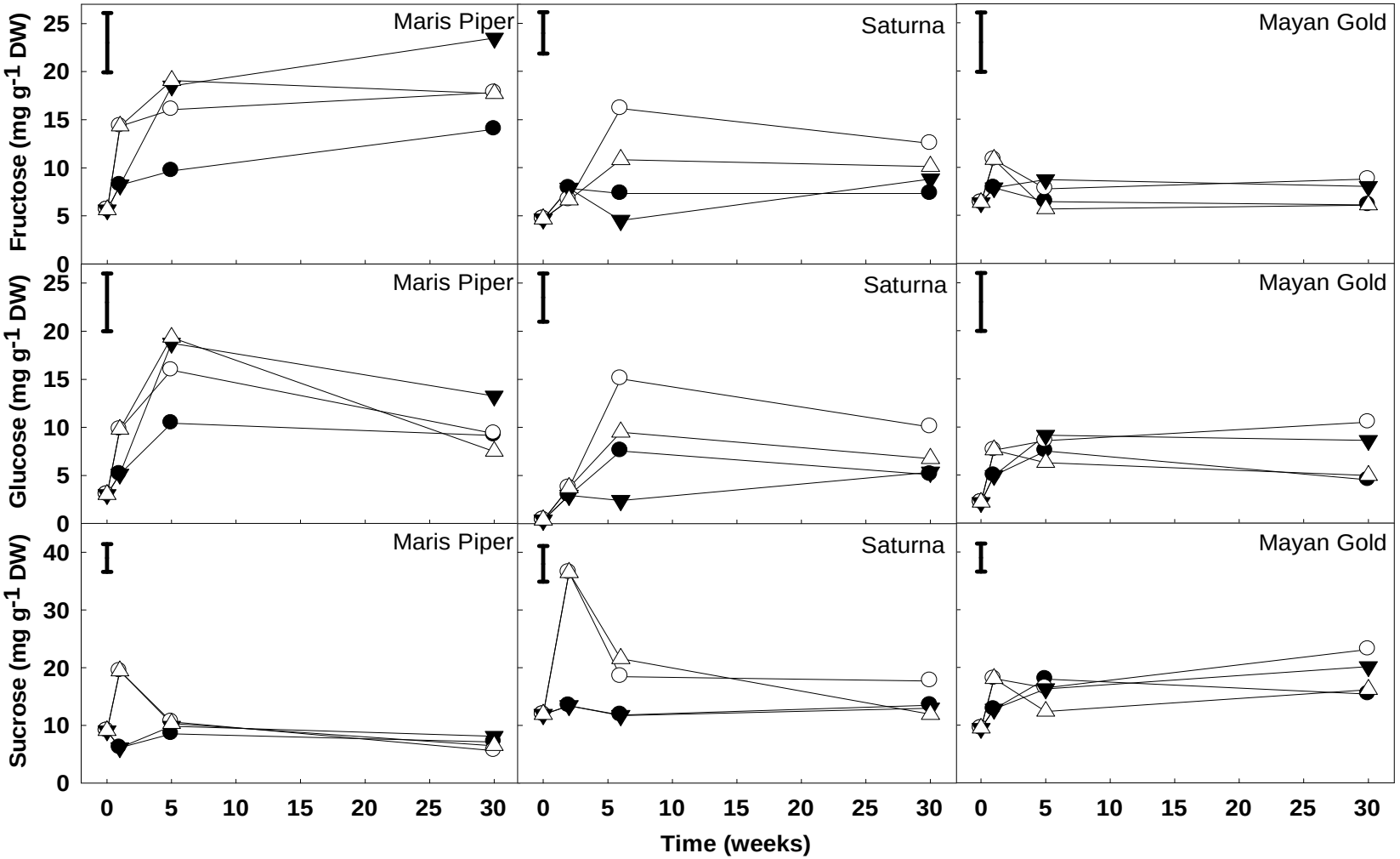

Figure 4.3 Fructose, glucose and sucrose concentrations (mg g^{-1} DW) in flesh of 'Maris Piper', 'Saturna' and 'Mayan Gold' potatoes measured after harvest (day 0), at first indication of sprouting, at 4 weeks after first indication of sprouting and at the end of the experiment (30 weeks). (●) continuous air; (○) continuous ethylene; (▼) transfer from air to ethylene; (△) transfer from ethylene to air. Individual treatment data are means; n=4. LSD bars (P<0.05) are shown (Appendix A, Tables A.18-A.20).

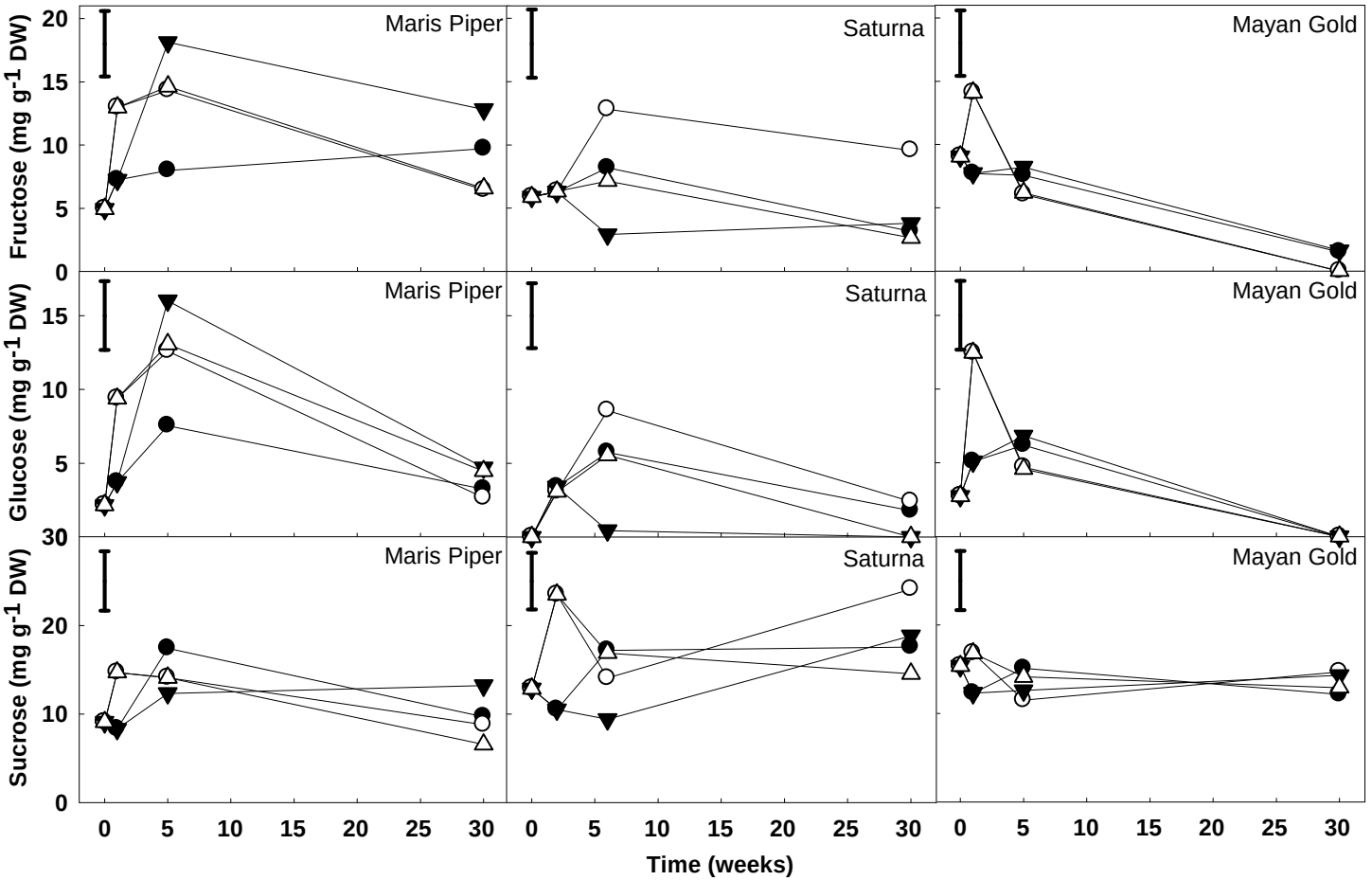

Figure 4.4 Fructose, glucose and sucrose concentrations (mg g^{-1} DW) in peel of 'Maris Piper', 'Saturna' and 'Mayan Gold' potatoes measured after harvest (day 0), at first indication of sprouting, at 4 weeks after first indication of sprouting and at the end of the experiment (30 weeks). (●) continuous air; (○) continuous ethylene; (▼) transfer from air to ethylene; (△) transfer from ethylene to air. Individual treatment data are means; n=4. LSD bars (P<0.05) are shown (Appendix A, Tables A.21-A.23).

4.4.3 Texture measurements

Potato cvs. Maris Piper and Saturna tubers stored in ethylene during the second storage period were significantly firmer than those stored in air for the second storage period (Figure 4.5). No significant differences in firmness between treatments were recorded for potato cv. Mayan Gold, although the firmest tubers of this cv. were those transferred from ethylene to air. There were no significant differences in firmness of potato cv. Saturna between the continuous ethylene or air treatments, however, tubers cv. Saturna transferred from air to ethylene were firmer than those transferred from ethylene to air. Potato cv. Maris Piper tubers stored under continuous ethylene were more elastic compared air-stored tubers. Potato cvs. Mayan Gold and Saturna tubers were most elastic under continuous ethylene treatment, or when transferred from air to ethylene.

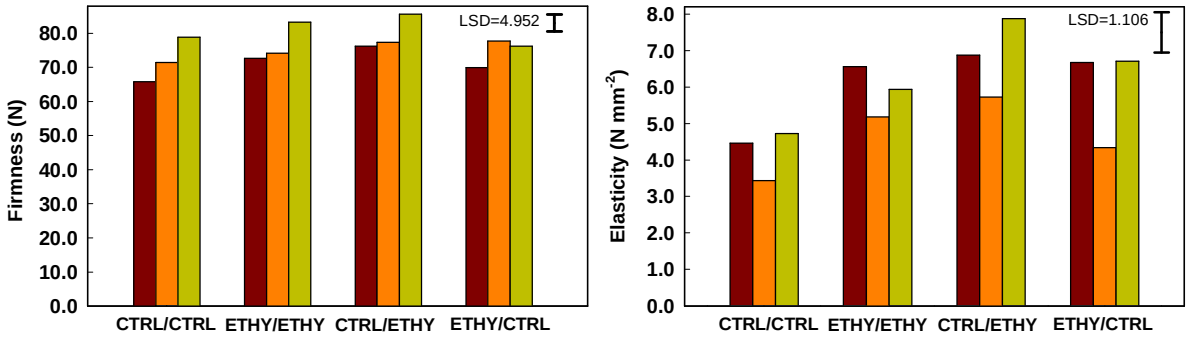

Figure 4.5 Firmness (N) and elasticity (N mm^{-2}) of potato cvs. Maris Piper Mayan Gold and Saturna measured after storage for 30 weeks in air (CTRL/CTRL), in ethylene (ETHY/ETHY), after transfer from air to ethylene at first indication of sprouting (CTRL/ETHY) and after transfer from ethylene to air at first indication of sprouting (ETHY/CTRL). Individual treatment data are means; n=12. $LSD_{0.05}$ value is for comparison of individual treatment means (Appendix A, Table A.24; A.25).

4.4.4 Sprouting

The number of total sprouts recorded in air-treated tubers of potato cv. Maris Piper was significantly greater than in ethylene-treated ones (Table 4.4). Tubers of potato cv. Maris Piper that were transferred from ethylene to had a significantly higher number of sprouts than those tubers transferred from air to ethylene. No significant differences in total number of sprouts were recorded between treatments for potato cv. Saturna. In all treatments and cultivars, sprouts at the length of <50mm were the most abundant.

Table 4.4 Sprouting assessment for potato cvs. Maris Piper and Saturna measured at the end of the experiment (30 weeks) after first indication of sprouting plus 4 weeks in air (CTRL/CTRL), in ethylene (ETHY/ETHY), after transfer from air to ethylene (CTRL/ETHY) and after transfer from ethylene to air (ETHY/CTRL). Individual treatment data are means; n=4. $LSD_{0.05}$ value is for comparison of individual treatment means (Appendix A, Table A.26-A.29 & Plate A.1)

	Varieties								
% of sprouts/length	**Maris Piper**				**Saturna**				**$LSD_{0.05}$**
	Treatments								
	CTRL/ CTRL	ETHY/ ETHY	CTRL/ ETHY	ETHY/ CTRL	CTRL/ CTRL	ETHY/ ETHY	CTRL/ ETHY	ETHY/ CTRL	
< 5 mm	56.0	99.0	75.5	62.0	72.0	100.0	71.0	73.0	36.69
5-10 mm	30.3	1.5	19.2	25.5	8.3	0.0	29.0	26.7	31.55
> 10 mm	14.0	0.0	5.4	12.2	19.4	0.0	0.0	0.0	16.00
Total number of sprouts	38.8	21.5	17.8	43.0	10.2	10.0	7.8	14.2	11.7

No significant differences were recorded between treatments regarding the total number of sprouts and/or size of sprouts in potato cv. Mayan Gold (Table 4.5).

Table 4.5 Sprouting assessment for potato cv. Mayan Gold measured at the end of the experiment (30 weeks) after first indication of sprouting plus 4 weeks in air (CTRL/CTRL), in ethylene (ETHY/ETHY), after transfer from air to ethylene (CTRL/ETHY) and after transfer from ethylene to air (ETHY/CTRL). Individual treatment data are means; n=4. $LSD_{0.05}$ value is for comparison of individual treatment means (Appendix A, Table A.30-A.32 & Plate A.1).

% of sprouts/size	Treatments				$LSD_{0.05}$
	CTRL/CTRL	ETHY/ETHY	CTRL/ETHY	ETHY/CTRL	
Small size of sprout	58.3	83.3	51.0	57.9	56.0
Big size of sprout	41.7	16.7	49.0	42.1	56.0
Total number of sprouts	2.75	3.75	4.25	5.25	2.6

4.5 Experiment 3

Effect of exogenous ethylene application on dry matter, sugars, texture and sprouting of potato cvs. Desiree, Estima, Marfona, Fianna, Russett Burbank and Sylvana

4.5.1 Dry matter content in flesh and peel

Dry weight content significantly increased between day 0 and 6-weeks storage in tubers of potato cv. Marfona stored in ethylene and air (Figure 4.6). After 6-weeks, significantly higher dry weight was recorded in ethylene-treated compared with air-treated potato cv. Russett Burbank tubers. No other significant differences were recorded for the remaining cultivars between treatments after 6-weeks storage or at first indication of sprouting. Dry weight content in ethylene-treated and air-treated potato cv. Marfona significantly decreased between 6-weeks storage and time of first indication of sprouting. At the time of first indication of sprouting plus 4 weeks, dry weight content in cvs. Marfona and Fianna tubers was significantly lower in those tubers transferred from ethylene to air, compared with those transferred from air to ethylene. No significant differences in dry weight were recorded for the remaining cultivars or treatments. Significantly lower values were recorded in the proportion of dry weight of the ethylene-treated potato cvs. Estima and Fianna tubers at the end of the experiment. Dry weight proportion was significantly decreased between outturn 4 and the end of storage in air-treated tubers of potato cv. Fianna, as well in those transferred from air to ethylene, while dry weight increased in those transferred from ethylene to air, or stored in continuous air.

Peel dry weight content significantly increased between day 0 and 6-weeks storage in potato cvs. Marfona and Sylvana stored in ethylene (Figure 4.7). No significant differences in peel dry weight were recorded between treatments in any cultivar after 6-weeks storage, but peel dry weight content was higher in ethylene-treated then air-treated cv. Russett Burbank at the time of first indication of sprouting. Peel dry weight content of ethylene-treated cv. Sylvana significantly increased between 6-weeks storage and time of first indication of sprouting. At the time of first indication of sprouting plus 4 weeks, peel dry weight content of cv. Marfona was significantly lower in those tubers transferred from ethylene to air, compared with those transferred from air to ethylene, however, the opposite was true for cv. Sylvana. No significant differences between treatments were recorded for the remaining cultivars at outturn 4. In the last outturn, after 30 weeks of storage, dry weight in peel of potato cv. Fianna was significantly lower when tubers were transferred from air to ethylene. Same pattern was followed for peel of Sylvana tubers that were transferred from ethylene to air. In contrast, dry weight proportion was significantly higher in peel of potato cv. Marfona tubers transferred from ethylene to air and Russett Burbank tubers stored under continuous air after 30 weeks of storage.

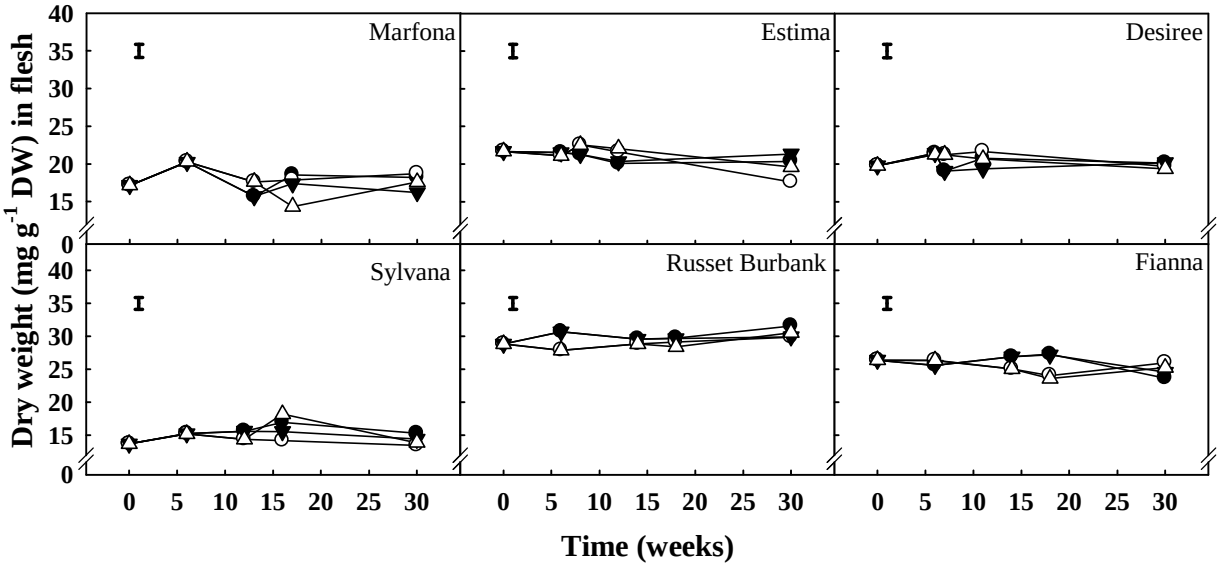

Figure 4.6 Dry weight content (g DW 100 g^{-1} FW) in flesh of potato cvs. Marfona, Estima, Desiree, Sylvana, Russet Burbank and potatoes measured after harvest (day 0), at 6 weeks after storage in ethylene and air, at first indication of sprouting, at 4 weeks after first indication of sprouting and at the end of the experiment (30 weeks). (●) continuous air; (○) continuous ethylene; (▼) transfer from air to ethylene; (△) transfer from ethylene to air. Individual treatment data are means; n=4. LSD bars (P<0.05) are shown (Appendix A, Table A.33).

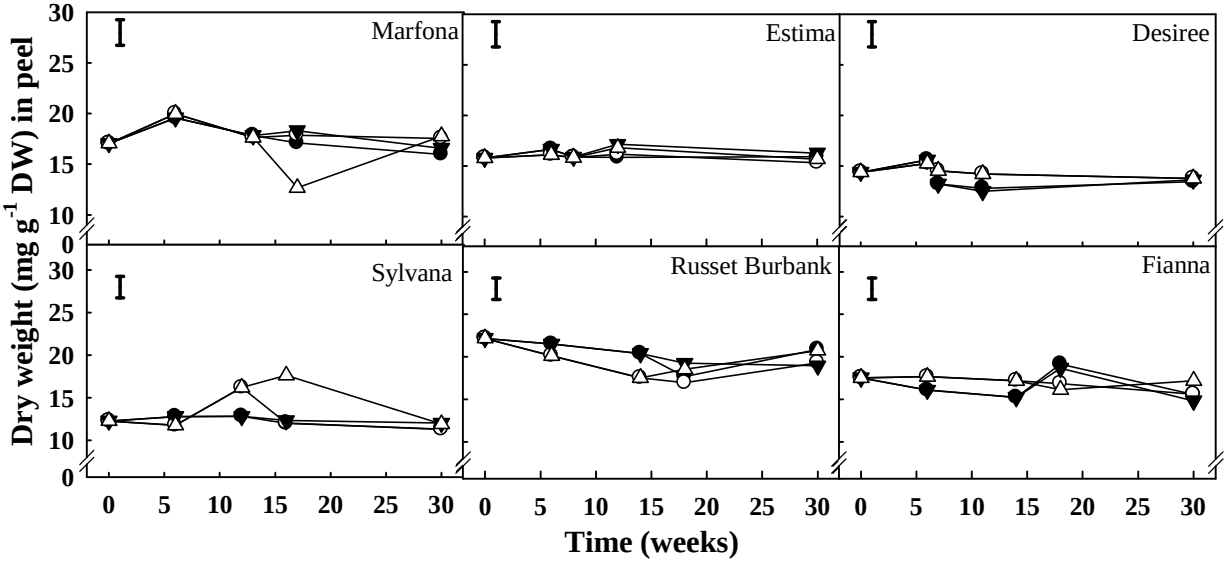

Figure 4.7 Dry weight content (g DW 100 g^{-1} FW) in peel of potato cvs. Marfona, Estima, Desiree, Sylvana, russet Burbank and potatoes measured after harvest (day 0), at 6 weeks after storage in ethylene and air, at first indication of sprouting, at 4 weeks after first indication of sprouting and at the end of the experiment (30 weeks). (●) continuous air; (○) continuous ethylene; (▼) transfer from air to ethylene; (△) transfer from ethylene to air. Individual treatment data are means; n=4. LSD bars (P<0.05) are shown (Appendix A, Table A.34).

4.5.2 Sugar analysis in flesh and peel

After harvest, the highest flesh and peel fructose (22.76 and 22.52 mg g^{-1} DW) and flesh and peel glucose (20.84 and 18.94 mg g^{-1} DW) concentrations were observed in 'Estima' tubers, while the highest flesh sucrose (13.13 mg g^{-1} DW) was shown in 'Sylvana' tubers and the highest peel sucrose (18.59 mg g^{-1} DW) in 'Desiree' tubers (Figures 4.8 and 4.9). In contrast, the lowest values were observed in flesh fructose (4.32 mg g^{-1} DW), flesh glucose (0.55 mg g^{-1} DW) and peel glucose (0.44 mg g^{-1} DW) content in 'Fianna' tubers, whereas 'Marfona', 'Sylvana' and 'Russet Burbank' tubers had the lowest values in flesh sucrose (7.82 mg g^{-1} DW), peel sucrose (8.17 mg g^{-1} DW) and peel fructose (4.68 mg g^{-1} DW), respectively.

Six weeks after storage in ethylene and in air, ethylene-treated 'Marfona' and 'Sylvana' tubers contained more than 2-fold higher flesh sucrose (19.75 and 24.96 mg g^{-1} DW respectively), glucose (44.42 and 57.82 mg g^{-1} DW respectively) and fructose (43.79 and 62.66 mg g^{-1} DW, respectively) content compared to air-treated (sucrose: 10.62 and 16.16 mg g^{-1} DW; glucose: 22.24 and 25.25 mg g^{-1} DW; fructose: 24.59 and 38.68 mg g^{-1} DW respectively) (Figure 4.8). The same pattern was shown for peel glucose and fructose content in 'Marfona' and 'Sylvana' tubers, as well as in peel sucrose, but only for 'Sylvana' tubers (Figure 4.9). Ethylene-treated 'Desiree' and 'Fianna' tubers contained about 2-fold higher flesh and peel fructose content, while ethylene-treated 'Fianna' tubers also had higher flesh and peel sucrose content than air-treated ones.

At the time of first indication of sprouting, there were no significant differences between ethylene-treated and air-treated tubers regarding flesh sucrose content (Figure

5). In contrast, ethylene-treated 'Sylvana' and 'Desiree' tubers had higher peel sucrose content (47.14 and 25.66 mg g^{-1} DW, respectively) than air-treated ones (35.97 and 16.18 mg g^{-1} DW, respectively), whereas the opposite was true for 'Fianna' tubers, at the same time point. 'Marfona', 'Sylvana' and 'Desiree' tubers contained more than 2-fold higher fructose (flesh and peel) and peel glucose content at the time of first indication of sprouting. However, only the ethylene-treated 'Marfona' tubers (65.11 mg g^{-1} DW) had significantly higher flesh glucose content than air-treated ones (27.08 mg g^{-1} DW), at the same time point.

Flesh sucrose content in ethylene-treated 'Sylvana', 'Russet Burbank' and 'Fianna' tubers significantly decreased between six weeks storage (24.96, 17.94 and 22.49 mg g^{-1} DW respectively) and time of first sprouting indication (18.40, 11.07 and 8.60 mg g^{-1} DW respectively) (Figure 4.8). Similarly, flesh fructose content in ethylene-treated 'Russet Burbank' tubers significantly decreased (from 25.07 to 13.52 mg g^{-1} DW) between the same time points. In contrast, flesh glucose and fructose content was significantly increased in ethylene-treated 'Marfona' tubers (from 44.42 to 65.11 and from 43.79 to 52.75 mg g^{-1} DW respectively) and flesh glucose content in air-treated 'Sylvana' tubers (from 25.25 to 45.56 mg g^{-1} DW). In contrast, there was a significant increase in flesh glucose and fructose content between six weeks storage and first indication of sprouting in the ethylene-treated 'Marfona' tubers (from 44.42 to 65.11 and from 43.79 to 52.75 mg g^{-1} DW respectively). There were no significant differences between six weeks storage and time of first indication of sprouting for the air-treated tubers in flesh sucrose content (Figure 4.8).

In contrast to the results for sugars in flesh, where significant differences were found mainly in the ethylene-treated tubers between six weeks storage and first

indication of sprouting; there were significant differences in the air-treated tubers between the same time points for sugar peel content. More specifically, sugar peel content in air-treated 'Sylvana' tubers significantly increased between six weeks storage and dormancy break in peel sucrose (from 21.03 to 35.97 mg g^{-1} DW), glucose (from 18.89 to 30.90 mg g^{-1} DW) and fructose (from 23.65 to 34.57 mg g^{-1} DW). The same pattern was shown in air-treated 'Fianna' tubers, but only for peel sucrose content between the same time points (from 13.56 to 24.63 mg g^{-1} DW), whereas there was a significant decrease between these time points for the ethylene-treated 'Fianna' tubers in peel glucose (from 14.51 to 1.54 mg g^{-1} DW) and fructose (from 22.03 to 5.57 mg g^{-1} DW) content (Figure 4.9). At the end of storage (30 weeks), there were no significant differences between treatments in flesh mean sucrose ('Marfona' and 'Estima'), glucose ('Estima', 'Desiree' and 'Fianna) and fructose ('Estima', 'Desiree', 'Russet Burbank' and 'Fianna) content (Figure 4.8). For the peel, there were no significant differences between treatments in mean sucrose ('Marfona', 'Estima', 'Desiree' and 'Fianna), glucose ('Desiree' and 'Fianna') and fructose ('Fianna') content (Figure 4.9). Flesh fructose and glucose levels in 'Marfona' were negatively correlated with starch (r = -0.66 and r = -0.61 respectively; $P < 0.001$), whereas a strongly significant positive correlation was found between fructose and glucose in flesh (r = 0.87).

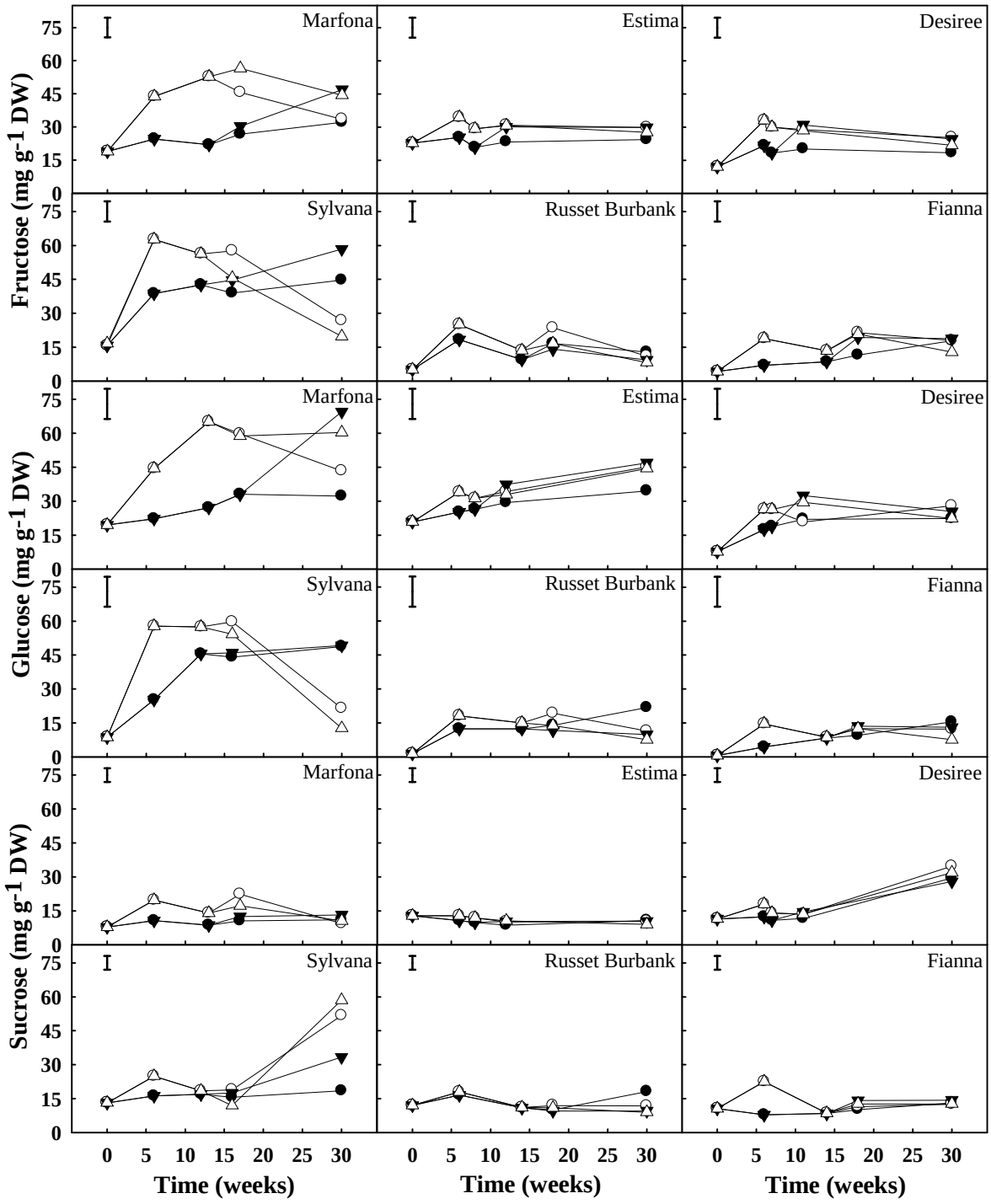

Figure 4.8 Fructose, glucose and sucrose (mg g^{-1} DW) in flesh of potato cvs. Marfona, Estima, Desiree, Sylvana, russet Burbank and potatoes measured after harvest (day 0), at 6 weeks after storage in ethylene and air, at first indication of sprouting, at 4 weeks after first indication of sprouting and at the end of the experiment (30 weeks). (●) continuous air; (○) continuous ethylene; (▼) transfer from air to ethylene; (△) transfer from ethylene to air. Individual treatment data are means; n=4. LSD bars (P<0.05) are shown (Appendix A, Tables A.35-A.37).

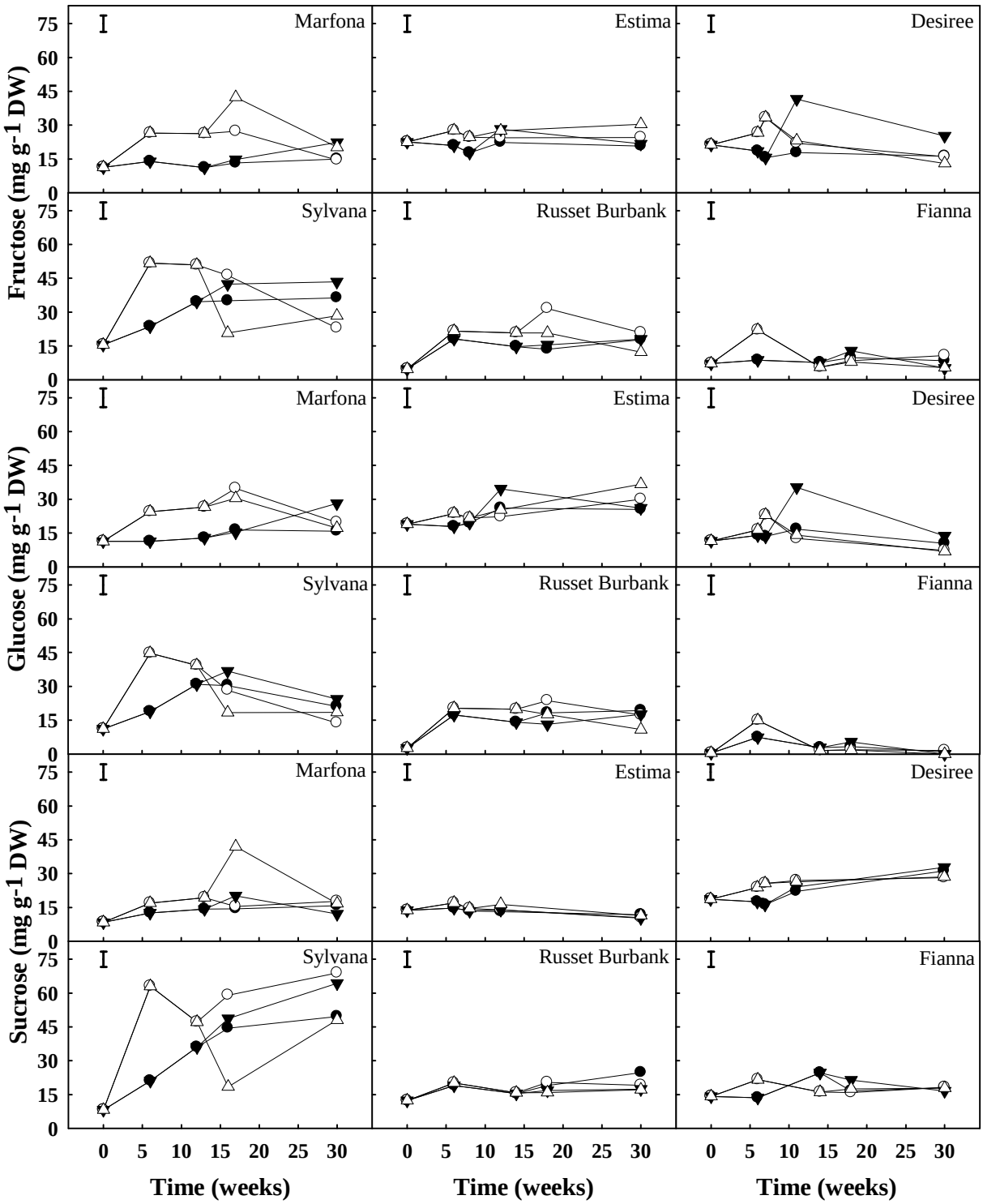

Figure 4.9 Fructose, glucose and sucrose (mg g^{-1} DW) in peel of potato cvs. Marfona, Estima, Desiree, Sylvana, russet Burbank and potatoes measured after harvest (day 0), at 6 weeks after storage in ethylene and air, at first indication of sprouting, at 4 weeks after first indication of sprouting and at the end of the experiment (30 weeks). (●) continuous air; (○) continuous ethylene; (▼) transfer from air to ethylene; (△) transfer from ethylene to air. Individual treatment data are means; n=4. LSD bars (P<0.05) are shown (Appendix A, Tables A.38-A.40).

4.5.3 Texture measurements

Potato cv. Russett Burbank tubers stored under continuous ethylene were the most firm, in contrast, cv. Sylvana tubers were less firm under the same treatment (after 4 weeks after first indication of sprouting) (Figure 4.10). Firmness of tubers cv. Russett Burbank and Fianna was not affected by ethylene treatment, but tubers of cv. Russett Burbank were affected by time. Potato cv. Marfona tubers were not affected by ethylene treatment, or by storage time. The greatest elasticity was measured in potato cv. Fianna tubers that were transferred to ethylene from air after showing signs of sprouting. Elasticity of potato cv. Sylvana tubers was not affected by ethylene treatment. Ethylene-treated Sylvana tubers were less elastic. In contrast, potato cv. Russett Burbank tubers were affected by ethylene treatment regarding elasticity and were more elastic (Figure 4.10).

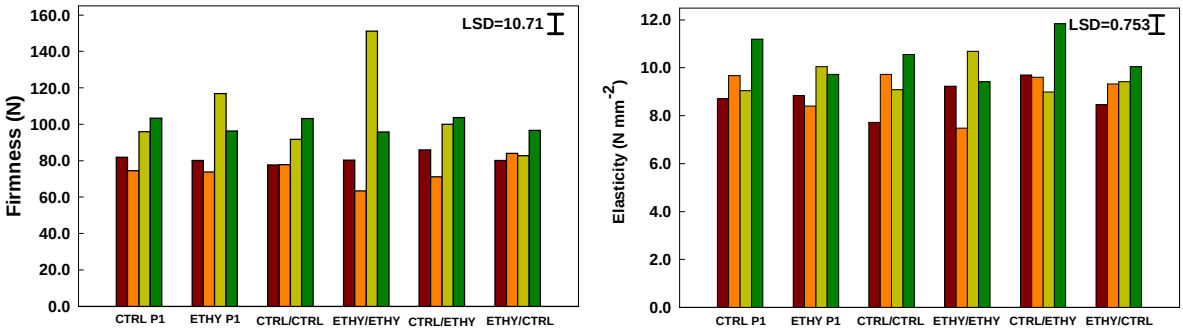

Figure 4.10 Firmness (N) and elasticity (N mm^{-2}) of potato cvs. Marfona ■ Sylvana ■ Russett Burbank ■ and Fianna ■ measured after storage at first indication of sprouting in air (CTRL P1) and ethylene (ETHY P1) and then after first indication of sprouting plus 4 weeks in air (CTRL/CTRL), in ethylene (ETHY/ETHY), after transfer from air to ethylene (CTRL/ETHY) and after transfer from ethylene to air (ETHY/CTRL). Individual treatment data are means; n=12. $LSD_{0.05}$ is for comparison of individual treatment means (Appendix A.41; A.42)

Significantly higher firmness values were recorded for cvs. Estima and Fianna tubers transferred from ethylene to air, compared with those transferred from air to

ethylene (at the end of the experiment) (Figure 4.11). In contrast, Sylvana tubers were less firm when transferred from ethylene to air, than from air to ethylene at the time of first indication of sprouting plus 4 weeks. No significant differences were recorded between treatments in any of the other cultivars. However, mean firmness of potato cvs. Fianna and Russett Burbank were greater than the rest of the cultivars. Significantly higher elasticity was recorded in cv. Desiree tubers transferred from air to ethylene at the time of first indication of sprouting plus 4 weeks. Potato cv. Marfona tubers treated under continuous ethylene were more elastic than those from the other treatments. No significant differences in elasticity were recorded between treatments for the other cultivars.

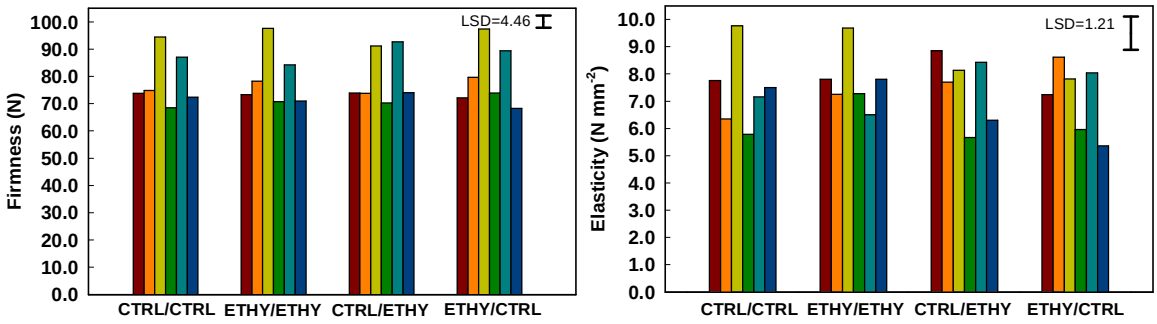

Figure 4.11 Firmness (N) and elasticity (N mm^{-2}) of potato cvs. Desiree Estima Fianna Marfona Russett Burbank and Sylvana measured after storage at the end of the experiment (30 weeks) after first indication of sprouting plus 4 weeks in air (CTRL/CTRL), in ethylene (ETHY/ETHY), after transfer from air to ethylene (CTRL/ETHY) and after transfer from ethylene to air (ETHY/CTRL). Individual treatment data are means; n=12. $LSD_{0.05}$ value is for comparison of individual treatment means (Appendix A, A.43; A.44).

4.5.4 Sprouting

Air-treated tubers of potato cvs. Marfona, Russett Burbank and Sylvana had a significantly higher number of total sprouts compared to ethylene-treated ones (Table 4.6). Higher number of sprouts was also recorded in air-treated tubers of potato cvs.

Estima and Fianna, but this was not significant. Tubers from all potato cvs. that were transferred from ethylene to air in the second storage period had significantly higher number of sprouts than those that were recorded on tubers transferred from air to ethylene on the same storage period.

Table 4.6 Sprouting assessment for potato cvs. Desiree, Estima, Marfona, Fianna, Russett Burbank and Sylvana measured at the end of the experiment (30 weeks) after first indication of sprouting plus 4 weeks in air (CTRL/CTRL), in ethylene (ETHY/ETHY), after transfer from air to ethylene (CTRL/ETHY) and after transfer from ethylene to air (ETHY/CTRL). Individual treatment data are means; n=4. $LSD_{0.05}$ value is for comparison of individual treatment means (Appendix A, A4.5-A.48 &Plate A.1).

Varieties	Treatments	% of sprouts/length			Total number of sprouts
		< 5 mm	5-10 mm	> 10 mm	
Desiree	CTRL/CTRL	46.90	28.19	24.95	15.00
	ETHY/ETHY	100.0	0.00	0.00	17.50
	CTRL/ETHY	100.0	0.00	0.00	19.50
	ETHY/CTRL	89.60	7.28	3.12	29.25
Estima	CTRL/CTRL	79.60	11.98	8.44	19.75
	ETHY/ETHY	100.0	0.00	0.00	13.50
	CTRL/ETHY	100.0	0.00	0.00	12.25
	ETHY/CTRL	86.8	11.16	2.08	20.75
Marfona	CTRL/CTRL	58.70	37.33	3.97	23.25
	ETHY/ETHY	81.30	18.69	0.00	14.75
	CTRL/ETHY	61.40	38.58	0.00	9.75
	ETHY/CTRL	61.40	38.58	0.00	24.50
Fianna	CTRL/CTRL	61.00	0.00	38.96	7.50
	ETHY/ETHY	100.0	0.00	0.00	2.50
	CTRL/ETHY	100.0	0.00	0.00	1.00
	ETHY/CTRL	45.00	36.39	28.61	8.75
Russett Burbank	CTRL/CTRL	73.60	17.14	9.29	12.25
	ETHY/ETHY	0.00	0.00	0.00	0.00
	CTRL/ETHY	0.00	0.00	0.00	0.00
	ETHY/CTRL	90.90	6.82	2.27	9.25
Sylvana	CTRL/CTRL	83.30	5.56	11.11	14.00
	ETHY/ETHY	0.00	0.00	0.00	0.00
	CTRL/ETHY	0.00	0.00	0.00	0.00
	ETHY/CTRL	82.80	0.00	17.22	12.75
$LSD_{0.05}$		22.70	13.80	13.63	6.66

4.6 Chemometrics

PCA analysis was performed in order to gain information on whether any of the varieties that were examined are grouped together and have similar or different patterns in terms of the variates measured.

PCA of sugars in flesh (DW), sprouting incidence and texture of potato cvs. Maris Piper, Marfona, Saturna, Russett Burbank, Desiree, Estima, Sylvana and Fianna

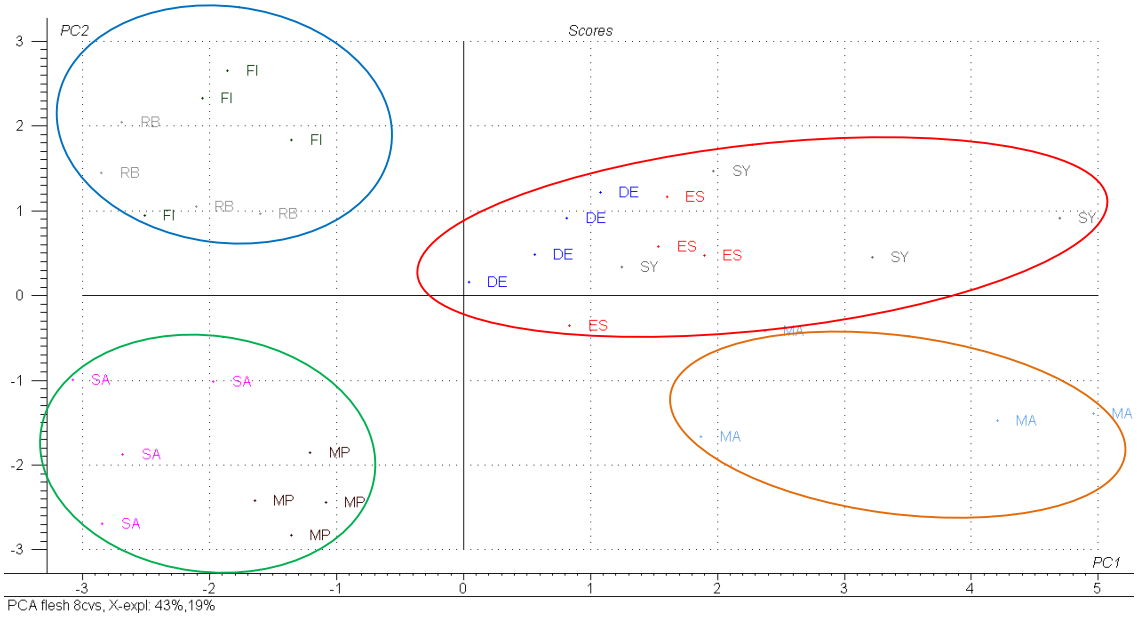

Figure 4.12 PCA score plot for PC1 (43%) versus PC2 (19%) of potato cvs. Marfona (MA), Saturna (SA), Maris Piper (MP), Russett Burbank (RB), Fianna (FI), Desiree (DE), Estima (ES) and Sylvana (SY). Grouping of cvs. on the score plot of PCA is based on the similarities in variation of sugars in flesh (DW), texture and sprouting incidence

According to the PCA (Figures 4.12 and 4.13), 62% of variance is explained by a combination of PCs 1 and 2, and the cultivars are separated into four groups. Potato cvs. Russett Burbank and Fianna form one group, Saturna and Maris Piper form a second one, Desiree, Estima and Sylvana form a third one and Marfona belongs to a fourth group. Potato cvs. Fianna, Russett Burbank, Desiree, Estima and Sylvana are separated from cvs. Saturna, Maris Piper and Marfona in PC2, while cvs. Fianna,

Russett Burbank, Saturna and Maris Piper are separated from potato cvs. Desiree, Estima, Sylvana and Marfona in PC1. According to the loadings (Figure 4.13), total sugars (DW), calculated tuber sweetness (DW), glucose and fructose content (DW) and the proportion of dry weight (g $100g^{-1}$ FW) are the most important variates in PC1. In contrast, the most important variates for PC2 are the number of total sprouts, number of sprout length < 5mm , firmness and elasticity of tubers. Thus, potato cvs. Fianna and Russett Burbank are separated from potato cvs. Desiree, Estima and Sylvana due to differences in firmness and elasticity where cvs. Fianna and Russett Burbank were firmer and more elastic, and cvs. Desiree, Estima and Sylvana had a higher number of sprouts < 5mm length. Potato cvs. Maris Piper and Saturna have a higher number of total sprouts than cvs. Fianna and Russett Burbank. Tubers cv. Marfona have higher fructose and glucose content (DW) than Saturna and Maris Piper tubers. Samples clustered by cultivar in this PCA, Differences between treatments could not be visualized with this technique and variables, perhaps due to complex interaction such that other techniques will be used (e.g. partial least square – discriminate analysis).

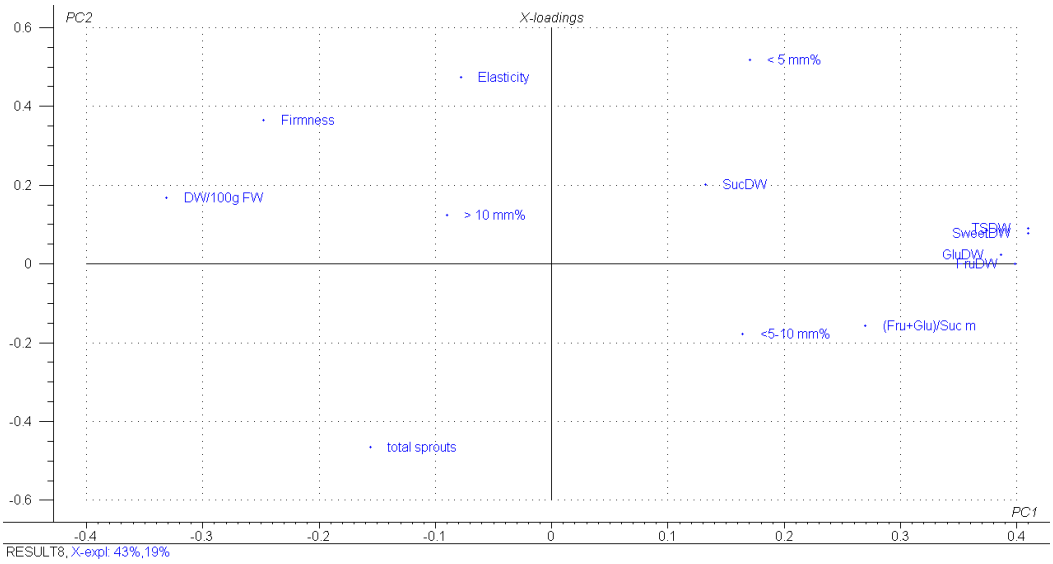

Figure 4.13 PCA plot for PC1 (43%) versus PC2 (19%) of potato cvs. Marfona (MA), Saturna (SA), Maris Piper (MP), Russett Burbank (RB), Fianna (FI), Desiree (DE), Estima (ES) and Sylvana (SY). Grouping of samples on the loading plot of PCA is based on the similarities in variation of sugars in flesh (DW), texture and sprouting incidence.

PCA of sugars in peel (DW), sprouting incidence and texture of potato cvs. Maris Piper, Marfona, Saturna, Russett Burbank, Desiree, Estima, Sylvana and Fianna

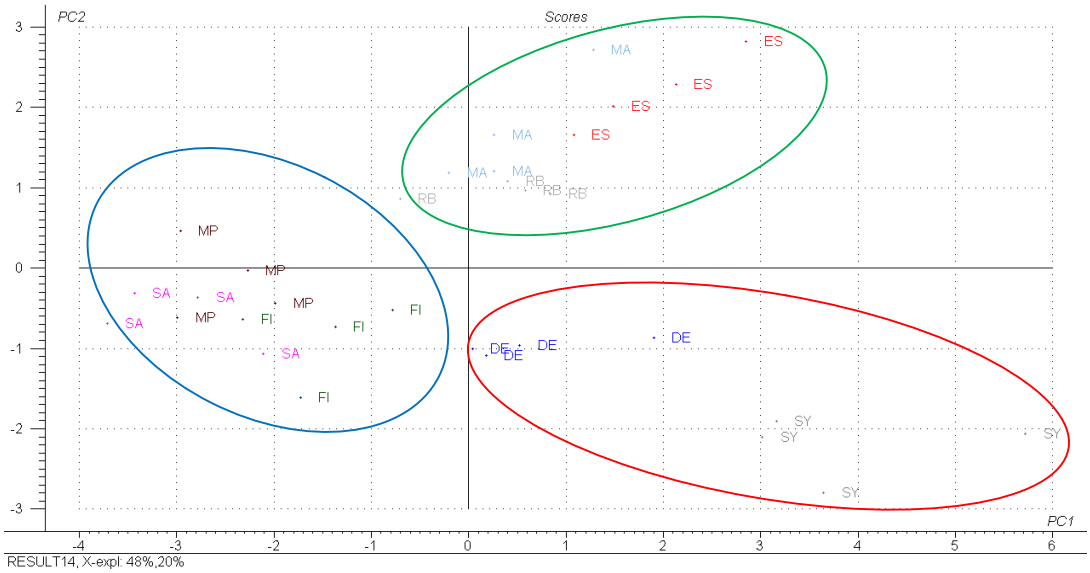

Figure 4.14 PCA plot for PC1 (48%) versus PC2 (20%) of potato cvs. Marfona (MA), Saturna (SA), Maris Piper (MP), Russett Burbank (RB), Fianna (FI), Desiree (DE), Estima (ES) and Sylvana (SY). Grouping of cvs. on the score plot of PCA is based on the similarities in variation of sugars in peel (DW), texture and sprouting incidence.

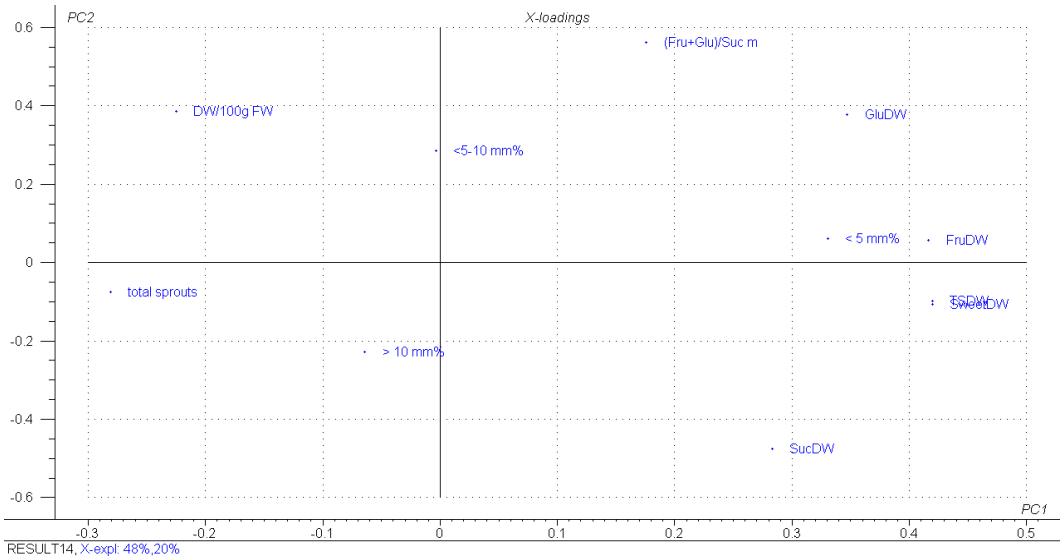

Figure 4.15 PCA plot for PC1 (48%) versus PC2 (20%) of potato cvs. Marfona (MA), Saturna (SA), Maris Piper (MP), Russett Burbank (RB), Fianna (FI), Desiree (DE), Estima (ES) and Sylvana (SY). Grouping of samples on the loading plot of PCA is based on the similarities in variation of sugars in peel (DW), texture and sprouting incidence.

According to the PCA (Figures 4.14 and 4.15), 68% of variance is explained by PCs 1 and 2, and potato varieties are separated into three groups. Potato cvs. Maris Piper, Saturna and Fianna form one group, Estima, Marfona and Russett Burbank form a second one and Desiree and Sylvana belong to the third group. Potato cvs. Russett Burbank, Estima and Marfona are separated from potato cvs. Saturna, Maris Piper, Fianna, Desiree and Sylvana in PC2. Potato cvs. Fianna, Saturna and Maris Piper are separated from potato cvs. Desiree, Sylvana, Russett Burbank, Estima and Marfona in PC1. According to the loadings in Figure 4.15, total sugars (DW), calculated tuber sweetness (DW), fructose content (DW), total sprouts and number of sprout length < 5mm are the most important variates in PC1. In contrast, the most important variates for PC2 are glucose and sucrose content (DW), the monosaccharide ratio [(Fructose+Glucose)/Sucrose] and the proportion of dry weight (gDW/100gFW). Potato cvs. Maris Piper, Saturna and Fianna are grouped together because they had a higher number of sprouts than the other cvs. and they also differ from Desiree and Sylvana tubers in that they contained a higher sucrose concentration (DW) in peel and had a higher number of sprouts < 5mm length. Potato cvs. Marfona and Estima tubers had a higher monosaccharide ratio [(Fructose+Glucose)/Sucrose], where Desiree and Sylvana tubers had a higher sucrose content (DW) in peel. Differences between cultivars where the most important and mostly visible in this PCA graph. Differences between treatments could not be visualized with the available techniques and variables maybe due to complex interaction.

4.7 Discussion

Effect of ethylene on tuber physiology and sprouting

Results show that all cultivars examined can be divided into three groups according to their response to ethylene in terms of sprout growth. In the first group, ethylene treatment of 'Estima', 'Desiree', 'Fianna', 'Russet Burbank' and 'Sylvana' resulted in better and/or complete sprout inhibition compared with air-treated tubers. The majority of the sprouts detected in the ethylene-treated tubers of 'Estima', 'Desiree' and 'Fianna' were not over 5 mm in length. Ethylene application after first indication of sprouting was as affective as continuous ethylene in 'Estima', 'Desiree', 'Fianna', 'Russet Burbank' and 'Sylvana' tubers that also had minimal ('Estima', 'Desiree' and 'Fianna') or no sprouts ('Russet Burbank' and 'Sylvana'). Indeed, exceptional sprout inhibition was achieved in 'Russet Burbank' and 'Sylvana' potato tubers, both relatively long dormant varieties, but not in 'Fianna', which is also a long dormant cultivar. In contrast, 'Estima' and 'Desiree' are characterized by a medium dormancy period. Also, according to Prange *et al.* (1998), 'Russet Burbank' potatoes that were exposed to 4 μL L^{-1} ethylene for 30 weeks at 9°C developed significantly smaller sprouts that those tubers stored in air. In the present study, complete sprout inhibition was recorded in the ethylene-treated 'Russet Burbank' tubers at 6°C for 30 weeks which is in agreement with Prange *et al.* (1998) and highlights the role of temperature and ethylene concentration on sprouting inhibition (Salunkhe and Kadam, 1998). 'Maris Piper', 'Marfona' and 'Kind Edward' form the second group, where ethylene treatment was not very effective at inhibiting sprouting. 'King Edward' is included in this group, as although there were only two treatments at the 30-week time point, there were

significantly more total sprouts in air-treated than ethylene-treated tubers. Sprouting in 'Maris Piper' and 'Marfona' was not inhibited by any of the transition treatments (transfer from air to ethylene and vice versa), however, significantly lower mean total sprouts were recorded in tubers that received ethylene after first indication of sprouting (*viz.* transfer from air to ethylene) than before (*viz.* transfer from ethylene to air).

'Mayan Gold' alone comprises the third group, where sprouting was not inhibited by the presence or absence of ethylene during storage. However, this was the only variety that sprouted differently to the other cultivars, forming clusters of sprouts. 'Mayan Gold' is a *Solanum phureja* variety, a different genotype to *Solanum tuberosum*, and was bred by Scottish Crop Research Institute (SCRI, Dundee, UK). *Phureja* is a diploid genotype, whereas *Tuberosum* is tetraploid (Dobson *et al.*, 2010*). Phureja*-type tuber*s* are less dormant than *tuberosum*-type and often show signs of sprouting at harvest or soon after (Huaman and Spooner, 2002). 'Mayan Gold' and 'King Edward' were the only two cultivars classified as very short dormant in this study. Given these results, it is noteworthy that dormancy period may be a crucial factor affecting the efficacy of ethylene treatments.

Effect of ethylene treatments on non-structural carbohydrates

The potato cultivars could also be divided into groups according to the variation in sucrose, glucose and fructose levels in flesh and peel between treatments during storage. 'Maris Piper', 'Marfona' and 'Sylvana' constitute the first group, where high variation was shown between treatments during storage. In the second group, 'Mayan Gold', 'Estima' and 'Desiree' tubers showed a similar pattern in sugars in all treatments during storage and finally in the third group are 'Russet Burbank' and 'Fianna'

potatoes, both long dormant varieties, that showed first sprouting indication at the same time and showed a similar pattern in non-structural carbohydrates in all treatments during storage. 'King Edward' cannot be included in any of the above groups due to the limited treatments and out-turns during this experiment.

Using ethylene (10 μL L^{-1}) as sprout suppressing agent and storage of tubers at 6°C resulted in greater sugar concentration in both flesh and peel in a treatment and cultivar-dependent manner. Previously, Day *et al.* (1978) and Prange *et al.* (1998) observed an increase in sugar concentration in ethylene-treated 'Russet Burbank' tubers. High levels of both fructose and glucose in tubers can lead to an undesirable tissue darkening during frying (Stadler *et al.*, 2002) and indeed ethylene-treated tubers have been generally associated with a darker fry colour (Prange *et al.*, 1998; Prange *et al.*, 2005; Daniels-Lake *et al.*, 2005; Daniels-Lake *et al.*, 2007). The changes in sugar content observed in this study varied according to cultivar. The cultivars were grown at different sites and the length of the growing season varied according to the cultivar. Kyriacou *et el.* (2009) demonstrated that tuber sugar accumulation is affected by crop management and there is a subsequent impact on potato processing quality. Variation in tuber sugar composition at harvest reflects the effect of growing season. Sucrose levels are considered to be a possible factor indicating biotic and abiotic stresses on the crop and tuber chemical maturity (Sowokinos, 1978). Differences between cultivars may be explained by differences in the cropping season, as the cultivars studied herein belong to different groups (*viz.* maincrop, early, medium early and second early maincrop). Besides, the genetic diversity among potato cultivars is well documented (Mondal *et al.*, 2007) and may be responsible for different responses to treatments since all studied varieties were of different parentage (British Potato Variety Database, 2009).

Additionally, differences in gene expression in *Solanum tuberosum* and *Solanum phureja* varieties accounted for variations in starch biosynthesis and cell wall stability, which may be linked to defining tuber texture (Davies *et al.*, 2008). It is also possible to speculate that variations in the response of potato tubers to ethylene treatments may be related to morphological differences in the skin of the tubers. Higher peel thickness may act as a barrier to ethylene gas to reach the metabolically active meristem tissue where sprouts are initiated and hence limiting its possible role in inducing sugar changes and sprout suppression. Similar hypotheses were proposed by Chope *et al.* (2007) when assessing the response to the ethylene inhibitor 1-MCP and Downes *et al.* (2010) after postharvest application with ethylene and 1-MCP on onions. Sugar concentration in peel tissue showed similar trends to those observed for flesh tissue in that each variety responded differently to each treatment. For instance, ethylene-treated 'Sylvana' tubers had significantly greater sucrose, glucose and fructose concentrations in peel tissue after six weeks of storage at 6°C than air-treated ones. However, significantly lower values were recorded for both glucose and fructose concentration in peel of ethylene-treated 'Maris Piper' and 'Mayan Gold' at the end of the experiment. To date and to the best of our knowledge, this is the first published information detailing changes in sugars in potato peel tissue during storage and may be of important nutritional information. Spatial differences in sugar content have already been reported for other horticultural crops (Abayomi and Terry, 2009; Landahl *et al.*, 2009), and in the particular case of potatoes may be connected to the formation of the skin through starch deposition after conversion from translocated sugars (Pringle *et al.*, 2009). In addition, it may be feasible to speculate that spatial differences in sugar content in potato tubers may lead to better understanding of sugar metabolism during storage.

Storage temperature plays an important role in dormancy break and subsequent sprout suppression of potato tubers (Salunkhe and Kadam, 1998). For instance, lower temperatures may be used as an alternative to chemicals for sprout suppression (de Wilde *et al.*, 2005) having also an effect on sugar conversion and hence tuber sweetness, which is negative for processed potatoes (Prange *et al.*, 1998). Sugars including glucose, fructose and sucrose together with starch account for almost the totality of dry matter in potato tubers (Miller *et al.*, 1975). Overall, and although to a different extent depending on the cultivar and treatment applied, sugar concentration increased during storage at 6°C as previously shown (Brown *et al.*, 1990; de Wilde *et al.*, 2005). The variability in the response of tubers from different cultivars to the conditions imposed in this study reveals the complex nature of both ethylene-induced sprout suppression and reduced sweetness (caused by high monosaccharide content) as well as suggesting that both these processes may be regulated via different pathways (Downes *et al.*, 2010). The inability of ethylene to limit sprout development in certain cultivars may be associated with skin thickness, as higher thickness may be a barrier for the gases to reach ethylene binding sites. Similarly, differences in gas permeability as a result of differences in peel thickness may be linked with the observed differential effect of ethylene on sugars of both peel and flesh.

Effect of ethylene treatments on mechanical characteristics

Summarizing the results for texture by taking into account both firmness and apparent elasticity, three groups can be distinguished. The first group showed no significant difference either in mean firmness or mean apparent elasticity between ethylene-treated tubers and those transferred from air to ethylene (‘Maris Piper’,

'Mayan Gold', 'Estima' and 'Desiree'). So, there was no effect on their texture, whether they were stored under continuous ethylene or whether they received ethylene after first sprouting indication. In the second group, 'Russet Burbank' and 'Fianna' tubers had significantly different firmness and apparent elasticity values (higher or lower) between ethylene-treated and those transferred from air to ethylene tubers. 'Marfona' and 'Sylvana' form the third group, where texture varied greatly between treatments so that no patterns could be discerned.

Texture of raw potato tubers is important, because it has a direct impact on the final texture of the product after processing (i.e. cooking). Texture may be influenced by composition and properties of the cell wall and middle lamella (van Marle *et al.*, 1997; 2002) and several works have measured firmness of potato tissues after processing (van Dijk *et al.*, 2002; Olsson *et al.*, 2004), but data on fresh tubers is a scarce. During storage, texture of the investigated tubers changed under different ethylene treatments and was cultivar-dependant. Although, most of the information regarding texture measurements is available on cooked potatoes, it is important that storage practices do not deteriorate texture before processing, as firm potatoes are generally demanded in the fresh market.

4.8 Conclusions

Storage time and ethylene treatments had a cultivar-specific effect on all the measured parameters (*viz*. sprouting, sugars, texture). Continuous ethylene application is currently an approved practice in the UK potato industry for extending potato storage life yet the effect of ethylene on the wide range of cultivars available is not fully understood. For certain cultivars, application of ethylene either before or after the trigger point of first indication of sprouting could be adopted as a more environmentally

and economically friendly alternative for inhibiting sprouting partially or totally in different potato cultivars. Ethylene applied after first indication of sprouting was as effective at sprout inhibition as when applied continuously; therefore the cost of ethylene application in store rooms could be minimized. However, it is evident that this could be a good practice only for specific potato varieties (*viz.* 'Estima', 'Desiree', 'Fianna', 'Russet Burbank' and 'Sylvana').

CHAPTER FIVE

EFFECT OF 1-MCP AND ETHYLENE TREATMENTS ON THE POSTHARVEST QUALITY OF FOUR UK-GROWN POTATO CULTIVARS

5.1 Introduction

In the previous Chapter Four, the effect of transition between ethylene and air storage on the postharvest quality of ten UK-grown potato cultivars was examined. Storing potatoes under ethylene resulted in an increase of sugars during storage; however, the results highlighted the fact that ethylene application at the time of first indication of sprouting was as effective as when applied continuously for specific potato cultivars. Thus, the cost of ethylene application in store rooms could be minimised. In this study, the effect of a 24h 1-MCP treatment either before storage of tubers in ethylene or at the time of first indication of sprouting was examined. According to the literature, 1-MCP is believed to successfully block the action of ethylene when applied before that. So, this study was based on the hypothesis that 1-MCP would successfully block ethylene action in terms of sugar accumulation, as well as sprouting incidence. Four potato cultivars were used in this study (*viz.* 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank'), while 1-MCP was applied either before storage of tubers in ethylene and air (Experiments 4 & 5) or at the time of first indication of sprouting (Experiments 6 & 7). Detailed explanation of the division of experiments is described in Section 3.2.2)

5.2 Materials and methods

Sample preparation for Chapter 5 was described in Section 3.7. The measurement and analysis of CO_2 and ethylene production, texture, sprouting and sugar analysis were described in Chapter 3: Materials and Methods.

5.3 Experiments 4 & 5: Effect of a 24h 1-MCP treatment before storage of tubers in ethylene and air on 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank' potatoes

5.3.1 Respiration rate (CO_2) and ethylene production

Immediately after harvest (day 0), the highest respiration rate was recorded in 'Estima' tubers (0.33 mmol $Kg^{-1}h^{-1}$) compared to the other varieties *viz.* 'Marfona' (0.11 mmol Kg^{-1} h^{-1}), 'Saturna' (0.16 mmol $Kg^{-1}h^{-1}$) and 'Russet Burbank' (0.07 mmol $Kg^{-1}h^{-1}$) (Figures 5.2, 5.1, 5.3 and 5.4 respectively). Significantly high respiration rates were recorded in all treatments for 'Marfona' and 'Saturna' (up to 0.7 mmol $Kg^{-1}h^{-1}$) at six weeks after first indication of sprouting in the +1-MCP-treated tubers, but not in the -1-MCP-treated ones (Figures 5.1 and 5.3). Also, significantly high respiration rates were recorded in both +1-MCP and -1-MCP-treated 'Marfona' and 'Saturna' tubers in all treatments between 26 and 30 weeks (Figures 5.1 and 5.3). Similar results were shown for 'Estima' except for the ethylene-treated tubers (Figure 5.1), whereas there were no significant differences between these two time points for 'Russet Burbank' tubers for both +1-MCP and -1-MCP-treated tubers (Figure 5.4)). Significantly higher values were recorded in both the +1-MCP and -1-MCP ethylene-treated 'Estima' (9.34

and 12.7 mmol $Kg^{-1}h^{-1}$ respectively; Figure 5.2) and 'Russet Burbank' (13.23 and 25.65 mmol $Kg^{-1}h^{-1}$ respectively; Figure 5.4) and tubers than the air-treated ones (0.00 mmol $Kg^{-1}h^{-1}$ for both cvs. and treatments) at two weeks after storage in ethylene and air stores. Same pattern was shown in the ethylene-treated tubers of 'Marfona' and 'Saturna' that were treated with +1-MCP before storage in ethylene and air stores, but not for the -1-MCP-treated ones (Figures 5.2 and 5.4 respectively).

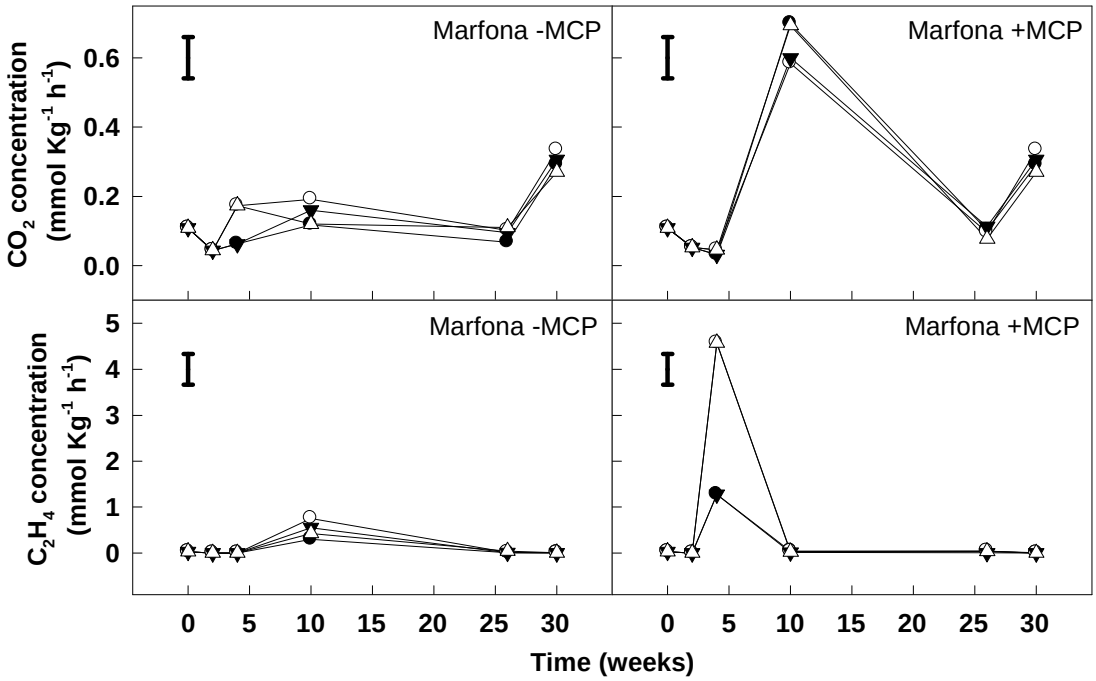

Figure 5.1 CO_2 and C_2H_4 concentrations of 'Marfona' potatoes measured after harvest (day 0), after the 24h +/- 1-MCP (1 μL L^{-1}) treatment, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) continuous ethylene; (●) continuous air; (△) transfer from ethylene to air; (▼) transfer from air to ethylene. Individual treatment data are means; n=9. LSD bars are shown (Appendix B, Tables B.2; B.6)

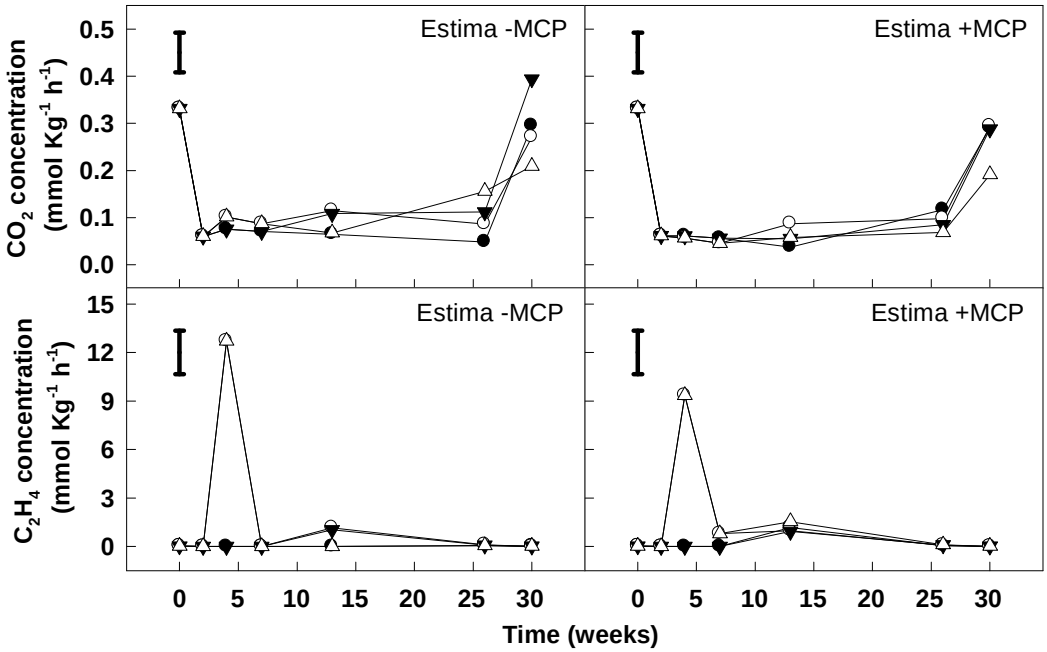

Figure 5.2 CO_2 and C_2H_4 concentrations of 'Estima' potatoes measured after harvest (day 0), after the 24h +/- 1-MCP (1 μL L^{-1}) treatment, at 2 weeks storage in ethylene and air, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) continuous ethylene; (●) continuous air, (△) transfer from ethylene to air; (▼) transfer from air to ethylene. Individual treatment data are means; n=9. LSD bars are shown (Appendix B, Tables B.3; B.7)

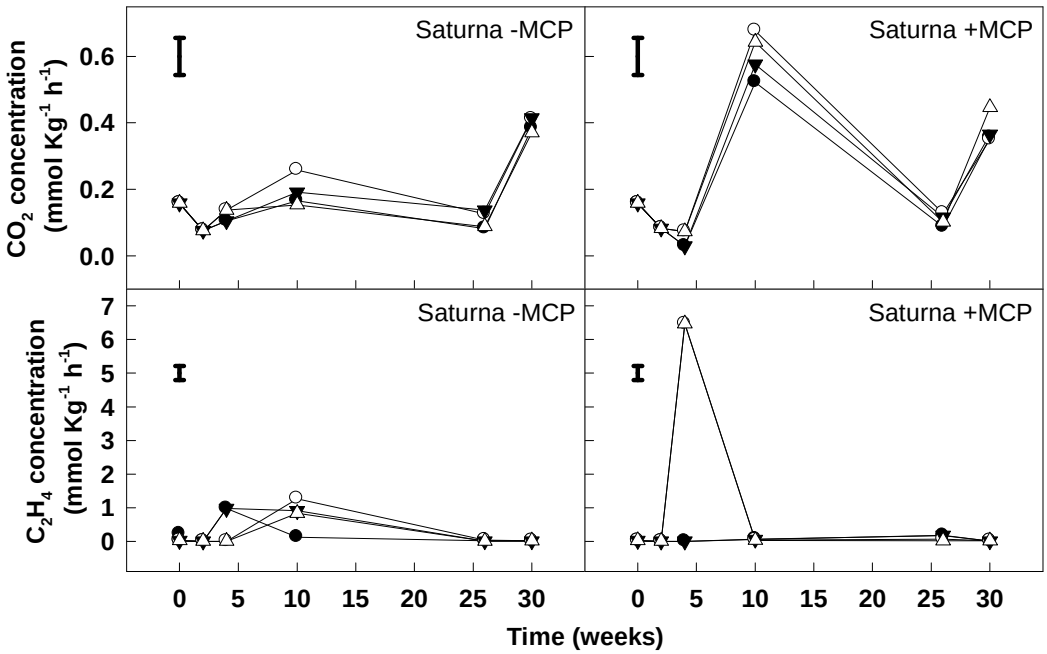

Figure 5.3 CO_2 and C_2H_4 concentrations of 'Saturna' potatoes measured after harvest (day 0), after the 24h +/- 1-MCP (1 μL L^{-1}) treatment, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) continuous ethylene; (●) continuous air; (△) transfer from ethylene to air; (▼) transfer from air to ethylene. Individual treatment data are means; n=9. LSD bars are shown (Appendix B, Tables B.4; B.8)

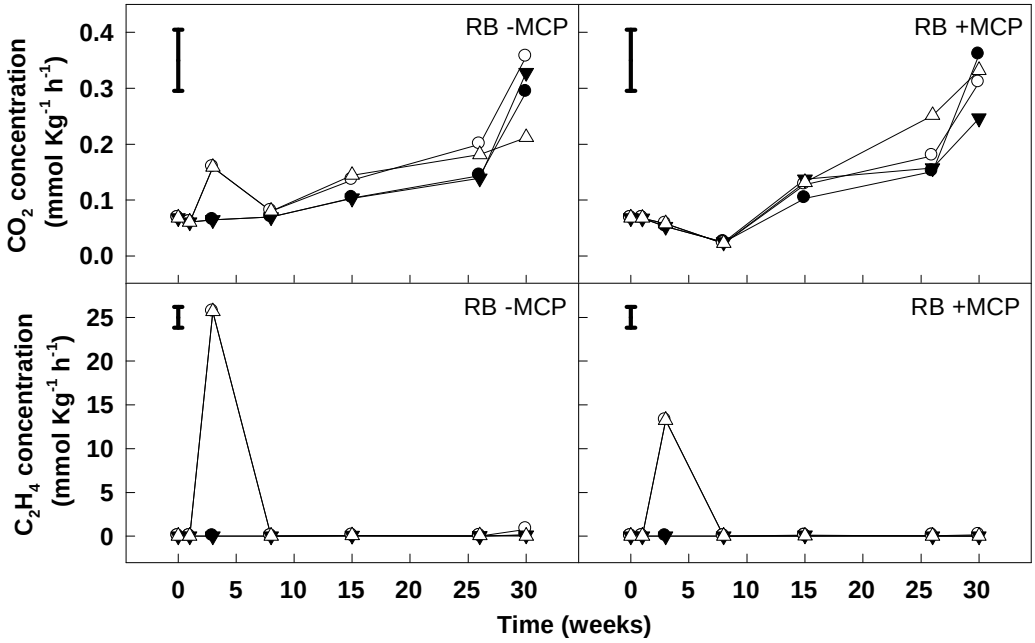

Figure 5.4 CO_2 and C_2H_4 concentrations of 'Russet Burbank' potatoes measured after harvest (day 0), after the 24h +/- 1-MCP (1 μL L^{-1}) treatment, at 2 weeks storage in ethylene and air, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) continuous ethylene; (●) continuous air, (△) transfer from ethylene to air; (▼) transfer from air to ethylene. Individual treatment data are means; n=9. LSD bars are shown (Appendix B, Tables B.5; B.9)

5.3.2 Non-structural carbohydrate concentration in flesh

No significant differences were detected between treatments during storage in the +1-MCP-treated tubers in any of the cultivars (Figures 5.5-5.8), in contrast to the -1-MCP-treated tubers were mainly differences were shown for 'Russet Burbank' (Figure 5.8). More specifically, -1-MCP-treated 'Russet Burbank' that were stored in ethylene continuously had higher fructose and glucose content at two weeks storage, at the time of first indication of sprouting and six weeks after that time point compared to those tubers stored in air (Figure 5.8). Similarly, the -1-MCP-treated 'Russet Burbank' and 'Saturna' that were stored in ethylene continuously had higher sucrose content than the air-treated ones at two weeks storage and at the time of first indication of sprouting, respectively (Figures 5.8 and 5.7 respectively).

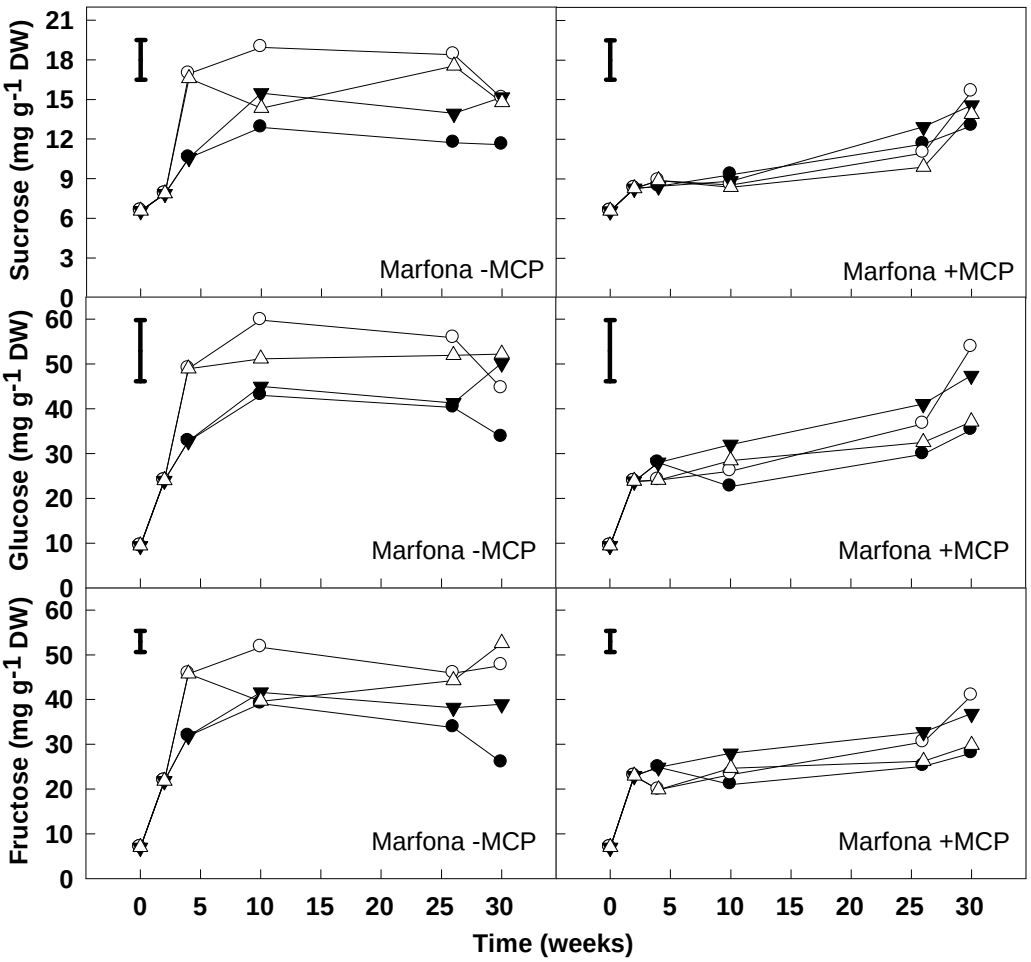

Figure 5.5 Fructose, glucose and sucrose concentrations of 'Marfona' potatoes measured after harvest (day 0), after the 24h +/- 1-MCP (1 μL L^{-1}) treatment, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) continuous ethylene; (●) continuous air; (△) transfer from ethylene to air; (▼) transfer from air to ethylene. Individual treatment data are means; n=9. LSD bars are shown (Appendix B, Tables B.10; B.11; B.12)

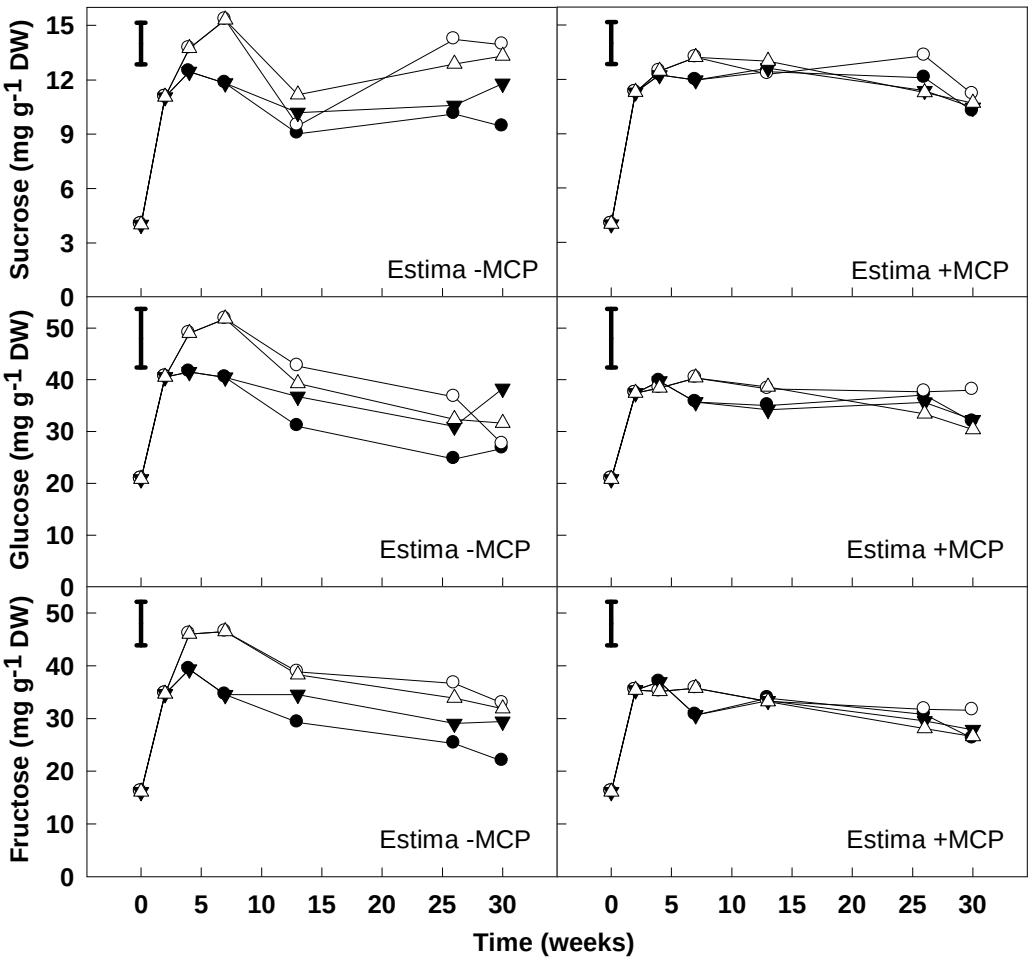

Figure 5.6 Fructose, glucose and sucrose concentrations of 'Estima' potatoes measured after harvest (day 0), after the 24h +/- 1-MCP (1 μL L^{-1}) treatment, at 2 weeks storage in ethylene and air, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) continuous ethylene; (●) continuous air; (△) transfer from ethylene to air; (▼) transfer from air to ethylene. Individual treatment data are means; n=9 (Appendix B, Tables B.13, B.14, B.15)

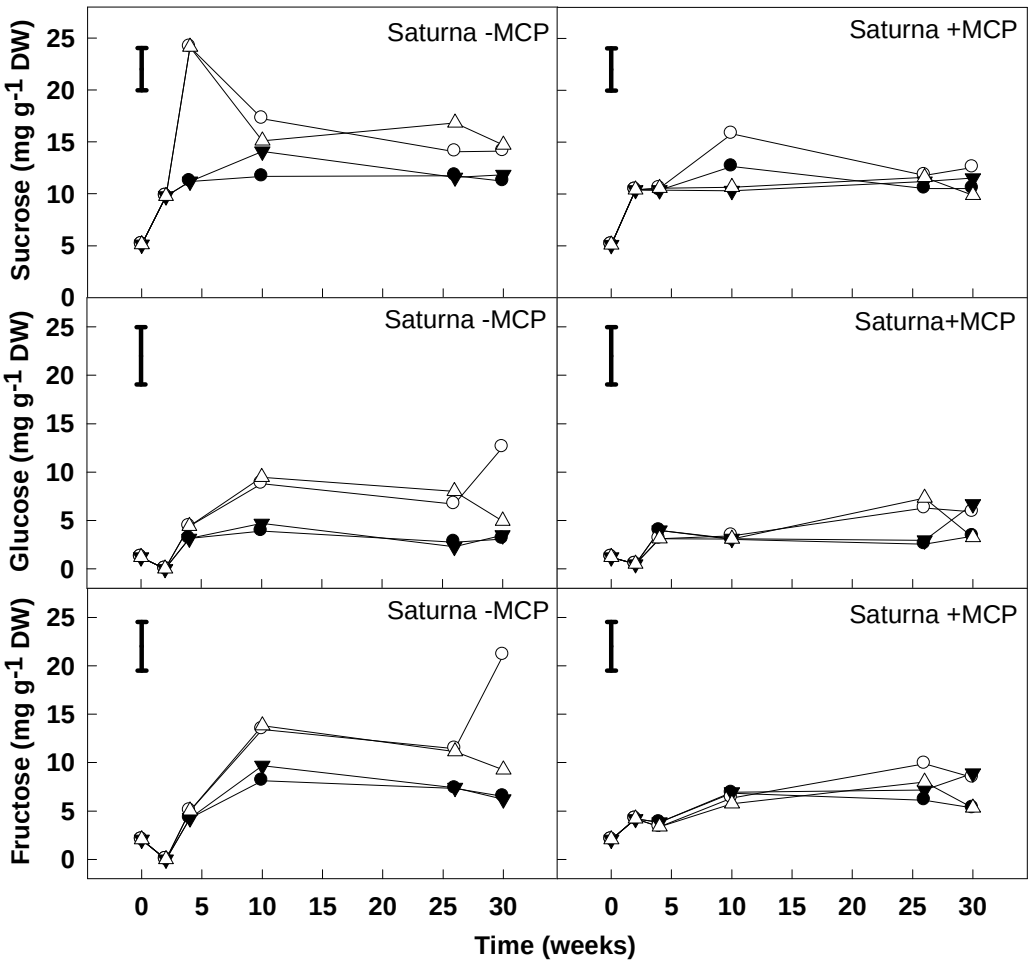

Figure 5.7 Fructose, glucose and sucrose concentrations of 'Saturna' potatoes measured after harvest (day 0), after the 24h +/- 1-MCP (1 μL L^{-1}) treatment, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) continuous ethylene; (●) continuous air; (△) transfer from ethylene to air; (▼) transfer from air to ethylene. Individual treatment data are means; n=9. LSD bars are shown (Appendix B, Tables B.16; B.17; B.18)

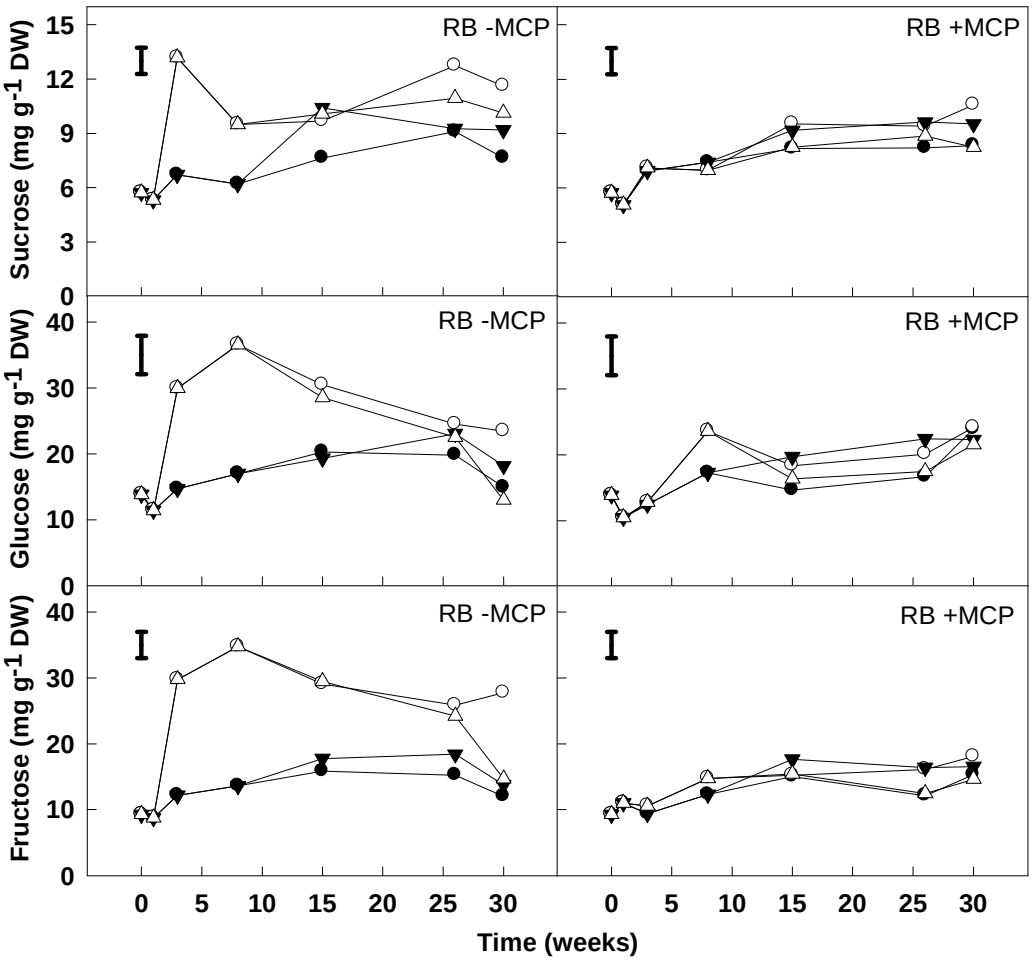

Figure 5.8 Fructose, glucose and sucrose concentrations of 'Russet Burbank' potatoes measured after harvest (day 0), after the 24h +/- 1-MCP (1 μL L^{-1}) treatment, at 2 weeks storage in ethylene and air, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) continuous ethylene; (●) continuous air; (△) transfer from ethylene to air; (▼) transfer from air to ethylene. Individual treatment data are means; n=9 (Appendix B, Tables B.19; B.20; B.21)

5.3.3 Firmness and apparent elasticity

Although there was a variation between treatments regarding firmness and elasticity, there were no significant differences between treatments during storage for 'Saturna' and 'Russet Burbank' potatoes for both non-1-MCP and 1-MCP-treated tubers (Figures 5.11 and 5.12). Some exceptions were detected in firmness and apparent elasticity of both non-1-MCP and 1-MCP-treated 'Estima' tubers though (Figure 5.10).

For ‘Marfona’ potatoes, there were no significant differences between treatments for firmness and apparent elasticity, either in the 1-MCP-treated or in the non-MCP-treated tubers during storage. However, non-MCP-treated ‘Marfona’ tubers that were continuously stored in ethylene were more elastic than non-MCP-air-treated ones at the end of storage (Figure 5.9).

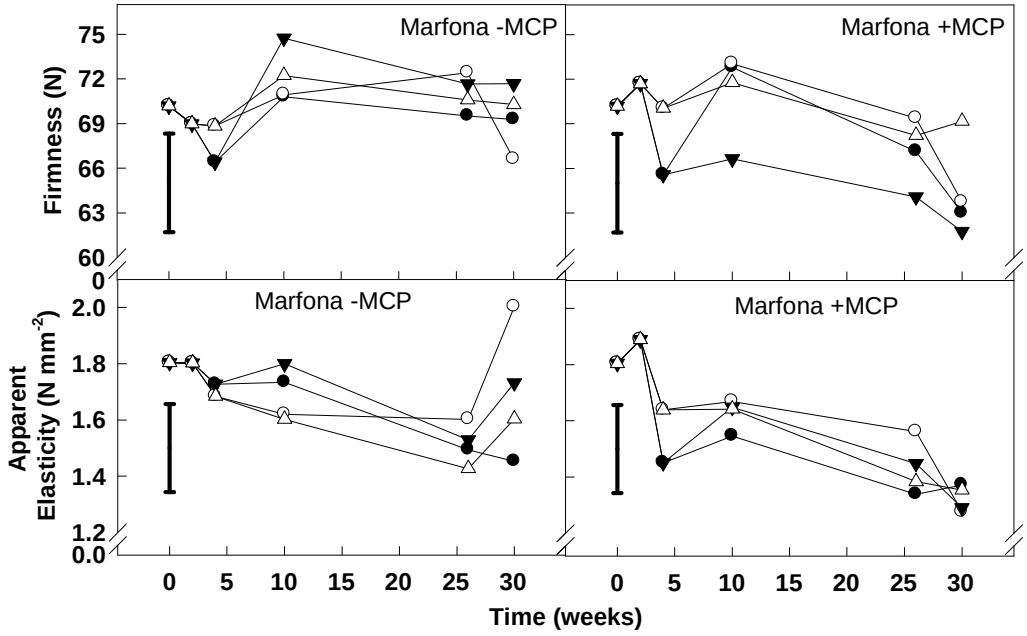

Figure 5.9 Firmness (N) and apparent elasticity (N mm^{-2}) of ‘Marfona’ potatoes measured after harvest (day 0), after the 24h +/- 1-MCP (1 μL L^{-1}) treatment, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) continuous ethylene; (●) continuous air; (△) transfer from ethylene to air; (▼) transfer from air to ethylene. Individual treatment data are means; n=9 (Appendix B, Tables B.22; B.23).

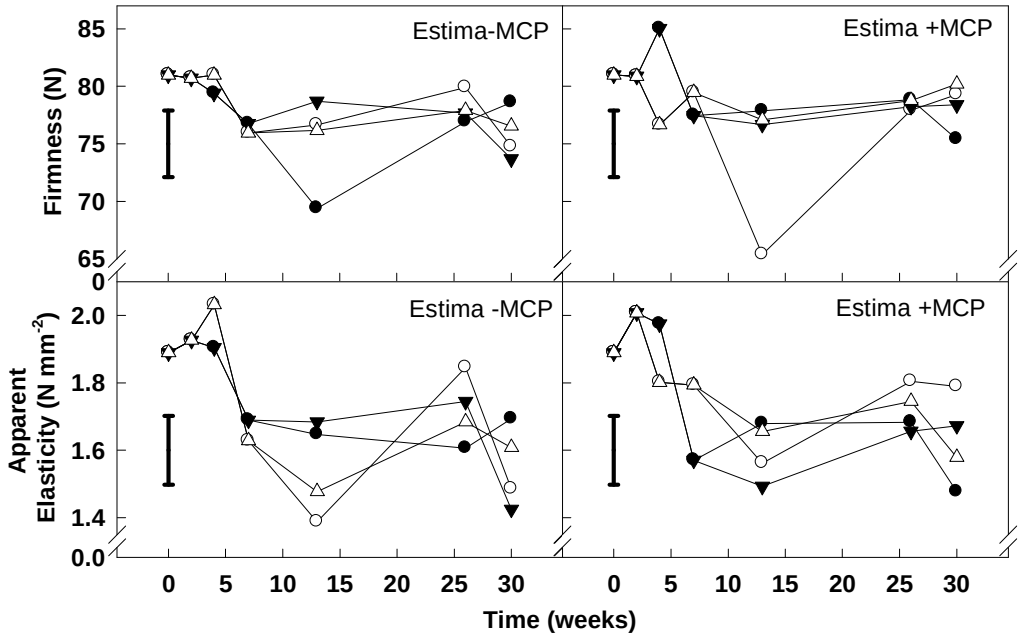

Figure 5.10 Firmness (N) and apparent elasticity (N mm^{-2}) of 'Estima' potatoes measured after harvest (day 0), after the 24h +/- 1-MCP (1 μL L^{-1}) treatment, at 2 weeks storage in ethylene and air, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) continuous ethylene; (●) continuous air; (△) transfer from ethylene to air; (▼) transfer from air to ethylene. Individual treatment data are means; n=9 Appendix B, tables B.24; B.25)

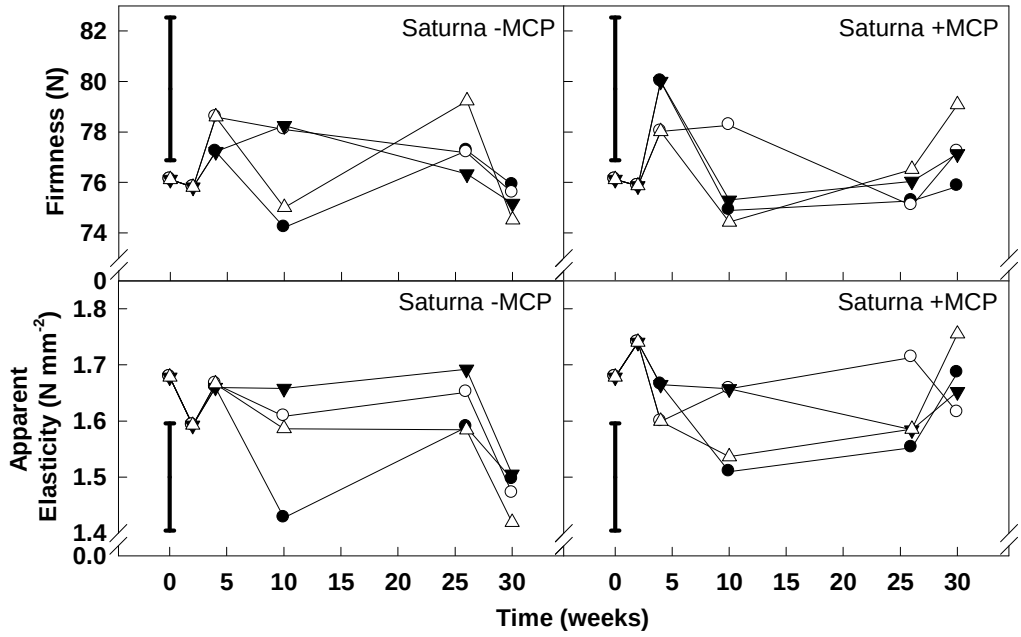

Figure 5.11 Firmness (N) and apparent elasticity (N mm^{-2}) of 'Saturna' potatoes measured after harvest (day 0), after the 24h +/- 1-MCP (1 μL L^{-1}) treatment, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) continuous ethylene; (●) continuous air; (△) transfer from ethylene to air; (▼) transfer from air to ethylene. Individual treatment data are means; n=9 (Appendix B, Tables B.26; B.27)

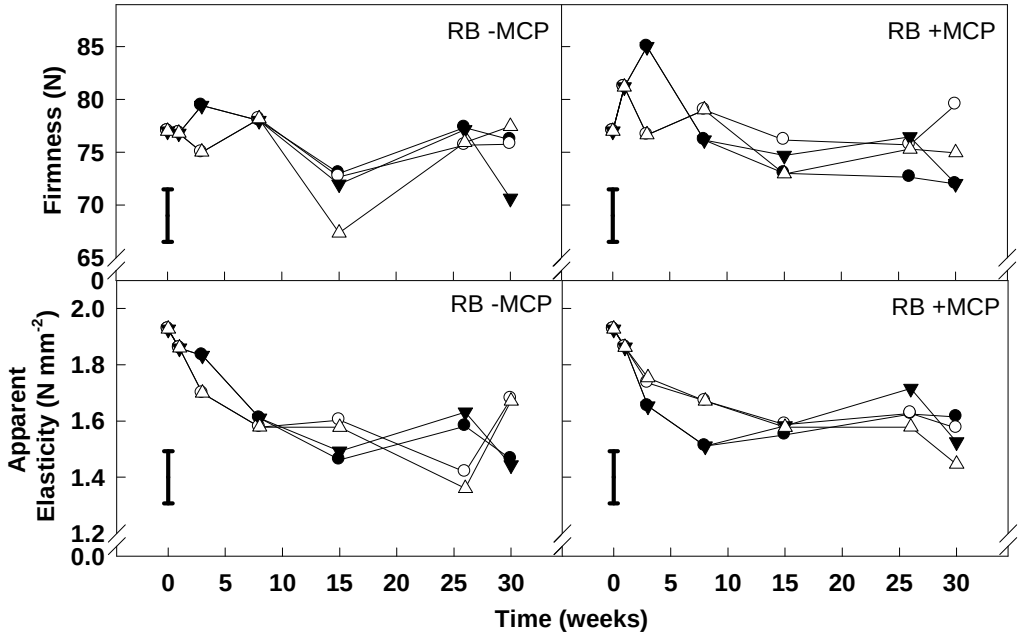

Figure 5.12 Firmness (N) and apparent elasticity (N mm^{-2}) of 'Russet Burbank' potatoes measured after harvest (day 0), after the 24h +/- 1-MCP (1 μL L^{-1}) treatment, at 2 weeks storage in ethylene and air, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) continuous ethylene; (●) continuous air; (△) transfer from ethylene to air; (▼) transfer from air to ethylene. Individual treatment data are means; n=9 (Appendix B, Tables B.28; B.29)

5.3.4 Sprouting at 30 weeks storage

There were no significant differences between treatments for 'Estima' potatoes treated with or without 1-MCP before storage of tubers in ethylene and air stores (Table 5.1). 1-MCP-treated tubers of 'Marfona' potatoes that were transferred from ethylene to air and from air to ethylene had significantly lower number of total sprouts that the non-1-MCP-tretaed ones at the same treatments. Significantly lower number of total sprouts were also detected under continuous ethylene and when transferred from air to ethylene tubers of 'Saturna' potatoes than the air-treated and those transferred from ethylene to air tubers that had been treated with 1-MCP before storage of tubers in ethylene and air

stores. ‘Russet Burbank’ 1-MCP-treated potatoes that were transferred from air to ethylene had higher number of total sprouts than the non-1-MCP-treated ones.

Table 5.1 Total sprouts of ‘Marfona’, ‘Estima’, ‘Saturna’ and ‘Russett Burbank’ potatoes recorded after 30 weeks storage at 6°C after tubers were treated with +/- 1-MCP (1 μL L^{-1}) before storage at +/- ethylene (10 μL L^{-1}) and at four ethylene treatments (continuous ethylene, continuous air, transfer from ethylene to air and from air to ethylene). Individual treatment data are means; n=9. LSD $_{(P\ 0.05)}$ = 15.84 (Appendix B, Table B.30).

Treatments		Cultivars			
		Marfona	Estima	Saturna	Russett Burbank
+MCP	Continuous ethylene	36.33	7.33	33.67	35.67
	Continuous air	32.00	9.00	50.67	64.00
	Ethylene to air	36.67	10.33	49.33	63.33
	Air to ethylene	34.33	10.00	32.67	52.33
-MCP	Continuous ethylene	36.67	14.33	35.00	46.33
	Continuous air	38.33	9.33	46.00	70.00
	Ethylene to air	64.67	14.00	46.00	59.33
	Air to ethylene	50.33	9.33	42.00	35.67

5.3.5 Sprouting during shelf life

No sprouts were detected in any treatment of ‘Estima’ non-1-MCP and 1-MCP-treated potatoes on day 0 (Table 5.2), while less sprouts were shown in ‘Marfona’ potatoes at the same day compared to ‘Saturna’ potatoes. Significantly higher number of total sprouts was detected in the non-1-MCP-treated tubers of ‘Russet Burbank’ potatoes that were transferred from ethylene to air than the 1-MCP-treated tubers at the same treatment (Figure 5.13).

Table 5.2 Total sprouts of 'Marfona', 'Estima', and 'Saturna' potatoes recorded during storage at 20°C for 18 days after tubers were treated with +/- 1-MCP (1 μL L^{-1}) before storage at +/- ethylene (10 μL L^{-1}) and at four ethylene treatments (continuous ethylene, continuous air, transfer from ethylene to air and from air to ethylene). Individual treatment data are means; n=15. LSD $_{(P\ 0.05)}$ = 8.11 (Appendix B, Table B.31).

Cvs.		Treatments	Days						
			0	3	6	9	12	15	18
Marfona	+1-MCP	Continuous ethylene	6.33	21.00	34.00	23.67	31.67	27.33	29.67
		Continuous air	14.00	19.00	32.33	21.67	27.33	27.33	27.67
		Ethylene to air	16.67	28.67	42.00	24.00	35.33	30.00	32.33
		Air to ethylene	11.00	27.33	40.67	21.67	32.00	28.00	32.33
Estima		Continuous ethylene	0.00	17.67	21.00	19.33	23.67	20.67	18.67
		Continuous air	0.00	17.67	19.67	16.33	18.00	24.67	25.33
		Ethylene to air	0.00	4.33	5.67	8.33	14.33	19.00	17.33
		Air to ethylene	0.00	11.33	14.33	11.00	15.67	21.33	20.33
Saturna		Continuous ethylene	27.00	34.00	42.00	16.00	30.67	30.00	29.67
		Continuous air	25.00	28.00	31.33	14.00	27.00	26.67	27.67
		Ethylene to air	25.67	31.67	36.67	18.00	24.67	27.33	30.33
		Air to ethylene	26.00	30.33	34.67	14.67	27.33	28.00	28.33
Marfona	-1-MCP	Continuous ethylene	3.33	20.00	21.67	28.33	24.33	23.00	26.33
		Continuous air	3.60	18.60	29.60	17.60	26.60	23.60	25.60
		Ethylene to air	5.10	15.67	35.60	26.10	30.60	29.60	33.10
		Air to ethylene	3.00	13.33	22.00	17.00	21.33	20.33	19.33
Estima		Continuous ethylene	0.00	15.33	19.67	20.67	28.33	22.33	21.67
		Continuous air	0.00	22.00	24.00	23.33	33.00	27.33	27.00
		Ethylene to air	0.00	14.00	17.33	19.67	24.00	21.33	21.00
		Air to ethylene	0.00	18.33	25.00	25.33	33.67	24.67	25.33
Saturna		Continuous ethylene	18.33	26.33	40.00	20.67	32.33	35.00	37.00
		Continuous air	33.00	36.67	41.00	15.00	38.67	34.00	36.00
		Ethylene to air	33.00	35.00	38.00	32.33	31.33	27.67	33.00
		Air to ethylene	23.33	28.33	41.00	21.00	39.33	37.33	38.00

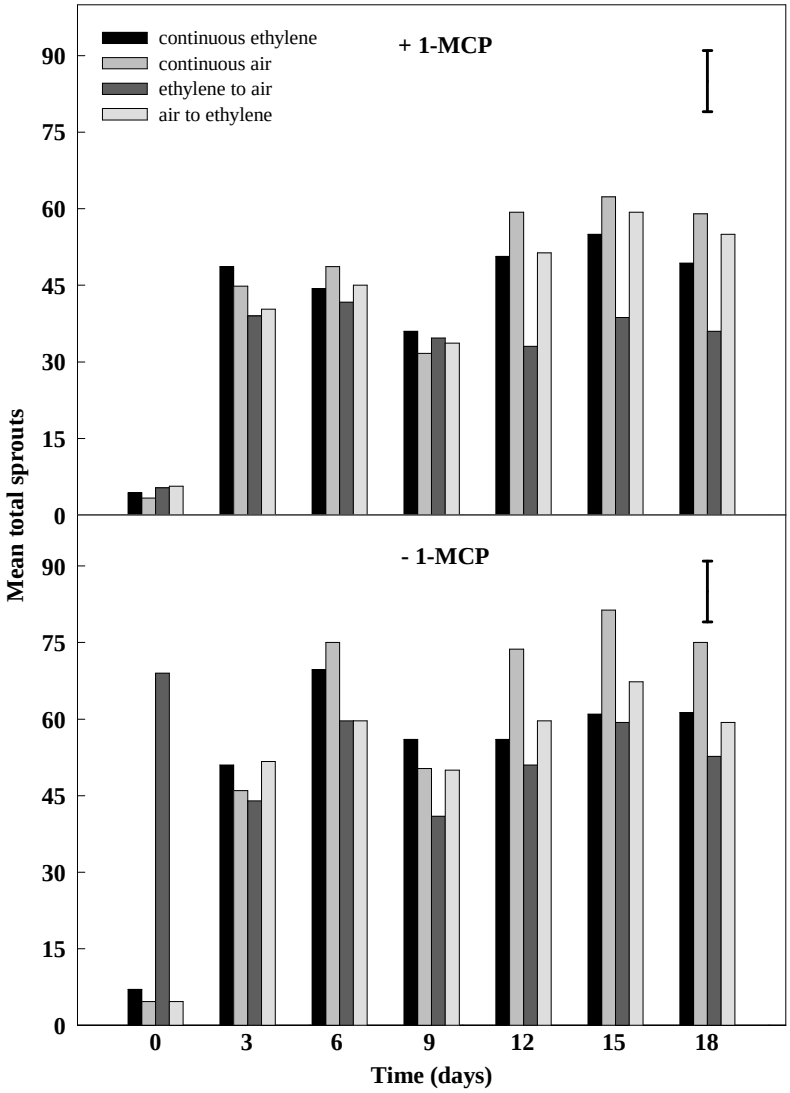

Figure 5.13 Total sprouts of 'Russett Burbank' potatoes recorded during storage at 20°C for 18 days after tubers were treated with +/- 1-MCP (1 μL L^{-1}) after first indication of sprouting after storage at +/- ethylene (10 μL L^{-1}) and at four ethylene treatments (continuous ethylene, continuous air, transfer from ethylene to air and from air to ethylene). Individual treatment data are means; n=15. LSD $_{(P\ 0.05)}$ = 11.95 (Appendix B, Table B.32)

5.4 Experiments 6 & 7: Effect of a 24h 1-MCP application at the time of first indication of sprouting on potato cvs. Marfona, Estima, Saturna and Russet Burbank

5.4.1 Respiration rate (CO_2) and ethylene production

There were no significant differences between treatments on the CO_2 concentration of 'Marfona' potatoes during storage in ethylene and in air stores; however CO_2 concentrations were higher at the end of storage in all treatments (Figure 5.14). Higher values (0.4-0.8 mmol Kg^{-1} h^{-1}) were shown at 6 weeks after first indication of sprouting in all treatments in both ethylene and air stores for 'Marfona' potatoes for ethylene concentration (Figure 5.14). A similar pattern was shown for 'Estima' (Figure 5.14), 'Saturna' (Figure 5.15) and 'Russet Burbank' (Figure 5.15) potatoes as found in 'Marfona' for CO_2 concentration. For ethylene concentration, 'Estima' (Figure 5.15) and 'Russet Burbank' (Figure 5.17) potatoes followed the same pattern during storage, while 'Marfona' (Figure 5.14) had the same pattern as 'Saturna' (Figure 5.16), but only for those tubers stored in ethylene.

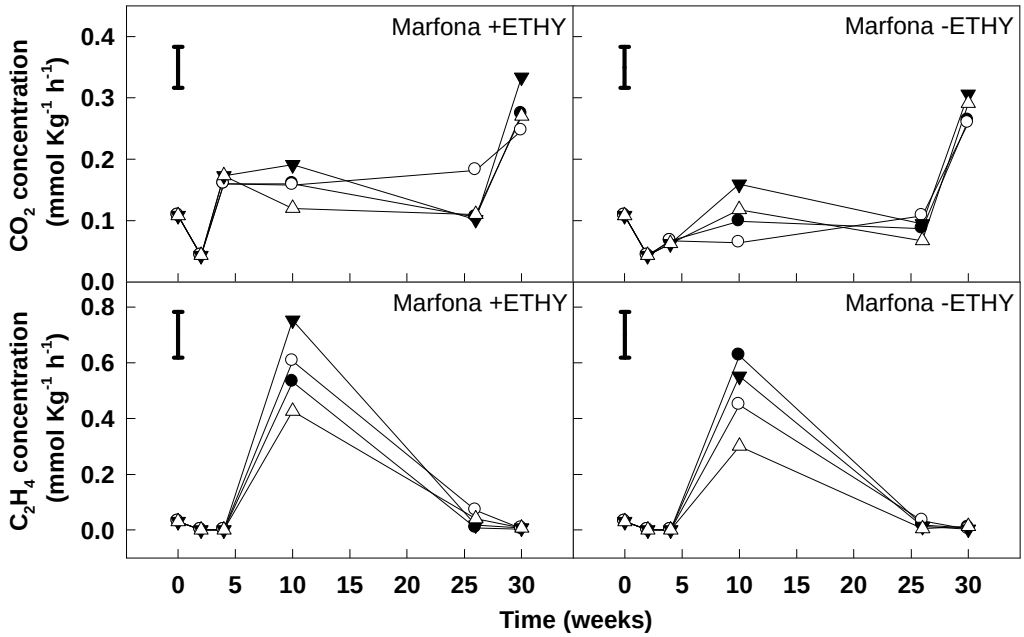

Figure 5.14 CO_2 and C_2H_4 concentrations of 'Marfona' potatoes measured after harvest (day 0), after curing for 2 weeks, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) +MCP-ETHY; (●) +MCP+ETHY; (△) -MCP-ETHY; (▼) -MCP+ETHY. Individual treatment data are means; n=9. LSD bars are shown (Appendix B, Tables B.34; B.38)

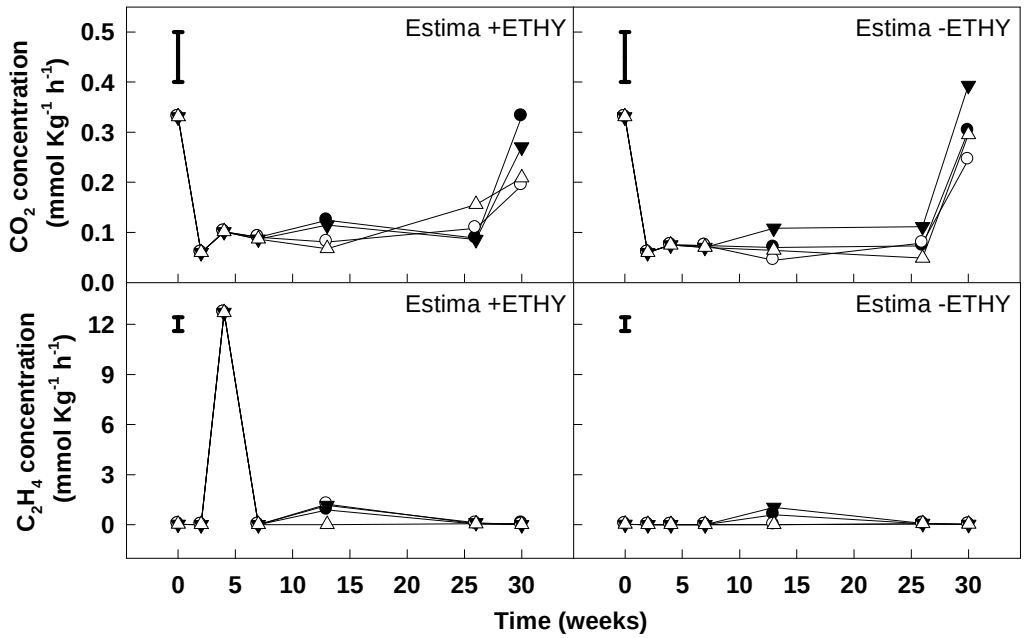

Figure 5.15 CO_2 and C_2H_4 concentrations of 'Estima' potatoes measured after harvest (day 0), after curing for 2 weeks, at 2 weeks storage in ethylene and air, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) +MCP-ETHY; (●) +MCP+ETHY; (△) -MCP-ETHY; (▼) -MCP+ETHY. Individual treatment data are means; n=9. LSD bars are shown (Appendix B, Tables B.35; B.39)

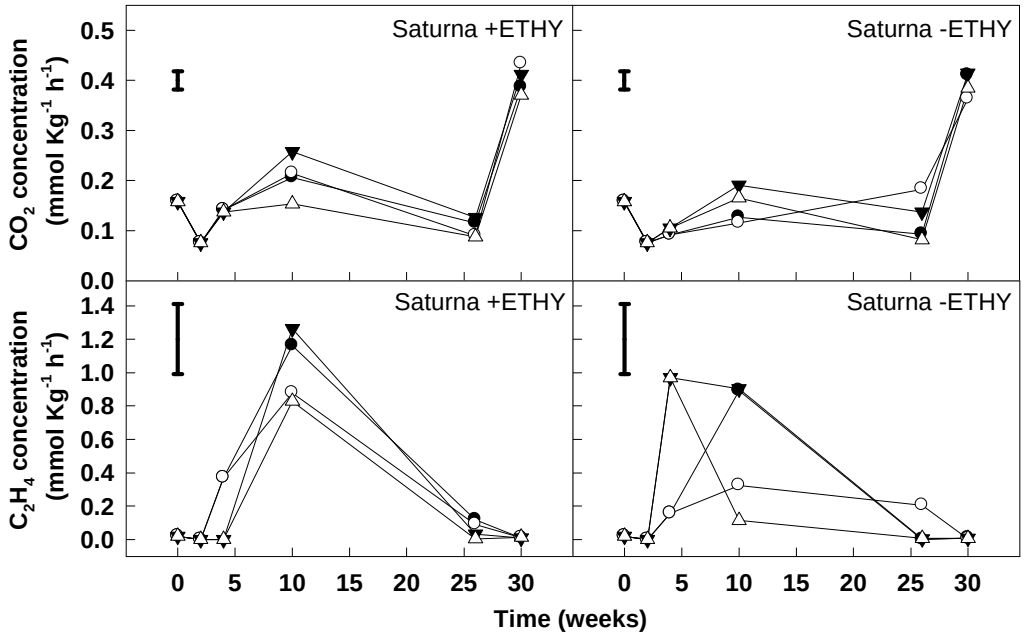

Figure 5.16 CO_2 and C_2H_4 concentrations of 'Saturna' potatoes measured after harvest (day 0), after curing for 2 weeks, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) +MCP-ETHY; (●) +MCP+ETHY; (△) -MCP-ETHY; (▼) -MCP+ETHY. Individual treatment data are means; n=9. LSD bars are shown (Appendix B, Tables B.36; B.40)

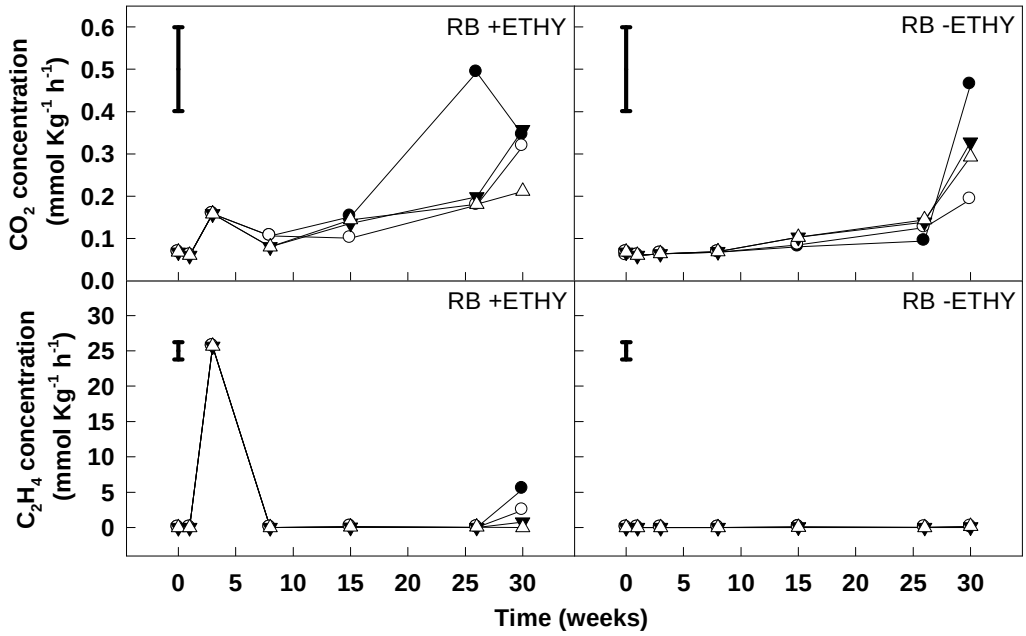

Figure 5.17 CO_2 and C_2H_4 concentrations of 'Russet Burbank' potatoes measured after harvest (day 0), after curing for 2 weeks, at 2 weeks storage in ethylene and air, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) +MCP-ETHY; (●) +MCP+ETHY; (△) -MCP-ETHY; (▼) -MCP+ETHY. Individual treatment data are means; n=9. LSD bars are shown (Appendix B, Tables B.37; B.41)

5.4.2 Non-structural carbohydrate concentration in flesh

There were no significant differences in sucrose, glucose and fructose concentration between treatments for 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank' potatoes, either in the tubers that were stored in ethylene or in air stores (Figures 5.18, 5.19. 5.20, 5.21). All cultivars seemed to have the same pattern in all treatments when they were either stored in ethylene or air and received 1-MCP at the time of first indication of sprouting.

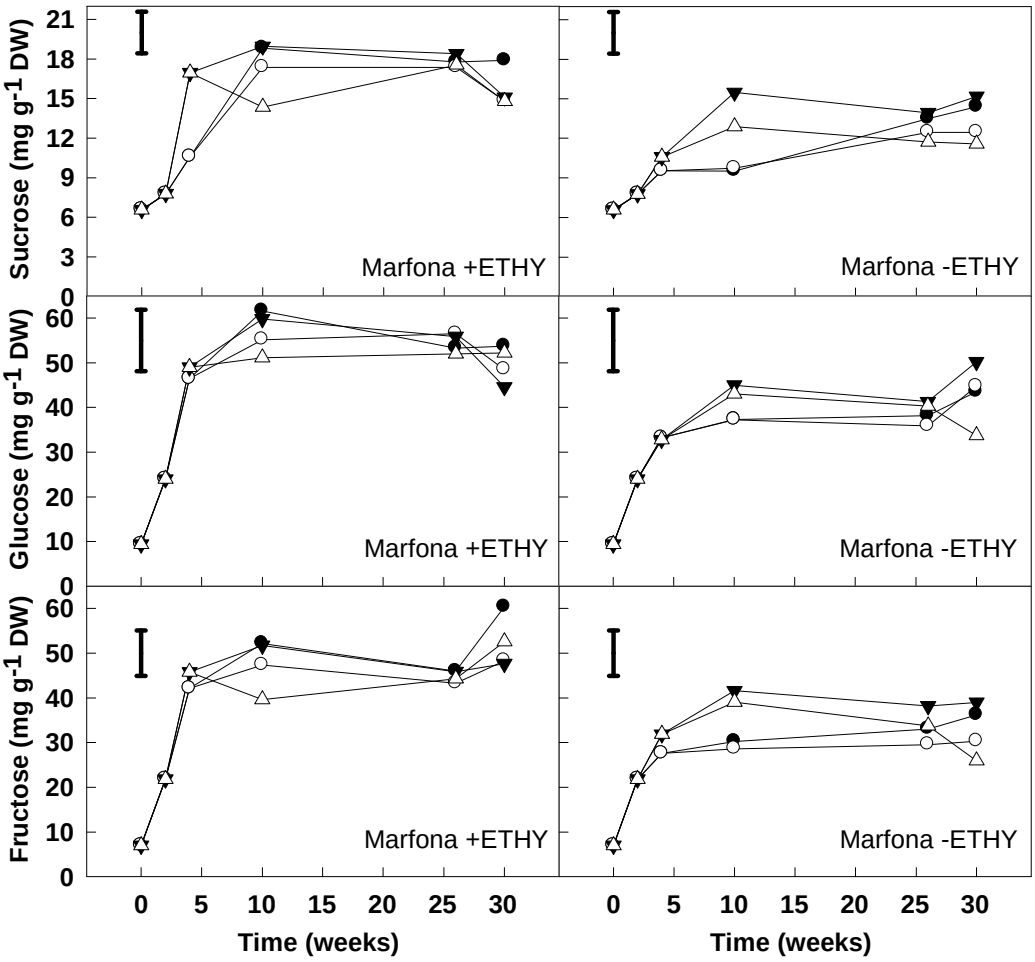

Figure 5.18 Fructose, glucose and sucrose concentrations of 'Marfona' potatoes measured after harvest (day 0), after curing for 2 weeks, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) +MCP-ETHY; (●) +MCP+ETHY; (△) -MCP-ETHY; (▼) -MCP+ETHY. Individual treatment data are means; n=9 (Appendix B, Tables B.42; B.43; B.44)

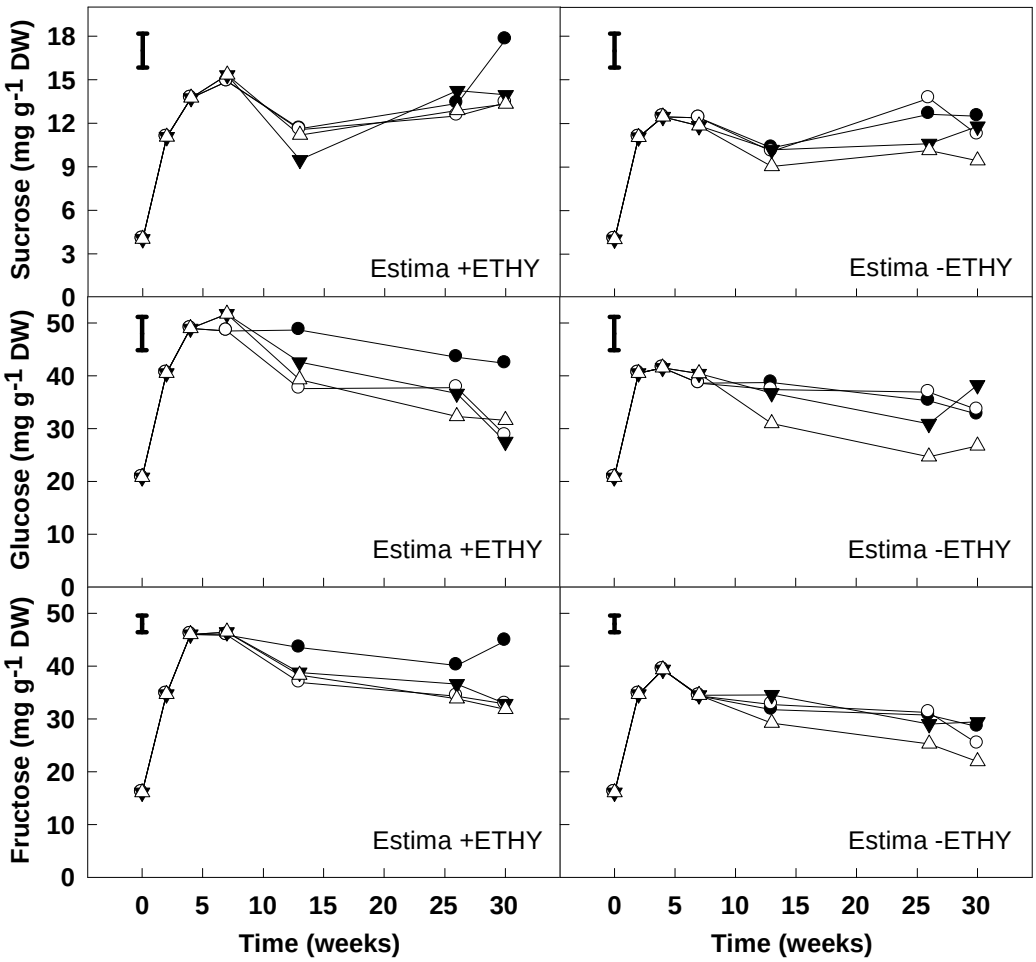

Figure 5.19 Fructose, glucose and sucrose concentrations of 'Estima' potatoes measured after harvest (day 0), after curing for 2 weeks, at 2 weeks storage in ethylene and air, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) +MCP-ETHY; (●) +MCP+ETHY; (△) -MCP-ETHY; (▼) -MCP+ETHY. Individual treatment data are means; n=9 (Appendix B, Tables B.45; B.46; B.47)

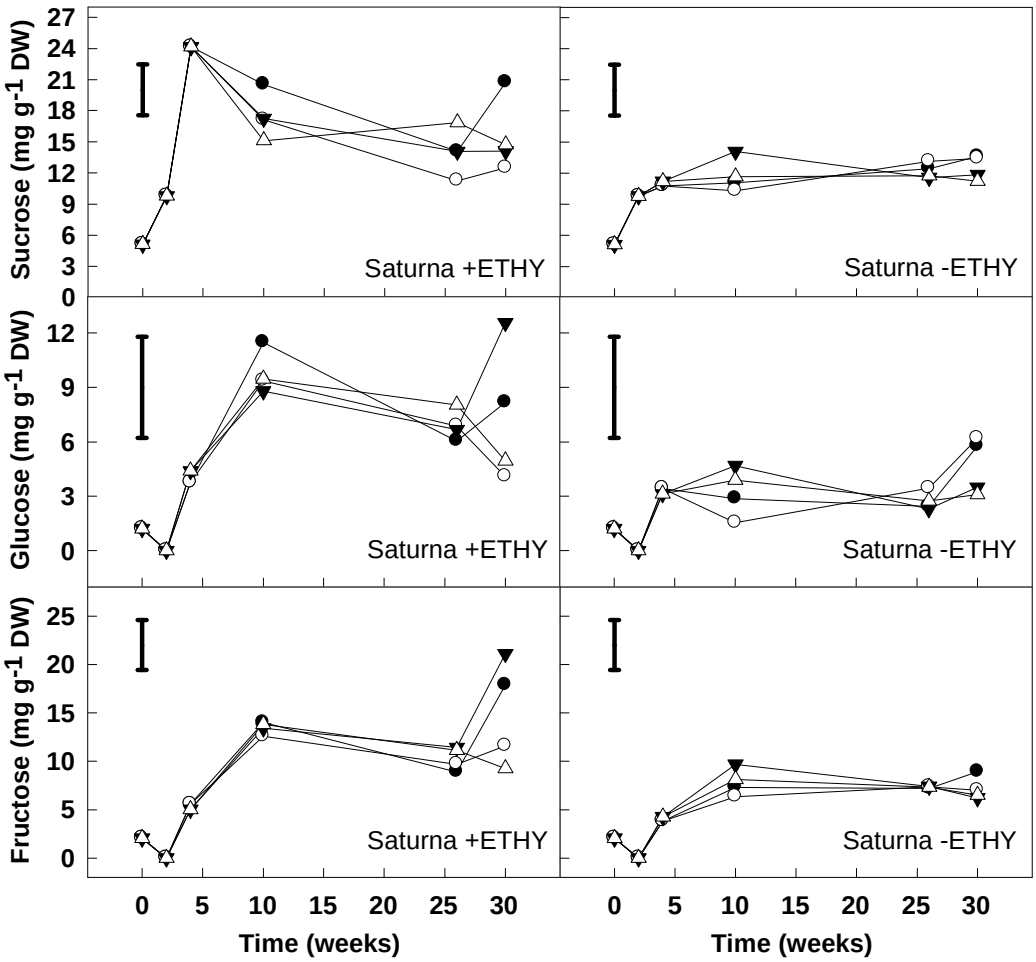

Figure 5.20 Fructose, glucose and sucrose concentrations of 'Saturna' potatoes measured after harvest (day 0), after curing for 2 weeks, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) +MCP-ETHY; (●) +MCP+ETHY; (△) -MCP-ETHY; (▼) -MCP+ETHY. Individual treatment data are means; n=9 (Appendix B, Tables B.48; B.49; B.50)

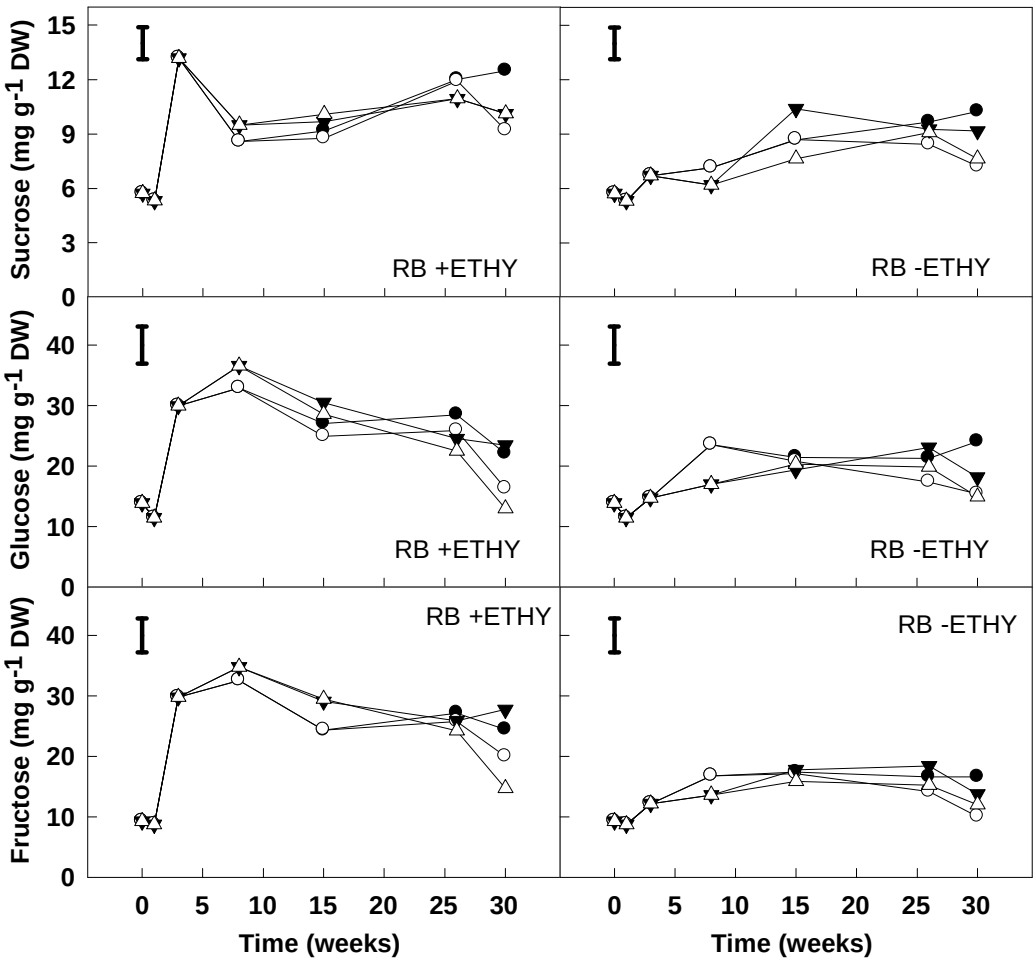

Figure 5.21 Fructose, glucose and sucrose concentrations of 'Russet Burbank' potatoes measured after harvest (day 0), after curing for 2 weeks, at 2 weeks storage in ethylene and air, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) +MCP-ETHY; (●) +MCP+ETHY; (△) -MCP-ETHY; (▼) -MCP+ETHY. Individual treatment data are means; n=9 (Appendix B, Tables B.51; B.52; B.53)

5.4.3 Firmness and apparent elasticity

Regarding firmness and apparent elasticity, there were no significant differences between treatments in any of the cultivars during storage when they were either stored in ethylene or air and received 1-MCP at the time of first indication of sprouting (Figures 5.22, 5.23, 5.24, 5.25).

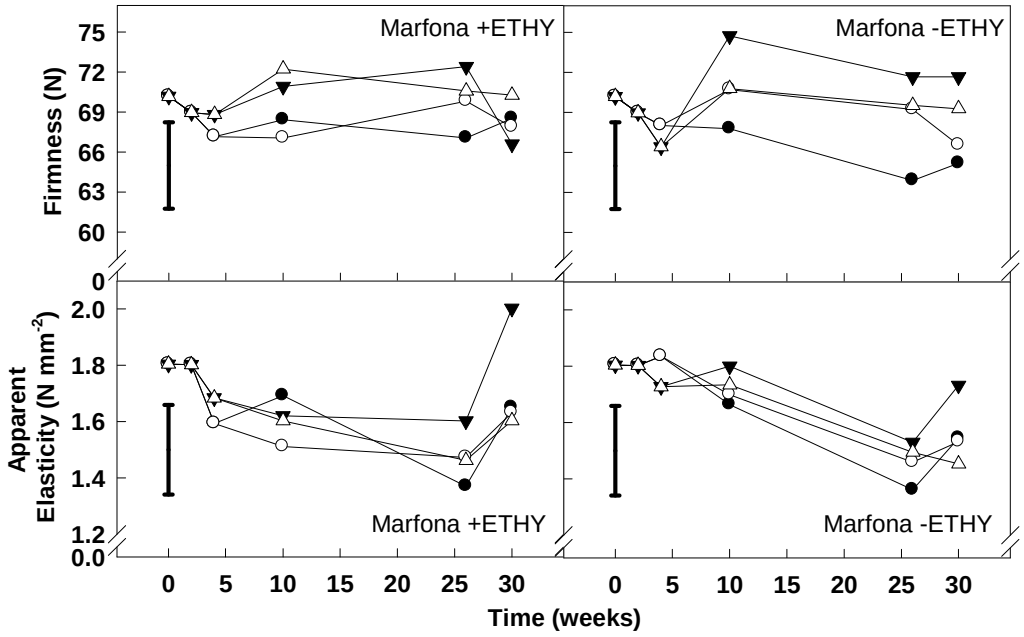

Figure 5.22 Firmness (N) and apparent elasticity (N mm^{-2}) of 'Marfona' potatoes measured after harvest (day 0), after curing for 2 weeks, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) +MCP-ETHY; (●) +MCP+ETHY; (△) -MCP-ETHY; (▼) -MCP+ETHY. Individual treatment data are means; n=9 (Appendix B, Tables B.54; B.55)

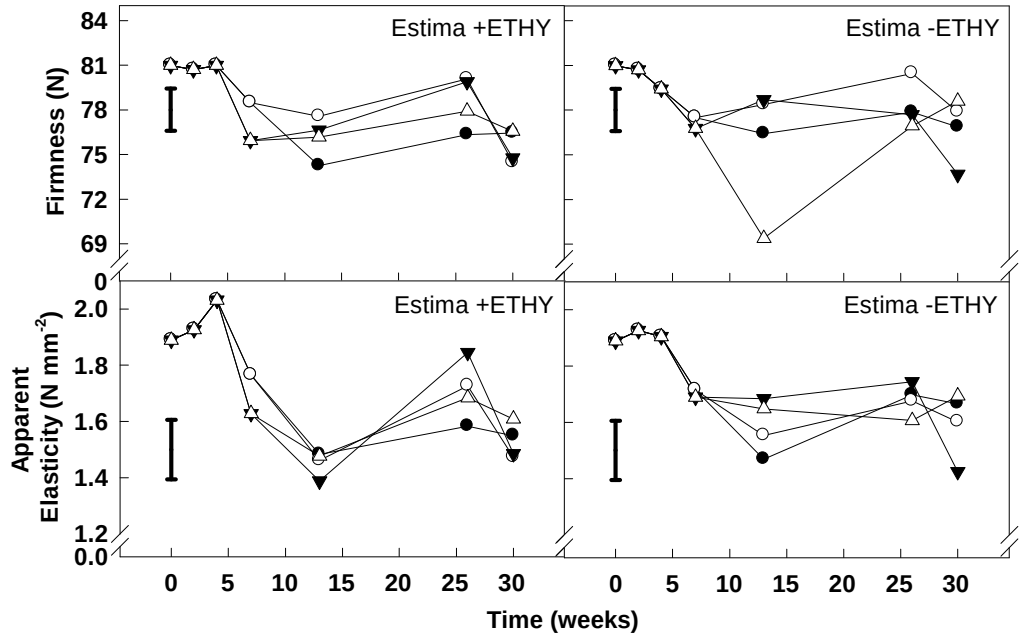

Figure 5.23 Firmness (N) and apparent elasticity (N mm^{-2}) of 'Estima' potatoes measured after harvest (day 0), after curing for 2 weeks, at 2 weeks storage in ethylene and air, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) +MCP-ETHY; (●) +MCP+ETHY; (△) -MCP-ETHY; (▼) -MCP+ETHY. Individual treatment data are means; n=9 (Appendix B, tables B.56; B.57)

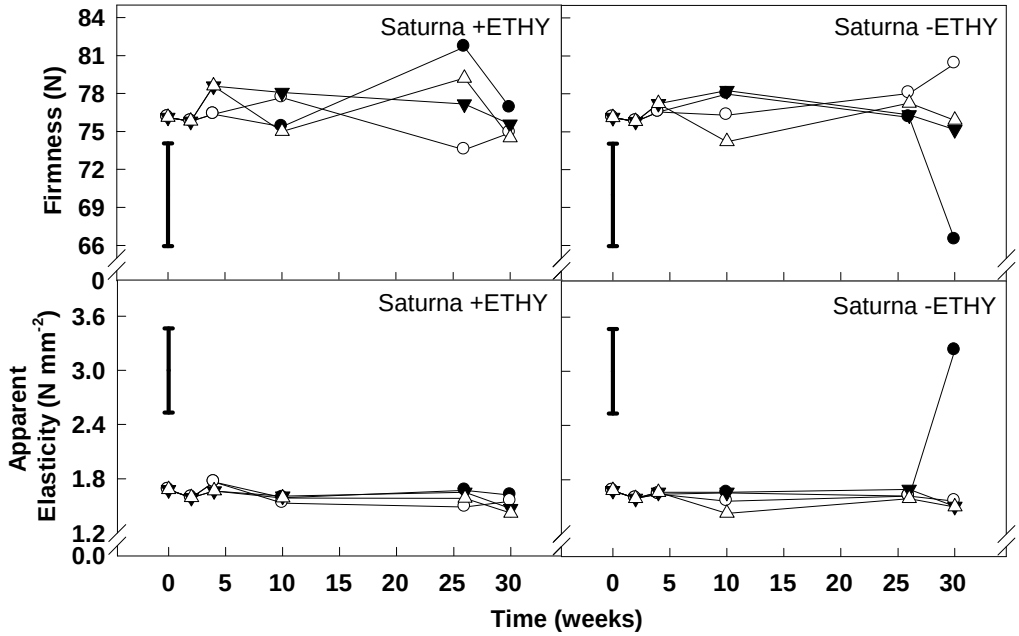

Figure 5.24 Firmness (N) and apparent elasticity (N mm^{-2}) of 'Saturna' potatoes measured after harvest (day 0), after curing for 2 weeks, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) +MCP-ETHY; (●) +MCP+ETHY; (△) -MCP-ETHY; (▼) -MCP+ETHY. Individual treatment data are means; n=9 (Appendix B, Tables B.58; B.59)

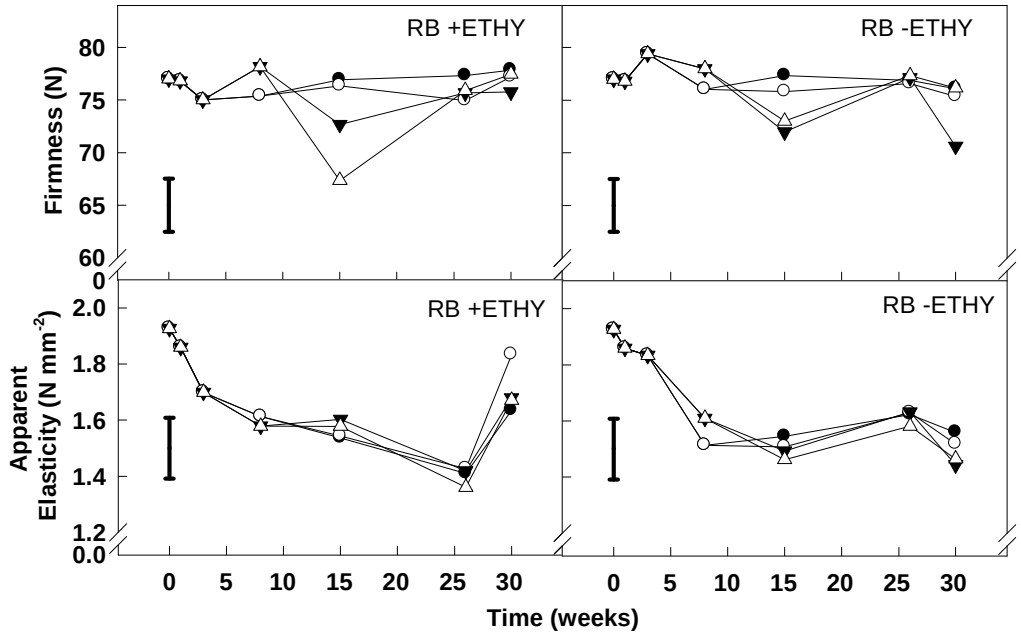

Figure 5.25 Firmness (N) and apparent elasticity (N mm^{-2}) of 'Russet Burbank' potatoes measured after harvest (day 0), after curing for 2 weeks, at 2 weeks storage in ethylene and air, at the time of first indication of sprouting, at 6 weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). (○) +MCP-ETHY; (●) +MCP+ETHY; (△) -MCP-ETHY; (▼) -MCP+ETHY. Individual treatment data are means; n=9 (Appendix B, Tables B.60; B.61)

5.4.4 Sprouting at 30 weeks storage

No significant differences were shown between treatments in 'Estima' potatoes regarding total sprout number (Table 5.3). In contrast, 'Marfona' and 'Russet Burbank' tubers that received 1-MCP at first indication of sprouting and were transferred from ethylene to air had less total sprouts, than those tubers that did not receive 1-MCP at the same treatment. Saturna tubers that had received 1-MCP at the time of first indication of sprouting and were continuously stored in air had no sprouts (Table 5.3).

Table 5.3 Total sprouts of 'Marfona', 'Estima', 'Saturna' and 'Russett Burbank' potatoes recorded at 30 weeks storage at 6°C. Tubers were stored in +/- ethylene (10 μL L^{-1}) and treated with +/-1-MCP (1 μL L^{-1}) at the time of first indication of sprouting. Tubers were collected at four ethylene treatments (continuous ethylene, continuous air, transfer from ethylene to air and from air to ethylene). Individual treatment data are means; n=9. LSD ($P_{0.05}$) = 14.99 (Appendix B, Tables 62).

Treatments			Varieties			
			Marfona	Estima	Saturna	Russet Burbank
Ethylene	+1-MCP	Ethylene	35.67	12.00	42.67	39.67
		Air	45.00	12.67	40.00	60.00
	-1-MCP	Ethylene	36.67	14.33	35.00	46.33
		Air	64.67	14.00	46.00	59.33
Air	+1-MCP	Ethylene	36.00	11.00	35.33	46.33
		Air	38.00	10.00	0.00	45.00
	-1-MCP	Ethylene	50.33	9.33	42.00	35.67
		Air	38.33	9.33	46.00	70.00

5.4.5 Sprouting during shelf life

There were no significant differences between treatments in 'Estima' potatoes that received +/- 1-MCP at the time of first indication of sprouting, either when stored in ethylene or air before the 1-MCP application (Table 5.4). Double number of total

sprouts was shown in 'Marfona' tubers that were initially stored in air and received 1-MCP at the time of first indication of sprouting and then stored in ethylene (31.24) and air (31.45), than those that did not receive 1-MCP at the time of first indication of sprouting and at the same treatments (16.62 and 20.83, respectively). 'Saturna' tubers that were stored under continuous ethylene and received 1-MCP at the time of first indication of sprouting had more total number of sprouts, than those that did not receive 1-MCP (38.76 and 29.95 respectively).

There were no significant differences between treatments for 'Russet Burbank' potatoes when they were treated with or without 1-MCP at the time of first indication of sprouting (Table 5.5).

Table 5.4 Total sprouts of 'Marfona', 'Estima' and 'Saturna' potatoes recorded during storage at 20°C for 18 days after tubers were treated with +/- 1-MCP (1 μL L^{-1}) after first indication of sprouting after storage at +/- ethylene (10 μL L^{-1}) and at four ethylene treatments (continuous ethylene, continuous air, transfer from ethylene to air and from air to ethylene). Individual treatment data are means; n=15. LSD $_{(P\ 0.05)}$ = 5.61 (Appendix B, Table 63).

Treatments			Marfona	Estima	Saturna
Ethylene	+1-MCP	Ethylene	23.00	17.38	38.76
		Air	19.95	15.33	36.10
	-1-MCP	Ethylene	22.43	18.29	29.95
		Air	26.31	16.76	32.90
Air	+1-MCP	Ethylene	31.24	14.48	31.43
		Air	31.45	15.67	28.86
	-1-MCP	Ethylene	16.62	21.76	32.62
		Air	20.83	22.38	33.48

Table 5.5 Total sprouts of 'Russett Burbank' potatoes recorded during storage at 20°C for 18 days after tubers were treated with +/- 1-MCP (1 μL L^{-1}) after first indication of sprouting after storage at +/- ethylene (10 μL L^{-1}) and at four ethylene treatments (continuous ethylene, continuous air, transfer from ethylene to air and from air to ethylene). Individual treatment data are means; n=15. LSD $_{(P\ 0.05)}$ = 12.64 (Appendix B, Table 64).

Treatments			Russet Burbank Total sprouts
Ethylene	+1-MCP	Ethylene	48.70
		Air	45.10
	-1-MCP	Ethylene	51.70
		Air	44.80
Air	+1-MCP	Ethylene	46.50
		Air	43.30
	-1-MCP	Ethylene	50.30
		Air	58.00

5.5 Chemometrics

Chemometric analysis was performed on data from Years 2009-2010 using Principal Component Analysis (PCA) which is an unsupervised technique. Partial Least Square Discriminant Analysis (PLS-DA) was also used to clarify observations from the results of PLS regression on indicator variables.

Experiments 4 & 5: PCA and PLS-DA of sugars in flesh (DW), ethylene and CO_2 production (mmol $Kg^{-1}h^{-1}$), firmness (N) and apparent elasticity (N mm^{-2}) and sprouting incidence of cvs. 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank' that received a 24h +/- 1-MCP treatment before storage of tubers in +/- ethylene.

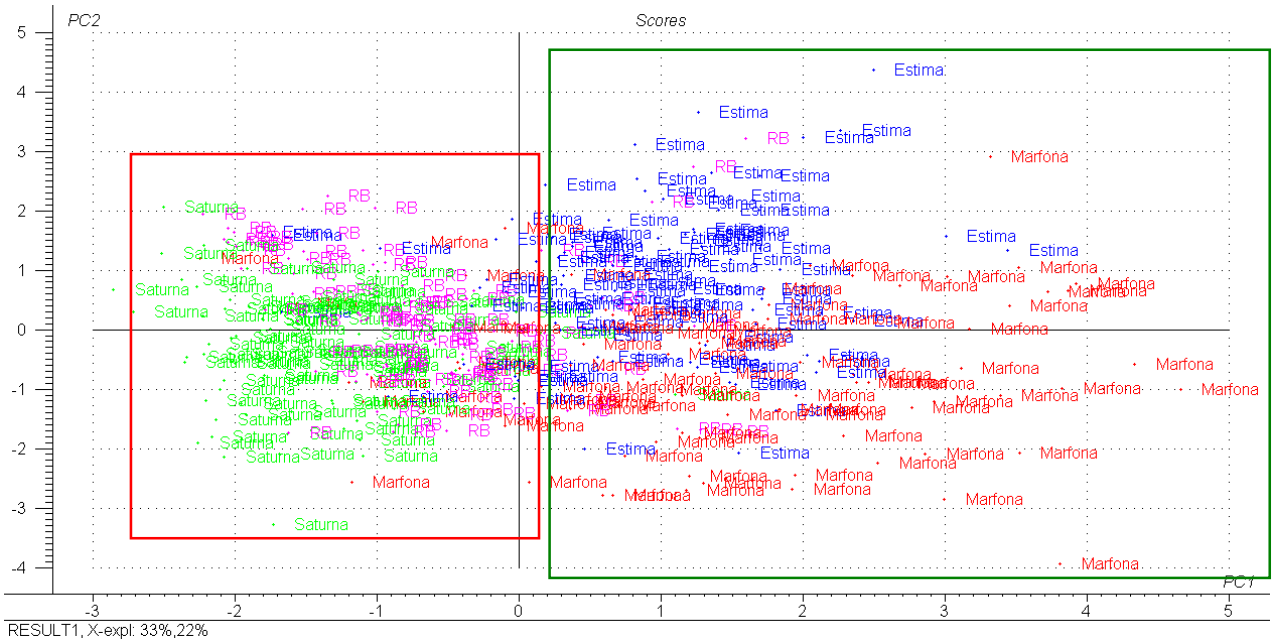

Figure 5.26 PCA score plot for PC1 (33%) versus PC2 (22%) of potatoes 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank'. Grouping of cvs. on the score plot of PCA is based on the similarities in variation of sugars in flesh (DW), ethylene and CO_2 production (mmol Kg^{-1} h^{-1}), firmness (N) and apparent elasticity (N mm^{-2})

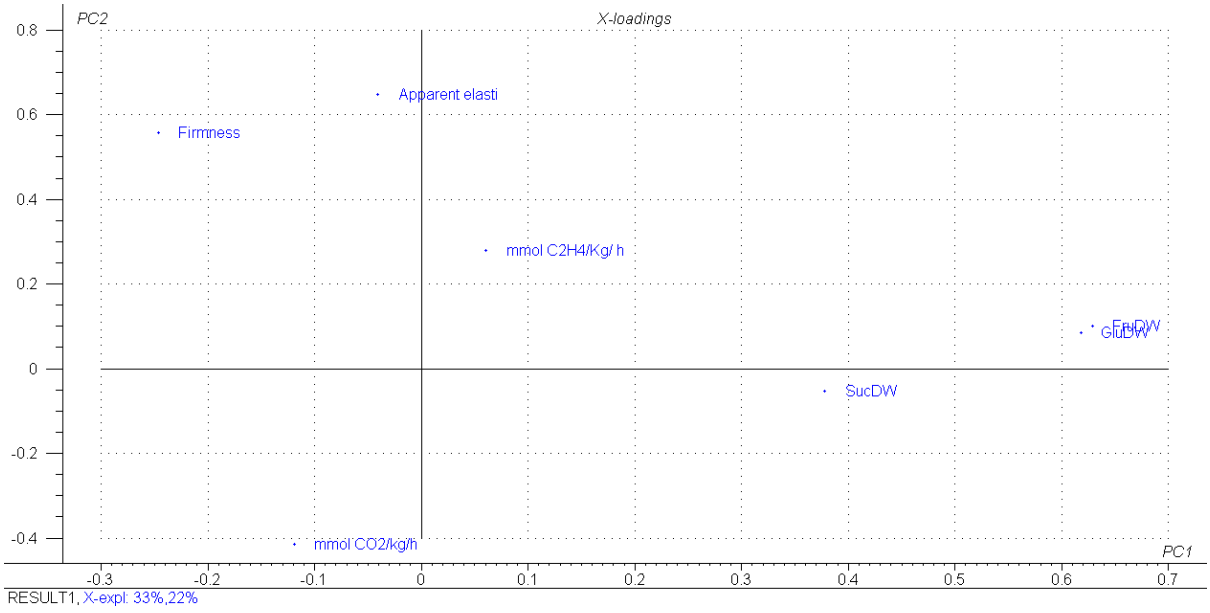

Figure 5.27 PCA loading plot for PC1 (33%) versus PC2 (22%) of potatoes 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank'. Grouping of cvs. on the loading plot of PCA is based on the similarities in variation of sugars in flesh (DW), ethylene and CO_2 production (mmol Kg^{-1} h^{-1}), firmness (N) and apparent elasticity (N mm^{-2})

According to the PCA (Figures 5.26 and 5.27), 55% of variance is explained by a combination of PCs 1 and 2 and the cultivars were separated into two groups. 'Marfona' and 'Estima' form the first group, while 'Saturna' and 'Russet Burbank' form the second group. 'Marfona' and 'Estima' are separated from 'Saturna' and 'Russet Burbank' in PC1. According to the loadings (Figure 5.26), the most important variates in PC1 are fructose and glucose in flesh of tubers. In contrast in PC2, the most important variates are apparent elasticity and respiration rate (CO_2) of tubers. Thus, 'Marfona' and 'Estima' tubers are separated from 'Saturna' and 'Russet Burbank' tubers due to differences in fructose and glucose content of tubers, whereas 'Estima' is separated from 'Marfona' due to differences in apparent elasticity and respiration rate. Samples are clustered by cultivar in this PCA. Difference between treatments could not be visualized either with PLS-DA technique, perhaps due to complex interactions.

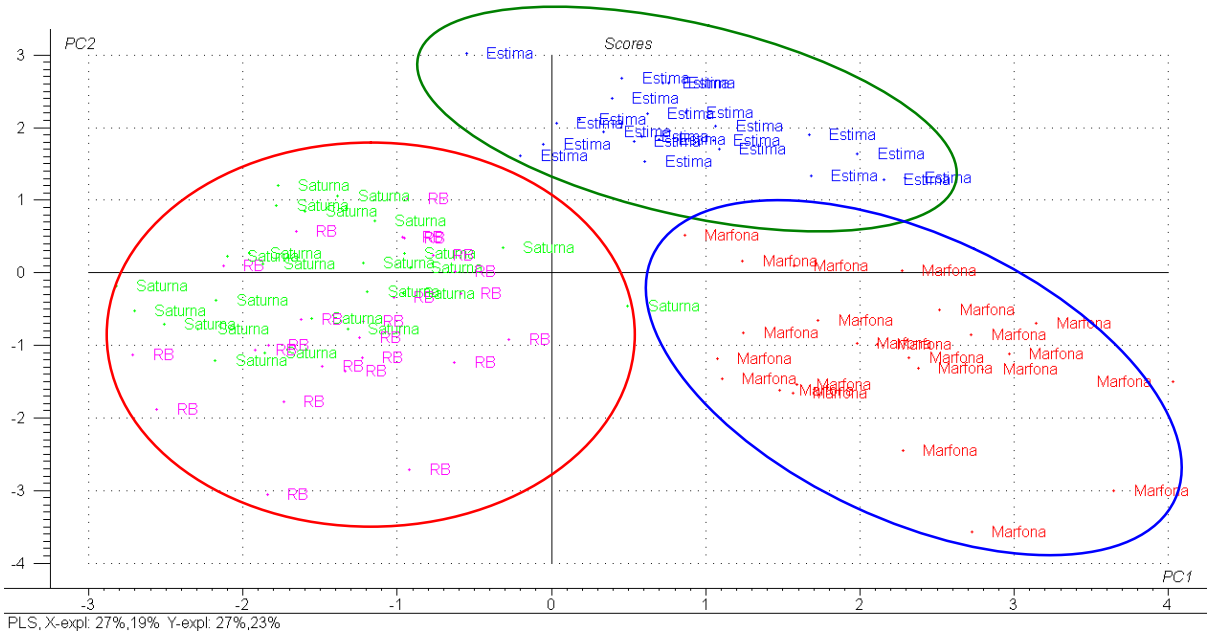

Figure 5.28 PLS-DA score plot for PC1 (27%) versus PC2 (19%) of 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank'. Grouping of cultivars on the score plot is based on the similarities in variation of sucrose, glucose and fructose (DW) in flesh, firmness and apparent elasticity of tubers, ethylene and CO_2 production, total sprouts and sprouting at different lengths measured in tubers at the end of the experiment. Y-variability was explained 50% by the model of the first two PCs

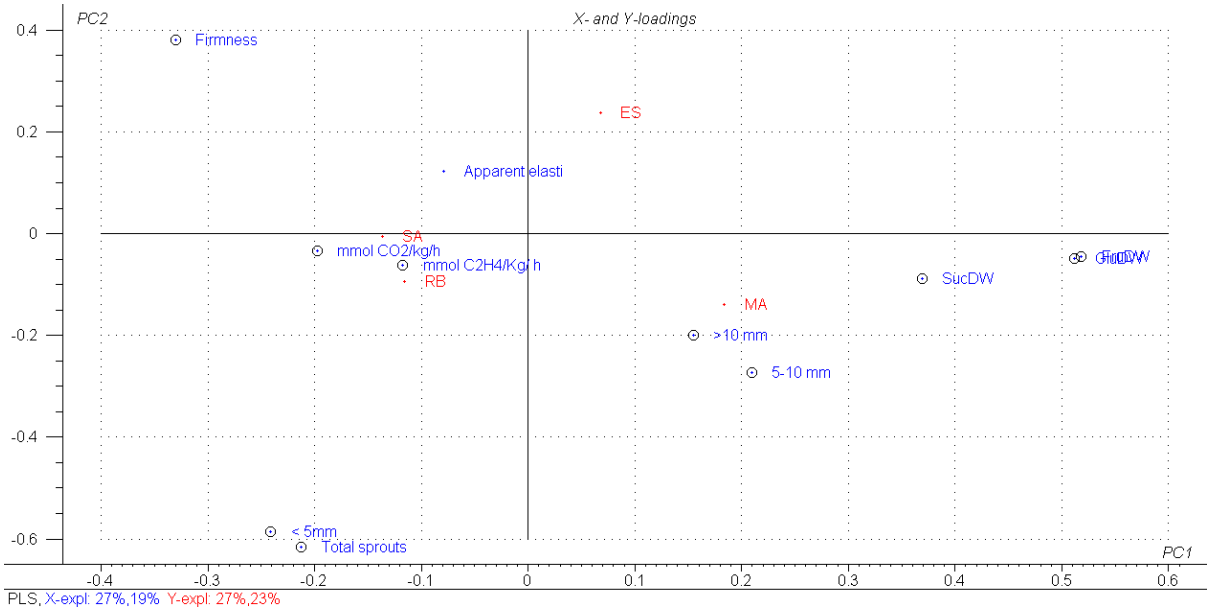

Figure 5.29 PLS-DA score plot for PC1 (27%) versus PC2 (19%) of 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank'. Grouping of cultivars on the loading plot is based on the similarities in variation of sucrose, glucose and fructose (DW) in flesh, firmness and apparent elasticity of tubers, ethylene and CO_2 production, total sprouts and sprouting at different lengths measured in tubers at the end of the experiment. Y-variability was explained 50% by the model of the first two PCs

In addition to the above findings, PLS-DA that was done on the final outturn of Experiment 1, and revealed slightly different groupings. 'Saturna' and 'Russet Burbank' still form one group, while 'Marfona' are differentiated from 'Estima' and belong to separate groups (Figure 5.28). According to the PLS-DA in Figure 5.28, 46% of variance was explained by a combination of PCs 1 and 2. The loading plot (Figure 5.29) showed that all variates analysed are important except for the apparent elasticity of tubers of those four cvs. More specifically, fructose and glucose (DW) in flesh are the most important variates in PC1, while firmness of tubers, total sprouts and sprouting at <5mm are the most important in PC2. Thus, 'Saturna' and 'Russet Burbank' potatoes are grouped together due to similarities in firmness of tubers, ethylene and CO_2 production, total number of sprouts and length of sprouts <5mm.

Experiment 6 & 7: PCA and PLS-DA of sugars in flesh (DW), ethylene and CO_2 production (mmol $Kg^{-1}h^{-1}$), firmness (N) and apparent elasticity (N mm^{-2}) and sprouting incidence of cvs. 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank' that received a 24h +/- 1-MCP treatment at the time of first indication of sprouting of tubers.

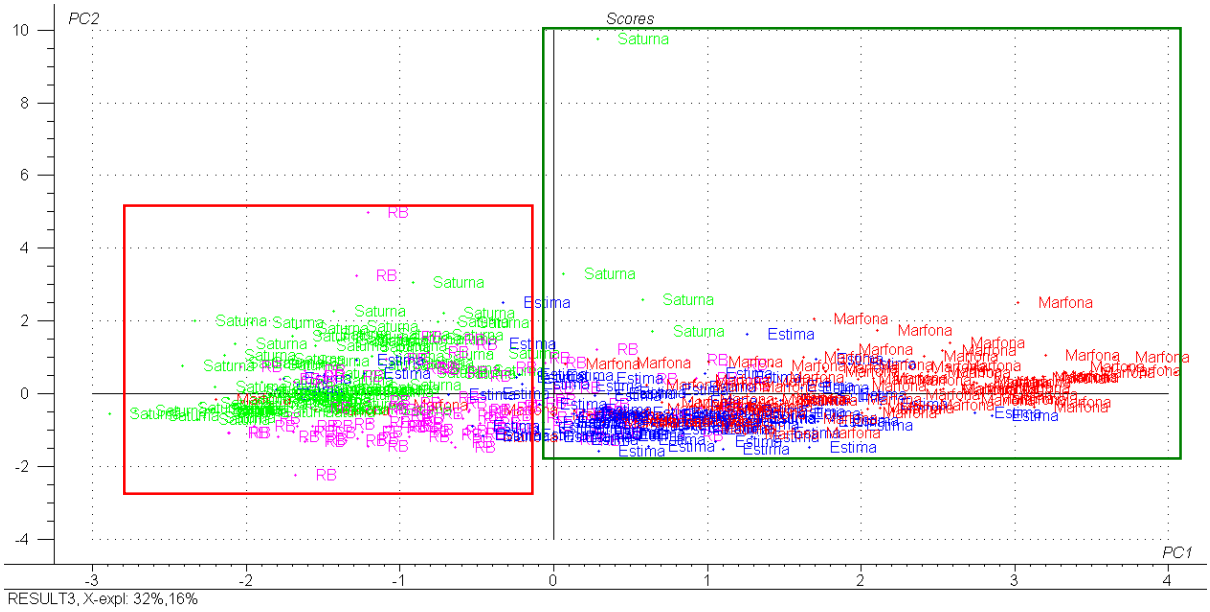

Figure 5.30 PCA score plot for PC1 (32%) versus PC2 (16%) of potatoes 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank'. Grouping of cvs. on the score plot of PCA is based on the similarities in variation of sugars in flesh (DW), ethylene and CO_2 production (mmol Kg^{-1} h^{-1}), firmness (N) and apparent elasticity (N mm^{-2})

According to the PCA (Figures 5.30 and 5.31), 48% of variance is explained by a combination of PCs 1 and 2 and the cultivars are separated into 2 groups, although the cultivars are overlapping at some points. 'Marfona' and 'Estima' form the first group, while 'Saturna' and 'Russet Burbank' form the second group. 'Marfona' and 'Estima' are separated from 'Saturna' and 'Russet Burbank' in PC1. According to the loadings (Figure 5.31), the most important variates in PC1 are fructose and glucose in flesh of tubers. In contrast in PC2, the most important variate is respiration rate (CO_2) of tubers. Thus, 'Marfona' and 'Estima' tubers are separated from 'Saturna' and 'Russet Burbank' tubers due to differences in fructose and glucose content of tubers, whereas 'Estima' is

separated from ‘Marfona’ due to differences in the respiration rate. Samples are clustered by cultivar in this PCA. Difference between treatments could not be visualized either with PLS-DA technique, perhaps due to complex interaction.

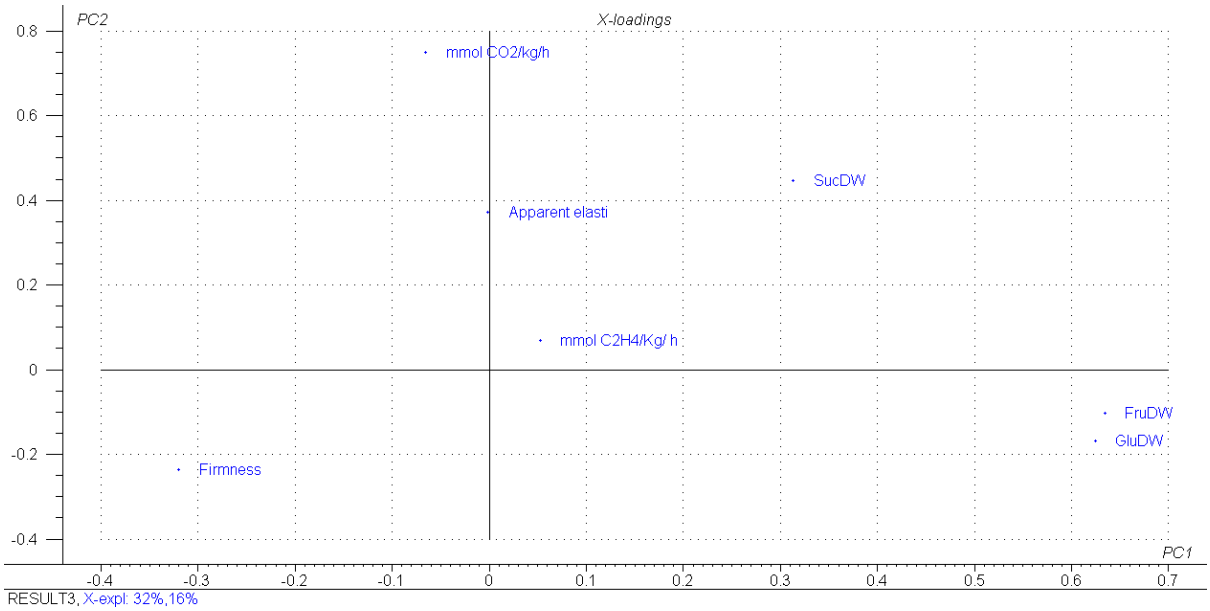

Figure 5.31 PCA loading plot for PC1 (32%) versus PC2 (16%) of potatoes ‘Marfona’, ‘Estima’, ‘Saturna’ and ‘Russet Burbank’. Grouping of cvs. on the loading plot of PCA is based on the similarities in variation of sugars in flesh (DW), ethylene and CO_2 production (mmol Kg^{-1} h^{-1}), firmness (N) and apparent elasticity (N mm^{-2})

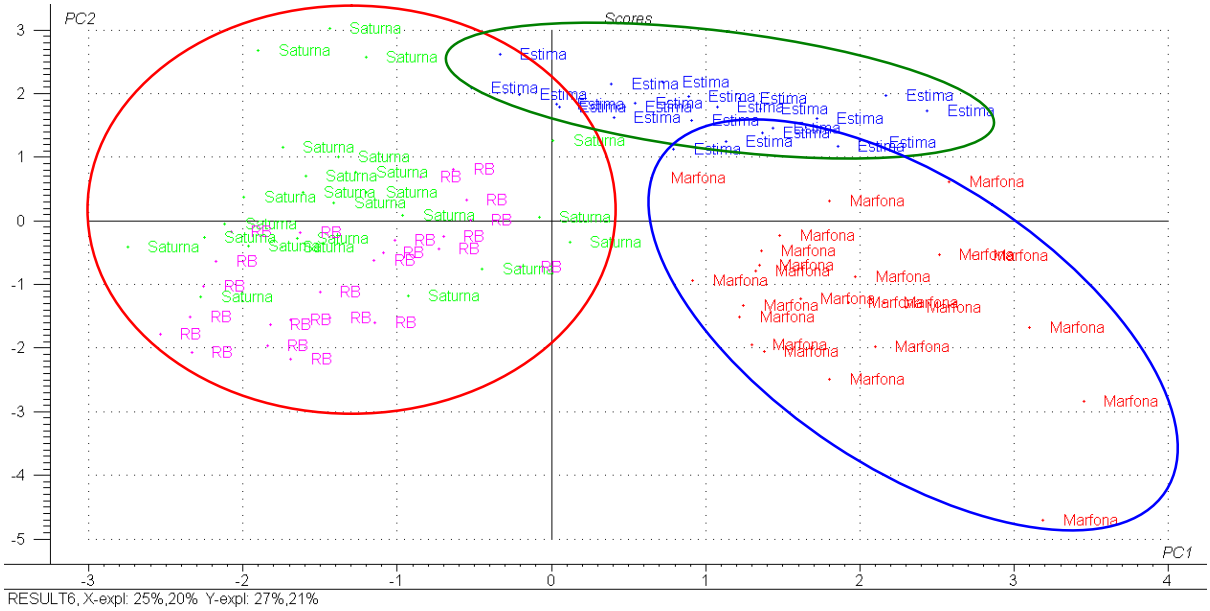

Figure 5.32 PLS-DA score plot for PC1 (25%) versus PC2 (20%) of 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank'. Grouping of cultivars on the score plot is based on the similarities in variation of sucrose, glucose and fructose (DW) in flesh, firmness and apparent elasticity of tubers, ethylene and CO_2 production, total sprouts and sprouting at different lengths measured in tubers at the end of the experiment. Y-variability was explained 48% by the model of the first two PCs

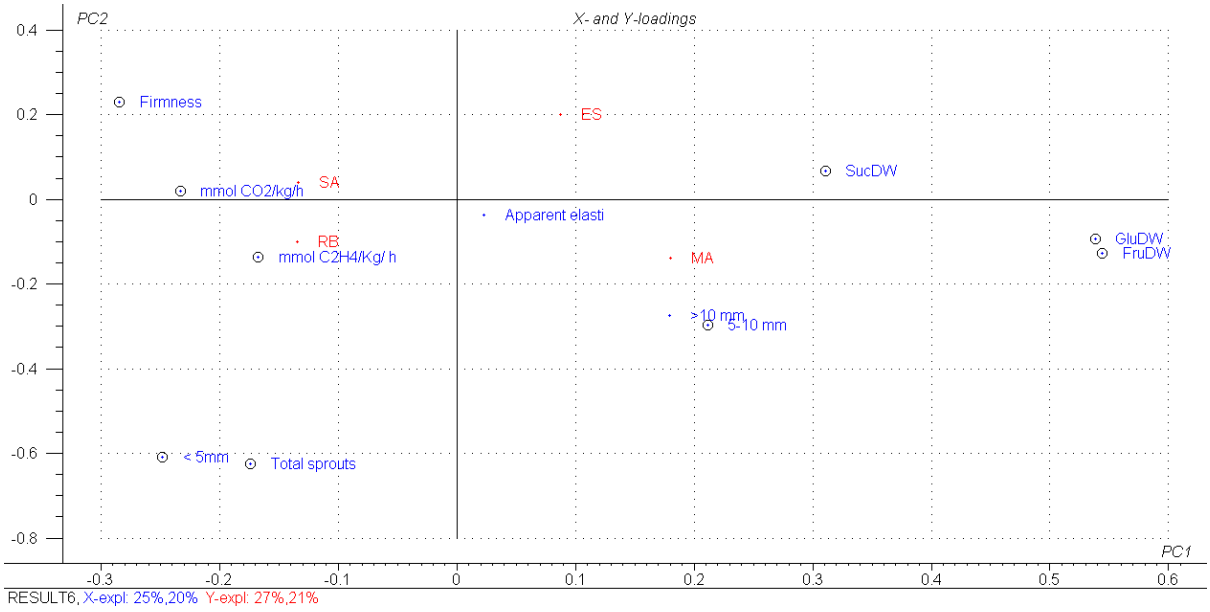

Figure 5.33 PLS-DA loading plot for PC1 (25%) versus PC2 (20%) of potatoes 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank'. Grouping of cvs. on the loading plot of PCA is based on the similarities in variation of sugars in flesh (DW), ethylene and CO_2 production (mmol Kg^{-1} h^{-1}), firmness (N) and apparent elasticity (N mm^{-2}), total sprouts and sprouting at different lengths in the tubers at the end of the experiment. Y-variability was explained 48% by the model of the first two PCs

In addition to the above findings, PLS-DA that was done on the final sampling of Experiments 6 & 7 and revealed slightly different groupings. 'Saturna' and 'Russet Burbank' still formed one group, while 'Marfona' were differentiated from 'Estima' and belonged to separate groups (Figure 5.32). According to the PLS-DA in Figure 5.32, 48% of variance was explained by a combination of PCs 1 and 2. The loading plot (Figure 5.33) showed that all variates analysed are important except for the apparent elasticity of tubers of those four cvs. and the amount of sprouts >10mm in length. More specifically, fructose and glucose (DW) in flesh are the most important variates in PC1, while firmness of tubers, total sprouts and sprouting at <5mm are the most important in PC2. Thus, 'Saturna' and 'Russet Burbank' potatoes are grouped together due to similarities in firmness of tubers, ethylene and CO_2 production, total number of sprouts and length of sprouts <5mm. 'Estima' potatoes differ from 'Marfona' in terms of sugar content in flesh and amount of sprouts 5-10 mm in length.

5.6 Discussion

Effect of ethylene and 1-MCP on tuber physiology and sprouting

There was a significant lower mean number on sprouts when the tubers of both 'Marfona' and 'Russet Burbank' cultivars were treated continuously with ethylene than air or when they received ethylene after first indication of sprouting and not before. In contrast, there were no significant differences between treatments for 'Estima' and 'Saturna' tubers. These results are in agreement with those of Prange *et al.* (1998) on 'Russet Burbank' potatoes that were exposed to 4 μL L^{-1} ethylene for 30 weeks at 9°C and developed significantly smaller sprouts than those stored in air. Additionally, there

was no effect of 1-MCP on sprouting in any treatment either in ‘Marfona’ or ‘Estima’ potatoes.

Effect of ethylene and 1-MCP on tuber respiration rate and ethylene production

Results showed that there was an effect of +1-MCP application on ‘Marfona’ and ‘Saturna’ potatoes at 6 weeks after first indication of sprouting, leading to higher respiration rate of the tubers in all treatments. There was also a significant higher ethylene production detected in the ethylene-treated than air-treated tubers of the same varieties that received a 24h +1-MCP treatment at the time of first indication of sprouting. Similar results were shown for ‘Estima’ and ‘Russet Burbank’ tubers, but at 2 weeks storage in ethylene and in air in both +1-MCP and -1-MCP-treated tubers. 1-MCP is believed to interact with ethylene receptors and thereby prevent ethylene-dependent responses (Sisler and Serek, 1997, 2003), but should be applied before ethylene, so that it is allowed to bind first (Watkins, 2006). 1-MCP has been successful in preventing or delaying the ethylene production increase and internal ethylene concentrations associated with the climacteric ripening stage of different agricultural products (Watkins, 2006). It is also believed that 1-MCP binds permanently to receptors present at the time of application and any reverse effects leading to ethylene sensitivity might be due to appearance of new sites (Blankenship and Dole, 2003). However, in this study, and even though potatoes are not climacteric products, exposure of tubers to +1-MCP did not suppress the action of ethylene in terms of the increase in the respiration rate or ethylene production at different stages during storage of potatoes; in contrast, +1-MCP exposure enhanced the increase of both respiration rate and

ethylene production, suggesting that there might have been a regeneration of new receptors or different receptors after the beginning of dormancy break of 'Marfona' and 'Saturna' potatoes, that led to the reversion of the 1-MCP effect. This effect took place at different time points during storage and was cultivar-specific.

Effect of ethylene and 1-MCP on tuber biochemistry

Using ethylene (10 μL L^{-1}) as a sprout suppressing agent and storage of tubers at 6°C resulted in greater sugar concentration in flesh in a treatment and cultivar-dependent manner. Previously, Day *et al.* (1978) and Prange *et al.* (1998) observed an increase in sugar concentration in ethylene-treated 'Russet Burbank' tubers. Exogenous ethylene treatment of potato tubers can mimic the effect of cold incubation. Indeed, Bagnaresi *et al.* (2008) showed through heterologous microarray experiments that identification of the early events associated with tuber cold sweetening could be achieved and ethylene responsive genes were upregulated as a consequence of cold incubation for 4 days at 4°C. High levels of both fructose and glucose in tubers can lead to an undesirable tissue darkening during frying (Stadler *et al.*, 2002) and indeed ethylene-treated tubers have been generally associated with a darker fry colour (Prange *et al.*, 1998; Prange *et al.*, 2005; Daniels-Lake *et al.*, 2005; Daniels-Lake *et al.*, 2007). The changes in sugar content observed in this study varied according to cultivar. The cultivars were grown at different sites and the length of the growing season varies according to the cultivar. Kyriacou *et al.* (2009) demonstrated that tuber sugar accumulation is affected by crop management and there has a subsequent impact on potato processing quality. Variation in tuber sugar composition at harvest reflects the effect of growing season. Sucrose levels are considered to be a possible factor indicating

biotic and abiotic stresses on the crop and tuber chemical maturity (Sowokinos, 1978). Differences between cultivars may be explained by differences in the cropping season, as the cultivars studied herein belong to different groups (viz. maincrop, early, medium early and second early maincrop). Besides, the genetic diversity among potato cultivars is well documented (Mondal *et al.*, 2007) and may be responsible for different responses to treatments since all studied varieties were of different parentage (British Potato Variety Database, 2009). It is also possible to speculate that variations in the response of potato tubers to ethylene treatments may be related to morphological differences in the skin of the tubers. Higher peel thickness may act as a barrier to ethylene gas to reach the metabolically active meristem tissue where sprouts are initiated and hence limiting its possible role in inducing sugar changes and sprout suppression. Similar hypotheses were proposed by Chope *et al.* (2007) when assessing the response to the ethylene inhibitor 1-MCP and Downes *et al.* (2010) after postharvest application with ethylene and 1-MCP on onions. Spatial differences in sugar content have already been reported for other horticultural crops (Abayomi and Terry, 2009; Landahl *et al.*, 2009), and in the particular case of potatoes may be connected to the formation of the skin through starch deposition after conversion from translocated sugars (Pringle *et al.*, 2009). In addition, it may be feasible to speculate that spatial differences in sugar content in potato tubers may lead to better understanding of sugar metabolism during storage.

5.7 Conclusions

1-MCP is believed to interact with ethylene receptors and thereby prevent ethylene-dependent responses. 1-MCP application before storage of tubers in ethylene and air stores was more effective than when applied at the time of first indication of

sprouting, whereas sugar concentration was significantly affected decreased and the action of ethylene was suppressed. In contrast, in the absence of 1-MCP, sugar concentration was significantly higher in the ethylene-treated tubers compared to air-treated ones. 1-MCP application did not seem to significantly affect either firmness or elasticity during storage of tubers in both experiments. Effect of 1-MCP on sprouting was cultivar-dependent yet could result from agronomical factors. 'Estima' tubers were not significantly affected under any treatment. It seems that 1-MCP effectively blocked ethylene binding sites when applied before storage of tubers in ethylene and air, but its action was inhibited when applied after storage at the time of first indication of sprouting. The inability of 1-MCP to block the effect of ethylene in certain cultivars may be associated with skin thickness, as higher thickness may be a barrier for the gas to reach ethylene binding sites. 1-MCP may also be unable to bind all ethylene receptors and thus its action is reduced which could also be cultivar-dependent.

CHAPTER SIX

THE USE AND TIMINGS OF 1-MCP AND ETHYLENE TREATMENTS ON THE POSTHARVEST QUALITY OF TWO UK-GROWN POTATO CULTIVARS

6.1 Introduction

In previous Chapter 5 the effects of a 24h 1 μL 1-MCP L^{-1} treatment either before storage of tubers in ethylene or air or after the trigger point of first indication of sprouting were discussed. The application of 1 μL 1-MCP L^{-1} before storage of tubers in ethylene resulted in a decrease of sugars during storage in a cultivar-dependent manner highlighting the possible action of 1-MCP in blocking the ethylene receptors at that time point. The aim of the present experiment was to study the effect of the same 24h 1 μL -/+1-MCP L^{-1} treatment before storage of 'Marfona' and 'Estima' cultivars in ethylene and air and also at the time of first indication of sprouting following a subsequent storage under ethylene or air. Thus, the efficacy of a combined 1-MCP and ethylene treatment could be tested.

6.2 Materials and methods

Sample preparation for Chapter 6 is described in Section 3.7. The measurement and analysis of ethylene production and respiration rate (CO_2), sprouting, sugar content and dry weight content are described in Chapter 3: Materials and Methods.

6.3 Results

6.3.1 Ethylene production and respiration rate

Ethylene production at intake for 'Marfona' was 0.008 mmol Kg^{-1} h^{-1} and 0.001 mmol Kg^{-1} h^{-1} 'Estima' (Tables 6.1; 6.2). Ethylene production of tubers of both potato cultivars was below detection limit during samplings 2 (after the 1st -/+1-MCP treatment; 15 days after harvest; Table 3.4, Chapter 3) and 3 (after the 2nd -/+1-MCP treatment at the time of first indication of sprouting; 3 months after the first 1-MCP treatment; Table 3.4, Chapter 3) under all treatments (Tables 6.1; 6.2). At sampling 4 (at 30 weeks storage), ethylene production was significantly higher in the ethylene-treated (-1-MCP: 0.954; +1-MCP: 1.152 mmol Kg^{-1} h^{-1}) than air-treated (-1-MCP: 0.000; +1-MCP: 0.007 mmol Kg^{-1} h^{-1}) 'Marfona' tubers which had only received the first 24h -/+1-MCP treatment (Table 6.1). Similar results were shown for 'Estima' potatoes but only for the +1-MCP-treated tubers (ethylene-treated: 0.455; air-treated: 0.000 mmol Kg^{-1} h^{-1}). However, there was no significant difference in ethylene production either between the -1-MCP-ethylene-treated (0.954 mmol Kg^{-1} h^{-1}) and the +1-MCP-ethylene-treated (1.152 mmol Kg^{-1} h^{-1}) nor between the -1-MCP-air-treated (0.000 mmol Kg^{-1} h^{-1}) and the +1-MCP-air-treated (0.007 mmol Kg^{-1} h^{-1}) 'Marfona' tubers. Opposite results were shown 'Estima' under the same ethylene treatments, where the +1-MCP-ethylene-treated tubers (0.455 mmol Kg^{-1} h^{-1}) had significantly higher ethylene production than the -1-MCP-ethylene-treated ones (0.000 mmol Kg^{-1} h^{-1}). Higher ethylene production by 'Marfona' tubers was also shown when the ethylene-treated tubers (1.011 mmol Kg^{-1} h^{-1}) received the 2nd 24h +1-MCP treatment, than air-treated ones (0.004 mmol Kg^{-1} h^{-1}). Similar results were shown for the same cultivar under the same treatments, but

when tubers had also received the 1st 24h +1-MCP treatment (ethylene-treated: 1.226 mmol Kg^{-1} h^{-1}; air-treated: 0.000 mmol $Kg^{-1}h^{-1}$). Even though the ethylene-treated 'Marfona' tubers which had received both +1-MCP treatments had higher ethylene production rate (1.226 mmol Kg^{-1} h^{-1}) than those that only received the second one (1.011 mmol Kg^{-1} h^{-1}), this was not significant (Table 6.1). For 'Estima', higher ethylene production was shown when the ethylene-treated tubers (0.756 mmol Kg^{-1} h^{-1}) received the 2nd 24h +1-MCP treatment, when compared to air-treated ones (0.070 mmol Kg^{-1} h^{-1}). Opposite results were shown for the same cultivar under the same treatments, but when tubers had also received the 1st 24h +1-MCP treatment (ethylene-treated: 0.221 mmol Kg^{-1} h^{-1}; air-treated: 0.063 mmol Kg^{-1} h^{-1}). The ethylene-treated 'Estima' tubers that had received both +1-MCP treatments had significantly higher ethylene production rate (0.221 mmol Kg^{-1} h^{-1}), than those that only received the second treatment alone (0.756 mmol Kg^{-1} h^{-1}) (Table 6.2).

Respiration rate at intake for 'Marfona' was 0.107 mmol Kg^{-1} h^{-1} and 0.066 mmol Kg^{-1} h^{-1} for 'Estima' (Tables 6.1; 6.2). There was no effect of the 24h -/+1-MCP treatment on the respiration rate of either 'Marfona' or 'Estima' tubers during sampling points 2 (after the 1st -/+1-MCP treatment) and 3 (After the 2nd -/+1-MCP treatment at time of first indication of sprouting) (Tables 6.1; 6.2). At sampling point 4, under the same treatments as described for ethylene production, there were no significant differences between any of the treatments and cultivars (Tables 6.1; 6.2).

Table 6.1 Ethylene production (mmol ethylene Kg^{-1} h^{-1}) and respiration rate (mmol CO_2 Kg^{-1} h^{-1}) of potato cv. Marfona tubers at (1) intake, (2) after the first 1-MCP (1 µL 1-MCP L^{-1}) treatment, (3) after the 2^{nd} 1-MCP treatment (1 µl 1-MCP L^{-1}) (time of first indication of sprouting) and (4) at 30 weeks storage. Values are means (n=3). LSD=0.62 for ethylene and LSD=0.09 for CO_2. (Appendix C, Tables C.2; C.3)

Samplings and Treatments (potato cv. Marfona)				Ethylene (mmol Kg^{-1} h^{-1})	CO_2 (mmol Kg^{-1} h^{-1})
Sampling 1: At intake				0.008	0.107
Sampling 2: After the 1st 1-MCP treatment					
+1-MCP				0.000	0.054
-1-MCP				0.000	0.070
Sampling 3: After the 2nd 1-MCP treatment					
-1-MCP (1st)	Ethylene	+1-MCP (2^{nd})		0.000	0.061
		-1-MCP (2^{nd})		0.000	0.048
	Air	+1-MCP (2^{nd})		0.000	0.026
		-1-MCP(2^{nd})		0.000	0.065
+1-MCP (1st)	Ethylene	+1-MCP(2^{nd})		0.000	0.042
		-1-MCP(2^{nd})		0.000	0.047
	Air	+1-MCP(2^{nd})		0.000	0.041
		-1-MCP(2^{nd})		0.000	0.042
Sampling 4: At 30 weeks storage					
-1-MCP (1st)	Ethylene	+1-MCP (2^{nd})	Ethylene	1.011	0.107
			Air	0.000	0.104
		-1-MCP (2^{nd})	Ethylene	0.954	0.066
			Air	0.518	0.055
	Air	+1-MCP (2^{nd})	Ethylene	0.944	0.093
			Air	0.004	0.170
		-1-MCP (2^{nd})	Ethylene	1.250	0.059
			Air	0.000	0.146
+1-MCP (1st)	Ethylene	+1-MCP (2^{nd})	Ethylene	1.226	0.133
			Air	0.084	0.095
		-1-MCP (2^{nd})	Ethylene	1.152	0.101
			Air	0.000	0.138
	Air	+1-MCP (2^{nd})	Ethylene	1.518	0.044
			Air	0.000	0.078
		-1-MCP (2^{nd})	Ethylene	0.998	0.043
			Air	0.007	0.114

Table 6.2 Ethylene production (mmol ethylene Kg^{-1} h^{-1}) and respiration rate (mmol CO_2 Kg^{-1} h^{-1}) of potato cv. Estima tubers at (1) intake, (2) after the first 1-MCP (1 µL1-MCP L^{-1}) treatment, (3) after the 2nd 1-MCP treatment (1 µl 1-MCP L^{-1}) (time of first indication of sprouting) and (4) at 30 weeks storage. Values are means (n=3). LSD=0.4 for ethylene and LSD=0.1 for CO_2 (Appendix C, Tables C.4; C.5).

Samplings and Treatments (potato cv. Estima)				Ethylene (mmol Kg^{-1} h^{-1})	CO_2 (mmol Kg^{-1} h^{-1})
Sampling 1: At intake				0.001	0.066
Sampling 2: After the 1st 1-MCP treatment					
-1-MCP				0.000	0.051
+1-MCP				0.000	0.046
Sampling 3: After the 2nd 1-MCP treatment					
-1-MCP (1st)	Ethylene	+1-MCP (2nd)		0.000	0.030
		-1-MCP (2nd)		0.000	0.035
	Air	+1-MCP (2nd)		0.000	0.036
		-1-MCP (2nd)		0.000	0.035
+1-MCP (1st)	Ethylene	+1-MCP (2nd)		0.000	0.040
		-1-MCP (2nd)		0.000	0.061
	Air	+1-MCP (2nd)		0.000	0.042
		-1-MCP (2nd)		0.000	0.040
Sampling 4: At 30 weeks storage					
-1-MCP (1st)	Ethylene	+1-MCP (2nd)	Ethylene	0.756	0.057
			Air	0.000	0.110
		-1-MCP (2nd)	Ethylene	0.000	0.037
			Air	0.041	0.148
	Air	+1-MCP (2nd)	Ethylene	0.894	0.057
			Air	0.070	0.127
		-1-MCP (2nd)	Ethylene	0.281	0.062
			Air	0.000	0.100
+1-MCP (1st)	Ethylene	+1-MCP (2nd)	Ethylene	0.221	0.114
			Air	0.000	0.055
		-1-MCP (2nd)	Ethylene	0.455	0.048
			Air	0.000	0.106
	Air	+1-MCP (2nd)	Ethylene	1.186	0.051
			Air	0.063	0.077
		-1-MCP (2nd)	Ethylene	0.000	0.050
			Air	0.000	0.286

6.3.2 Non-structural carbohydrate concentration in flesh

Sucrose, glucose and fructose values ranged from 8.02 - 11.34 and 13.53 – 15.73 mg g^{-1} DW at intake for 'Marfona' and 'Estima' respectively (Tables 6.3; 6.4). There were no significant differences between -/+1-MCP treated (Sampling 2; First 1-MCP treatment) 'Marfona' and 'Estima' tubers for any of the sugars measured (Tables 6.3; 6.4). 'Marfona' tubers that were stored in ethylene after the first +1-MCP treatment and then received either +/- 1-MCP (Sampling 3; Table 6.3) had significantly lower sugars concentrations than those that did not receive 1-MCP before storage in ethylene (Table 6.3). Opposite results were shown for potato cv. Estima under the same treatments (Sampling 3; Table 6.4). At sampling 4 (at 30 weeks storage), sucrose, glucose and fructose content was significantly higher in the ethylene-treated than air-treated 'Marfona' tubers that had only received the first 24h -/+1-MCP treatment (Table 6.3). Similar results were shown for 'Estima' potatoes but only for the +1-MCP-treated tubers in all sugars and only for glucose and fructose (Table 6.4). Also, for potato cv. Marfona, sucrose, glucose and fructose content were significantly higher in the -1-MCP-ethylene-treated than the +1-MCP-ethylene-treated. Similar results were shown for the air-treated tubers of the same cultivar under the same treatments (Table 6.3). Similar results were also detected for potato cv. Estima for sucrose, glucose and fructose content under the same treatments in the -1-MCP-ethylene-treated and the +1-MCP-ethylene-treated (Table 6.4).

Table 6.3 Sucrose, glucose and fructose concentrations (mg g^{-1} DW) of potato cv. Marfona tubers at (1) intake, (2) after the first 1-MCP (1 µL 1-MCP L^{-1}) treatment, (3) after the 2nd 1-MCP treatment (1 µl 1-MCP L^{-1}) (time of first indication of sprouting) and (4) at 30 weeks storage. Values are means (n=9). LSD=2.547 (sucrose); 3.590 (glucose) and 8.067 (fructose) (Appendix C, Tables C.6-C8).

Samplings and Treatments (potato cv. Marfona)				Sugars (mg g^{-1} DW)		
				Sucrose	Glucose	Fructose
Sampling 1: At intake				11.34	8.14	8.02
Sampling 2: After the 1st 1-MCP treatment						
-1-MCP				14.05	15.08	13.81
+1-MCP				13.86	13.99	13.42
Sampling 3: After the 2nd 1-MCP treatment						
-1-MCP (1st)	Ethylene	+1-MCP (2nd)		19.67	47.34	49.32
		-1-MCP (2nd)		19.59	48.44	49.70
	Air	+1-MCP (2nd)		17.92	28.88	28.53
		-1-MCP (2nd)		16.77	27.19	27.05
+1-MCP (1st)	Ethylene	+1-MCP (2nd)		15.04	30.52	26.77
		-1-MCP (2nd)		16.39	29.17	25.66
	Air	+1-MCP (2nd)		15.59	28.80	25.97
		-1-MCP (2nd)		15.35	22.51	21.87
Sampling 4: At 30 weeks storage						
-1-MCP (1st)	Ethylene	+1-MCP (2nd)	Ethylene	19.00	89.75	88.02
			Air	13.14	54.20	56.84
		-1-MCP (2nd)	Ethylene	16.72	59.91	58.12
			Air	14.82	57.03	57.83
	Air	+1-MCP (2nd)	Ethylene	10.85	44.66	38.75
			Air	4.94	40.54	36.89
		-1-MCP (2nd)	Ethylene	12.28	56.12	50.83
			Air	4.74	52.27	46.29
+1-MCP (1st)	Ethylene	+1-MCP (2nd)	Ethylene	10.75	46.90	41.16
			Air	4.62	44.19	38.60
		-1-MCP (2nd)	Ethylene	11.74	51.88	43.39
			Air	6.70	50.04	41.46
	Air	+1-MCP (2nd)	Ethylene	10.83	57.73	47.74
			Air	3.33	40.19	25.34
		-1-MCP (2nd)	Ethylene	10.97	57.93	47.89
			Air	5.15	41.99	35.20

Table 6.4 Sucrose, glucose and fructose concentrations (mg g^{-1} DW) of potato cv. Estima tubers at (1) intake, (2) after the first 1-MCP (1 µL 1-MCP L^{-1}) treatment, (3) after the 2nd 1-MCP treatment (1 µl 1-MCP L^{-1}) (time of first indication of sprouting) and (4) at 30 weeks storage. Values are means (n=9). LSD=4.302 (sucrose); 3.509 (glucose) and 6.561 (fructose) (Appendix C, Tables C.9-C11).

Samplings and Treatments (potato cv. Estima)				Sugars (mg g^{-1} DW)		
				Sucrose	Glucose	Fructose
Sampling 1: At intake				15.73	14.49	13.53
Sampling 2: After the 1st 1-MCP treatment						
-1-MCP				15.86	15.72	13.58
+1-MCP				19.26	16.33	13.58
Sampling 3: After the 2nd 1-MCP treatment						
-1-MCP (1st)	Ethylene	+1-MCP (2nd)		9.74	32.26	27.43
		-1-MCP (2nd)		8.81	28.10	21.70
	Air	+1-MCP (2nd)		9.56	26.17	20.54
		-1-MCP (2nd)		8.45	29.45	23.03
+1-MCP (1st)	Ethylene	+1-MCP (2nd)		12.76	40.05	39.65
		-1-MCP (2nd)		14.07	47.68	45.05
	Air	+1-MCP (2nd)		9.32	31.13	26.15
		-1-MCP (2nd)		10.28	29.44	25.27
Sampling 4: At 30 weeks storage						
-1-MCP (1st)	Ethylene	+1-MCP (2nd)	Ethylene	9.26	55.78	44.65
			Air	8.65	51.05	41.07
		-1-MCP (2nd)	Ethylene	9.54	61.33	48.78
			Air	11.18	57.62	42.07
	Air	+1-MCP (2nd)	Ethylene	7.52	40.51	32.75
			Air	9.84	46.21	35.14
		-1-MCP (2nd)	Ethylene	10.44	55.58	45.46
			Air	11.33	50.91	37.96
+1-MCP (1st)	Ethylene	+1-MCP (2nd)	Ethylene	13.35	57.77	53.82
			Air	12.32	49.79	47.91
		-1-MCP (2nd)	Ethylene	13.39	47.45	48.78
			Air	12.96	49.50	47.73
	Air	+1-MCP (2nd)	Ethylene	9.97	54.13	43.45
			Air	7.84	50.18	39.79
		-1-MCP (2nd)	Ethylene	12.51	50.23	43.99
			Air	8.14	43.49	36.81

6.3.3 Sprouting at 30 weeks storage

Sprouting incidence and severity (number and length) was recorded at sampling 4 (at 30 weeks storage) only. Mean number of sprouts at <5mm, 5-10mm and >10mm length was significantly lower in the ethylene-treated (-1-MCP: 13.00; 0.00; 0.00, respectively) compared to air-treated (-1-MCP: 30.00; 11.33; 5.00, respectively) 'Marfona' tubers which had only received the first 24h -/+1-MCP treatment (Table 6.5). Similar results were shown for the +1-MCP-ethylene and air-treated tubers but these were not significant (Table 6.5).

Similar results were shown for 'Estima' potatoes for the mean number of sprouts at <5mm, 5-10mm and >10mm length of the -1-MCP-treated tubers (ethylene-treated: 10.00, 0.00, 0.000 and air-treated: 15.67, 4.67, 4.00 respectively) (Table 6.6). However, for the +1-MCP treated tubers, there were significantly less sprouts only in the ethylene-treated tubers than the air-treated ones at the length of <5mm (ethylene-treated: 5.67; air-treated: 18.67) (Table 6.6). There was a significantly lower mean number of the <5mm sprouts in the ethylene-treated (14.30) tubers of potato cv. Marfona that had received both 1-MCP treatments than observed in the air-treated ones (37.30) (Table 6.5). Similar results were shown for potato cv. Estima under the same treatments (ethylene-treated: 7.33 and air-treated: 15.33) (Table 6.6).

Table 6.5 Sprout length of potato cv. Marfona tubers at 30 weeks storage. Tubers were initially tretated with -/+1-MCP and then stored in ethylene and air, while they received another -/+1-MCP treatment at the time of first indication of sprouting, following a subsequent storage under ethylene and air. Values are means (n=9). LSD ($P_{0.05}$) = 14.58 (<5mm); 6.286 (5-10mm) and 4.581 (>10mm) (Appendix C, Tables C12-C.14).

Treatments				**Sprout length**		
				<5mm	**5-10mm**	**>10mm**
-1-MCP (1st)	Ethylene	+1-MCP (2nd)	Ethylene	19.70	0.00	0.00
			Air	27.70	12.67	3.33
		-1-MCP (2nd)	Ethylene	13.00	0.00	0.00
			Air	38.70	5.33	1.33
	Air	+1-MCP (2nd)	Ethylene	15.70	0.00	0.00
			Air	29.70	2.33	7.00
		-1-MCP (2nd)	Ethylene	20.00	0.00	0.00
			Air	30.00	11.33	5.00
+1-MCP (1st)	Ethylene	+1-MCP (2nd)	Ethylene	14.30	0.00	0.00
			Air	25.00	3.67	3.00
		-1-MCP (2nd)	Ethylene	17.70	0.00	0.00
			Air	26.70	1.67	0.33
	Air	+1-MCP (2nd)	Ethylene	19.70	0.00	0.00
			Air	37.30	12.67	3.33
		-1-MCP (2nd)	Ethylene	10.70	0.00	0.00
			Air	28.00	1.33	2.33

Table 6.6 Sprout length of potato cv. Estima tubers at 30 weeks storage. Tubers were initially tretated with -/+1-MCP and then stored in ethylene and air, while they received another -/+1-MCP treatment at the time of first indication of sprouting, following a subsequent storage under ethylene and air. Values are means (n=9). LSD ($P_{0.05}$) = 6.845 (<5mm); 2.288 (5-10mm) and 0.9567 (>10mm) (Appendic C, Tables C.15-C.17).

Treatments				**Sprout length**		
				<5mm	**5-10mm**	**>10mm**
-1-MCP (1^{st})	Ethylene	+1-MCP (2^{nd})	Ethylene	9.67	0.00	0.00
			Air	17.33	1.67	0.00
		-1-MCP (2^{nd})	Ethylene	10.00	0.00	0.00
			Air	11.33	0.33	0.00
	Air	+1-MCP (2^{nd})	Ethylene	11.00	0.00	0.00
			Air	11.33	8.33	5.00
		-1-MCP (2^{nd})	Ethylene	12.00	0.00	0.00
			Air	15.67	4.67	4.00
+1-MCP (1^{st})	Ethylene	+1-MCP (2^{nd})	Ethylene	7.33	0.00	0.00
			Air	12.67	0.00	0.00
		-1-MCP (2^{nd})	Ethylene	5.67	0.00	0.00
			Air	16.33	0.67	0.00
	Air	+1-MCP (2^{nd})	Ethylene	9.67	0.00	0.00
			Air	15.33	3.33	4.00
		-1-MCP (2^{nd})	Ethylene	10.00	0.00	0.00
			Air	18.67	0.00	0.00

6.3.4 Dry weight

There were no significant differences in dry weight content between the treatments in any of the sampling points for 'Marfona' tubers (Table 6.7). In contrast, there was significantly lower dry weight content in 'Estima' tubers that were continuously stored in ethylene after receiving both 1-MCP treatments (19.65 g DW 100^{-1} FW) than those stored in air at the second storage (21.77 g DW 100^{-1} FW) (Table 6.8).

Table 6.7 Proportion of dry weight (g DW 100 g^{-1} FW) of 'Marfona' tubers at (1) intake, (2) after the first 1-MCP (1 µL 1-MCP L^{-1}) treatment, (3) after the 2nd 1-MCP treatment (1 µl 1-MCP L^{-1}) (time of first indication of sprouting) and (4) at 30 weeks storage. Values are means (n=9). LSD ($P_{0.05}$) = 1.712 (Appendix C, Table C.18)

Samplings and Treatments ('Marfona')				**Dry weight (g DW 100 g^{-1} FW)**
Sampling 1: At intake				18.44
Sampling 2: After the 1st 1-MCP treatment				
-1-MCP				18.39
+1-MCP				18.09
Sampling 3: After the 2nd 1-MCP treatment				
-1-MCP (1st)	Ethylene	+1-MCP (2nd)		18.98
		-1-MCP (2nd)		19.23
	Air	+1-MCP (2nd)		18.57
		-1-MCP (2nd)		19.19
+1-MCP (1st)	Ethylene	+1-MCP (2nd)		18.90
		-1-MCP (2nd)		19.51
	Air	+1-MCP (2nd)		18.42
		-1-MCP (2nd)		18.09
Sampling 4: At 30 weeks storage				
-1-MCP (1st)	Ethylene	+1-MCP (2nd)	Ethylene	17.82
			Air	19.00
		-1-MCP (2nd)	Ethylene	19.15
			Air	19.30
	Air	+1-MCP (2nd)	Ethylene	19.42
			Air	19.03
		-1-MCP (2nd)	Ethylene	18.78
			Air	17.67
+1-MCP (1st)	Ethylene	+1-MCP (2nd)	Ethylene	17.83
			Air	19.21
		-1-MCP (2nd)	Ethylene	20.68
			Air	19.05
	Air	+1-MCP (2nd)	Ethylene	19.90
			Air	18.92
		-1-MCP (2nd)	Ethylene	17.92
			Air	19.03

Table 6.8 Proportion of dry weight (g DW 100 g^{-1} FW) of 'Estima' tubers at (1) intake, (2) after the first 1-MCP (1 µL 1-MCP L^{-1}) treatment, (3) after the 2nd 1-MCP treatment (1 µl 1-MCP L^{-1}) (time of first indication of sprouting) and (4) at 30 weeks storage. Values are means (n=9). LSD ($P_{0.05}$) = 2.015 (Appendix C, Table C.19).

Samplings and Treatments ('Estima')				Dry weight (g DW 100 g^{-1} FW)
Sampling 1: At intake				20.94
Sampling 2: After the 1st 1-MCP treatment				
-1-MCP				20.07
+1-MCP				21.17
Sampling 3: After the 2nd 1-MCP treatment				
-1-MCP (1st)	Ethylene	+1-MCP (2nd)		20.29
		-1-MCP (2nd)		21.69
	Air	+1-MCP (2nd)		21.12
		-1-MCP (2nd)		21.19
+1-MCP (1st)	Ethylene	+1-MCP (2nd)		20.85
		-1-MCP (2nd)		20.01
	Air	+1-MCP (2nd)		20.28
		-1-MCP (2nd)		20.94
Sampling 4: At 30 weeks storage				
-1-MCP (1st)	Ethylene	+1-MCP (2nd)	Ethylene	20.97
			Air	21.61
		-1-MCP (2nd)	Ethylene	21.34
			Air	19.91
	Air	+1-MCP (2nd)	Ethylene	21.62
			Air	19.76
		-1-MCP (2nd)	Ethylene	20.51
			Air	20.31
+1-MCP (1st)	Ethylene	+1-MCP (2nd)	Ethylene	19.65
			Air	21.77
		-1-MCP (2nd)	Ethylene	19.67
			Air	21.00
	Air	+1-MCP (2nd)	Ethylene	21.13
			Air	21.11
		-1-MCP (2nd)	Ethylene	20.01
			Air	21.21

6.4 Chemometrics

PLS-DA of sugars in flesh (DW), ethylene concentration (mmol Kg^{-1} h^{-1}), respiration rate (CO_2) (mmol Kg^{-1} h^{-1}) and sprouting at different lengths of potato cvs. Marfona and Estima

PLS-DA that was done on the final (4) sampling point (30 weeks storage) revealed a different grouping where the cvs. (Figure 6.1) and treatments were separated (Figure 6.2). According to the PLS-DA score plot in Figure 6.3, 60% of variance was explained by a combination of PCs 1 and 2. The loading plot (Figure 6.3) showed that all variates analysed are important except for fructose and glucose content in flesh of both cultivars (DW). The most important variates in PC1 are ethylene production rate and length of sprouts at >10mm, while the most important ones in PC2 are respiration rate and sucrose content in flesh (DW). According to Figure 6.1, potato cvs. Marfona and Estima are separated due to differences in respiration rate and sucrose concentration, while the treatments in Figure 6.2 are grouped due to differences in ethylene production rate and length of sprouts >10mm

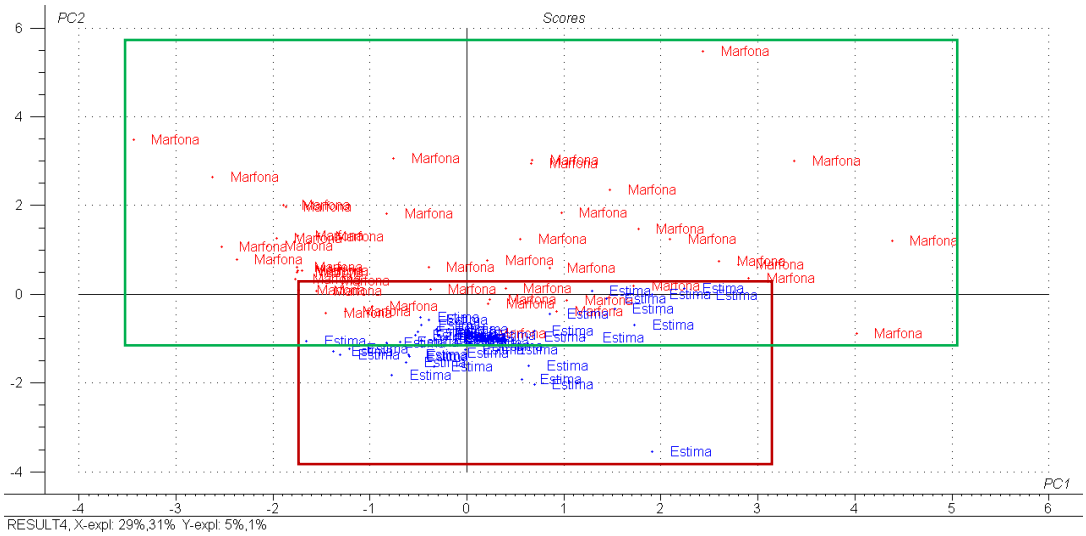

Figure 6.1 PLS-DA score plot for PC1 (29%) versus PC2 (31%) of potato cvs. Marfona and Estima. Grouping of cultivars on the score plot is based on similarities in variation of sucrose, glucose and fructose (DW) in flesh, ethylene concentration (mmol Kg^{-1} h^{-1}), respiration rate (CO_2) (mmol Kg^{-1} h^{-1}) and sprouts at different length measured at sampling point 4 (30 weeks storage). Tubers were transferred to the second ethylene/air storage after the 2nd -/+1-MCP treatment. Y-variability was explained 6% by the model of the first two PCs

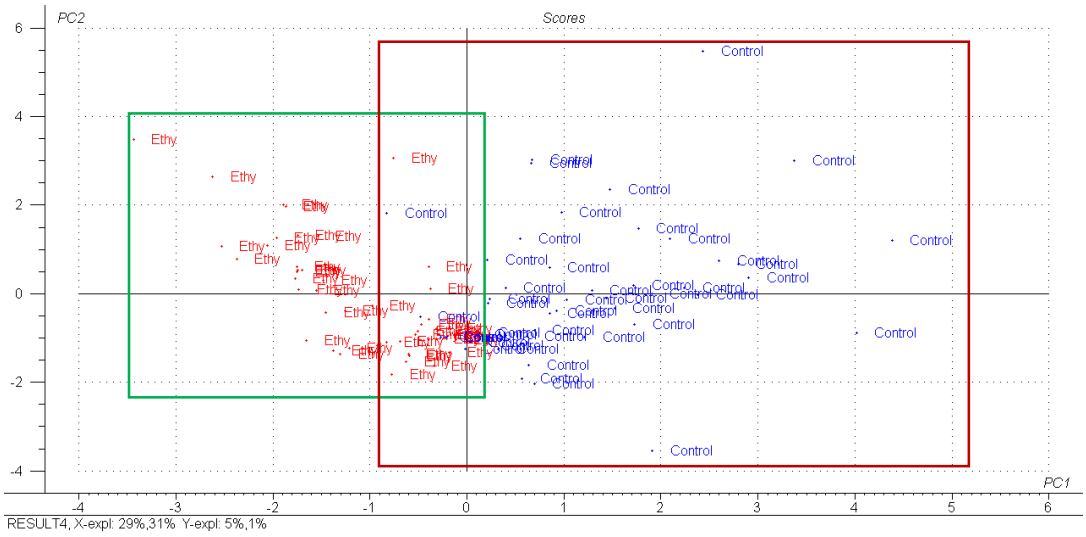

Figure 6.2 PLS-DA score plot for PC1 (29%) versus PC2 (31%) of potato cvs. Marfona and Estima. Grouping of treatments on the score plot is based on similarities in variation of sucrose, glucose and fructose (DW) in flesh, ethylene concentration (mmol Kg^{-1} h^{-1}), respiration rate (CO_2) (mmol Kg^{-1} h^{-1}) and sprouts at different length measured at sampling point 4 (30 weeks storage). Tubers were transferred to the second ethylene/air storage after the 2nd -/+1-MCP treatment. Y-variability was explained 6% by the model of the first two PCs

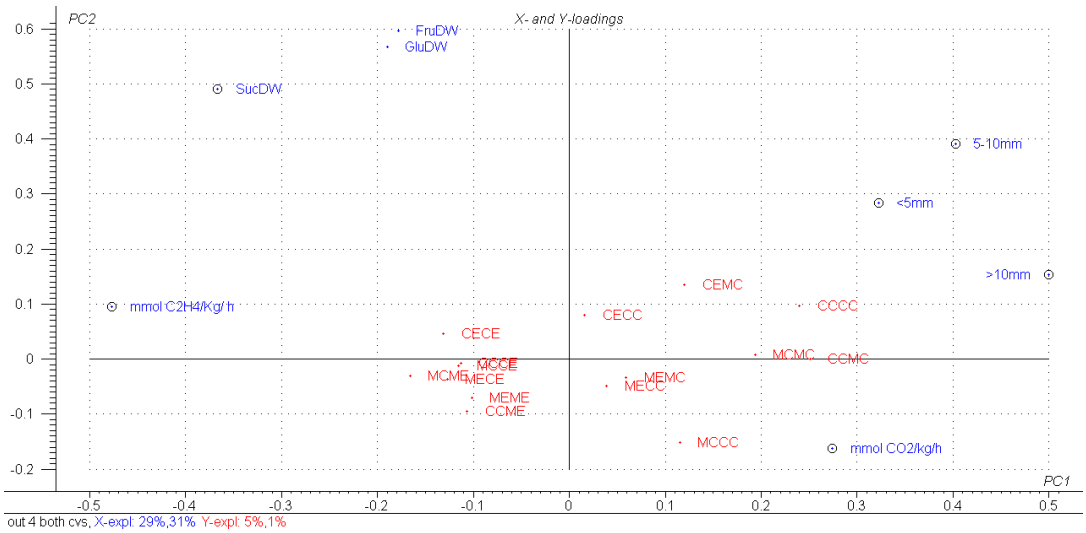

Figure 6.3 PCA loading plot for PC1 (42%) versus PC2 (22%) of potato cv. Estima. Grouping on the loading plot of PCA is based on the similarities in variation of sugars in flesh (DW), ethylene concentration (mmol Kg^{-1} h^{-1}), respiration rate (CO_2) (mmol Kg^{-1} h^{-1}) and sprouts at different length measured at sampling point 4 (30 weeks storage). Tubers were transferred to the second ethylene/air storage after the 2nd -/+ 1-MCP treatment. Y-variability was explained 6% by the model of the first two PCs

6.5 Discussion

According to the results, there was a significantly reduced number of sprouts in the continuously ethylene-treated tubers of potato cv. Marfona which had not received a 24h 1-MCP treatment either before or after storage under ethylene and air, but not in Estima. These results are in agreement with work by Prange *et al.* (1998), where after exposure of potato cv. Russet Burbank' potatoes to 4 μL L^{-1} ethylene for 30 weeks at 9°C they developed significantly smaller sprouts than those stored in air. However, there was no effect of +1-MCP treatment on sprouting of either Marfona or Estima potatoes, since the sprouts that were developed under the +1-MCP treatment were not significantly higher or lower than the -1-MCP treatment. Thus, the 24h 1-MCP application did not block the action of ethylene in terms of sprout suppression when applied before storage of tubers in ethylene. This suggests that the 1-MCP may not bind

to the ethylene receptors as they may not be available. Ethylene then may regulates sprout growth by binding to newly formed ethylene receptors in the sprout eyes.

Results showed that there was no effect of the first +1-MCP treatment on the ethylene production rate of potato cv. Marfona, but there was for potato cv. Estima. Tubers of potato cv. Estima that received a 24h 1-MCP treatment had higher ethylene production rate than the untreated tubers. In contrast, there was an effect of the second +1-MCP treatment (at the time of first indication of sprouting) on the ethylene-treated potato cv. Marfona leading to higher ethylene production rate. On the other hand, there was actually no significant effect of 1-MCP on the respiration rate of tubers of both cvs.

1-MCP is believed to interact with ethylene receptors and prevent ethylene-dependent responses (Sisler and Serek, 1997, 2003), but should be applied before ethylene, so that it is allowed to bind first (Watkins, 2006). 1-MCP has been successful in preventing or delaying the ethylene production increase and internal ethylene concentrations associated with the climacteric ripening stage of different agricultural products (Watkins, 2006). It is also believed that 1-MCP binds permanently to receptors present at the time of application and any reverse effects leading to ethylene sensitivity might be due to appearance of new sites (Blankenship and Dole, 2003). In this study, exposure of tubers to +1-MCP suppressed the action of ethylene in terms of the increase in the respiration rate or ethylene production, but this was cultivar dependent.

According to the results, a 24h 1-MCP treatment resulted in a greater glucose and fructose concentration in the ethylene treated potato cv. Marfona tubers at the time of first indication of sprouting, while opposite results were shown for Estima potatoes at the same time point. However, at the end of the experiment reverse results were shown for potato cv. Marfona under the same treatments, but remained the same for potato cv.

Estima. Using ethylene (10 μL L^{-1}) as a sprout suppressing agent and storage of tubers at 6°C resulted in greater sugar concentration in flesh in a treatment and cultivar-dependent manner, however it seems that a 24h 1-MCP treatment was effective in suppressing the action of ethylene in terms of sugar accumulation of tubers in a cultivar-dependent manner. Previously, Day *et al.* (1978) and Prange *et al.* (1998) observed an increase in sugar concentration in ethylene-treated 'Russet Burbank' tubers. High levels of both fructose and glucose in tubers can lead to an undesirable tissue darkening during frying (Stadler *et al.*, 2002) and indeed ethylene-treated tubers have been generally associated with a darker fry colour (Prange *et al.*, 1998; Prange *et al.*, 2005; Daniels-Lake *et al.*, 2005; Daniels-Lake *et al.*, 2007). The changes in sugar content observed in this study varied according to cultivar. The cultivars were grown at different sites and the length of the growing season varies according to the cultivar. Kyriacou *et al.* (2009) demonstrated that tuber sugar accumulation is affected by crop management and there is a subsequent impact on potato processing quality. Variation in tuber sugar composition at harvest reflects the effect of growing season. In addition, it may be feasible to speculate that spatial differences in sugar content in potato tubers may lead to better understanding of sugar metabolism during storage.

6.6 Conclusions

A 24h 1-MCP treatment did not result in effective sprout suppression in both potato cultivars during storage, when applied before ethylene. This suggests that there may not have been available ethylene receptors, so that the 1-MCP could bind.

Thus, ethylene may regulate sprout growth by binding to newly formed ethylene receptors in the sprout eyes.

CHAPTER SEVEN

EFFECT OF ETHYLENE STORAGE AND 1-MCP APPLICATION ON THE LEVELS OF VARIOUS PHYTOHORMONES IN SELECTED POTATO SAMPLES

7.1 Introduction

Phytohormones are very important regulators in the potato and many scientists have described the effect of them on potato tuber dormancy (Claassens and Vreugdenhill, 2000; Galuszka *et al.*, 2008). Abscisic acid (ABA) and ethylene can inhibit sprouting, whereas gibberellins (GAs) and cytokinins have been reported to promote growth (Sonnewald, 2001). In this study, the effect of ethylene and 1-MCP application during three years of study on the concentration of various phytohormones in 'Saturna' and 'Marfona' potatoes was described. For 'Saturna' potatoes, the effect of ethylene and air storage and the transition between the two regimes in year 2008-2009 on ABA concentration was evaluated. For 'Marfona' potatoes the effect of ethylene and 1-MCP during all three years on the effect of selected phytohormones and their metabolites (viz. ABA, 7'-OH-ABA, PA, ZR, IPA, Z, GA_4) was examined. Briefly, in Year 2008-2009 tubers were collected at harvest and then stored in ethylene and air. In Years 2009-2010 and 2010-2011, tubers were treated with a 24h 1-MCP treatment and then stored in ethylene and air. Detailed selection of samples is presented in Chapter 3, Figure 3.10.

7.2 Materials and Methods

Sample preparation for Chapter 7 is described in Section 3.7 and 3.9.3. The measurement and analysis of different phytohormones in potato are described in Chapter 3: Materials and Methods.

7.3 Results

7.3.1 ABA concentration in 'Saturna' tubers in Year 2008-2009

ABA concentration (ng g^{-1} DW) in tubers of potato cv. Saturna ranged between 14-80 ng g^{-1} DW during storage for 6 months at 6ºC under four ethylene treatments (viz. continuous ethylene, continuous air, transfer from ethylene to air and visa versa). ABA content of ethylene treated tubers of potato cv. Saturna significantly increased between time of first indication of sprouting (30.6 ng g^{-1} DW) and four weeks after that time point (75.9 ng g^{-1} DW) and then significantly decreased thereafter until the end of the experiment (30 weeks) (15.2 ng g^{-1} DW) (Figure 7.1).

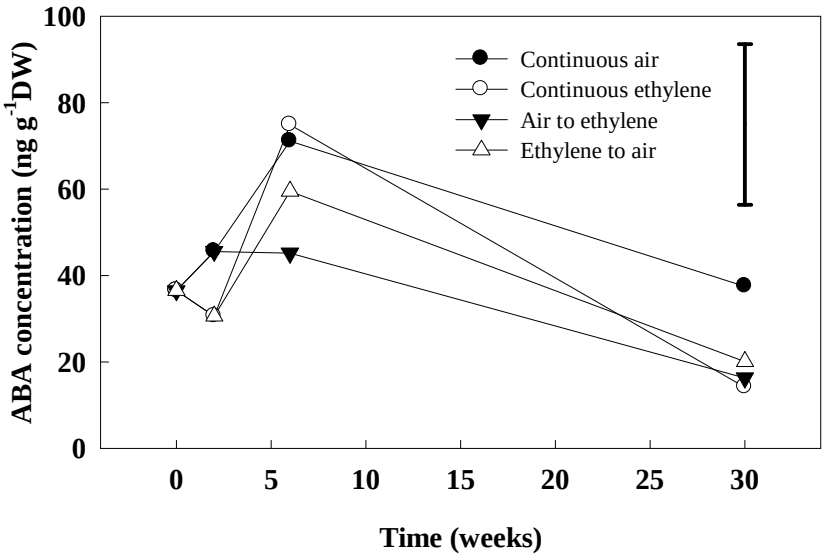

Figure 7.1 ABA concentration (ng g^{-1} DW) in flesh of potato cv. Saturna measured after harvest (day 0), at first indication of sprouting, at four weeks after first indication of sprouting and at the end of the experiment (30 weeks). Keys for graph: (●) continuous air, (○) continuous ethylene, (▼) transfer from air to ethylene and (△) transfer from ethylene to air. LSD bar is shown (Appendix D, Table D.1)

7.3.2 Various phytohormones concentration in ‘Marfona’ tubers during Years 2008-2011

Year 2008-2009

There was no significant effect of ethylene at harvest, at ca. 6 weeks storage in ethylene and air and at time of first indication of sprouting for any of the phytohormones measured (*viz.* ABA, 7’-OH-ABA, PA, ZR, IPA and Z) (Figure 7.2). However, at four weeks after first indication of sprouting there was a significantly lower content of ABA, ZR and IPA in the ethylene-treated compared to air-treated tubers. Similarly, PA content in ethylene-treated tubers was lower than air-treated ones at the same time point, but this was not significant. In contrast, 7’-OH-ABA concentration significantly increased in both ethylene and air-treated tubers at four weeks after first indication of sprouting and then significantly decreased at 30 weeks of storage. Z content in ethylene-treated tubers was significantly higher than air-treated ones at four weeks after first indication of sprouting (Figure 7.2).

Year 2009-2010

There were no significant differences between any of the treatments in ‘Marfona’ samples taken after the 24 h 1-MCP treatment for ABA, PA, GA4, IPA and ZR (Figure 7.3). However, at the same time point, tubers which had received the 1-MCP treatment had significantly higher 7’-OH-ABA content that the ones that did not. At the time of first indication of sprouting, there were no significant differences between treatments for ABA, PA, GA4, IPA and ZR. On the contrary, 7’-OH-ABA content was higher in the air-treated tubers that had received 1-MCP compared to all the

other treatments and was also increased until sampling at six weeks after first indication of sprouting and subsequently decreased until the end of the experiment. In contrast, IPA content in ethylene-treated tubers that had received 1-MCP was at low levels until six weeks after first indication of sprouting, but was significantly increased by the end of the experiment. Similarly, ZR content in the same tubers significantly rose at six weeks after first indication of sprouting and then decreased until the end of the experiment. ABA content in ethylene-treated tubers which had not received 1-MCP was high at the time of six weeks after first indication of sprouting and then significantly decreased until the end of the experiment (Figure 7.3).

Year 2010-2011

There was no significant difference between any of the treatments at harvest and after the 1-MCP treatment for any of the phytohormones (*viz.* ABA, 7'OH-ABA, PA, IPA and ZR) (Figure 7.4). However, ABA and PA content was significantly higher in the ethylene-treated than air-treated tubers at the time of first indication of sprouting, while opposite results were shown for 7'-OH-ABA at the same time point. There were no differences between treatments at the time of first indication of sprouting for either IPA or ZR (Figure 7.4).

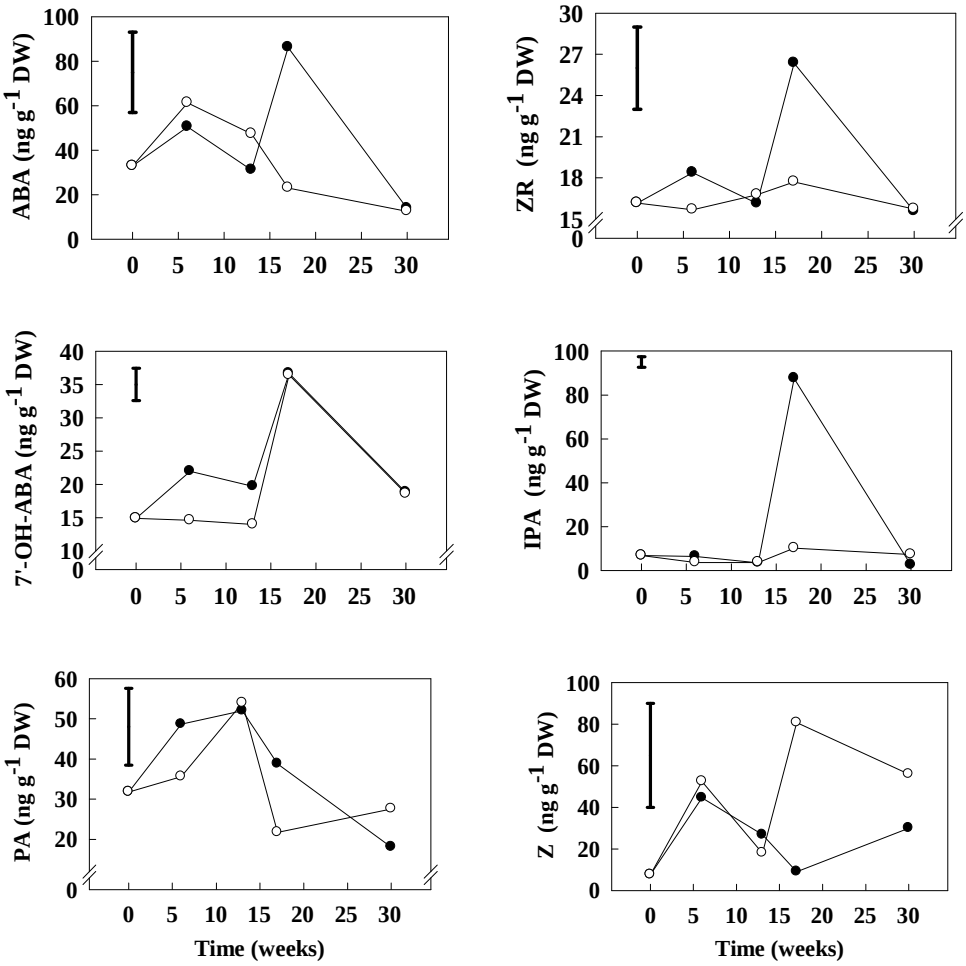

Figure 7.2 ABA, 7'-OH-ABA, PA, ZR, IPA and Z concentration (ng g^{-1} DW) in flesh of 'Marfona' potatoes in year 2008-2009 that were measured after harvest (day 0), at *ca.* 6 weeks after storage in ethylene and air, at first indication of sprouting, at four weeks after first indication of sprouting and at the end of the experiment (30 weeks). Keys for graph: (●) continuous air, (○) continuous ethylene. LSD bar is shown (Appendix D, Tables D.2-D.7).

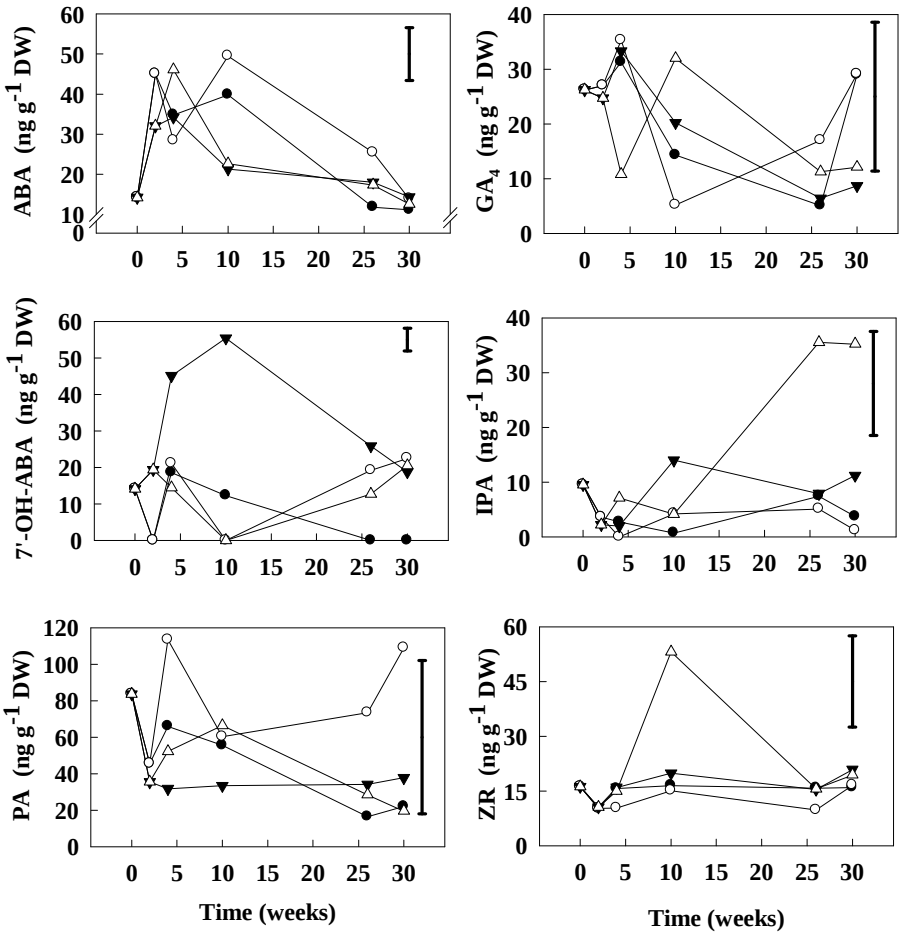

Figure 7.3 ABA, 7'-OH-ABA, PA, GA4, IPA and ZR concentration (ng g^{-1} DW) in flesh of 'Marfona' potatoes in year 2009-2010 that were measured after harvest (day 0), after the 24h 1-MCP treatment, at first indication of sprouting, at six weeks after first indication of sprouting, at 26 weeks storage and at the end of the experiment (30 weeks). Keys for graph: (●) -1-MCP in continuous air, (○) -1-MCP in continuous ethylene, (▼) +1-MCP in continuous air and (△) +1-MCP in continuous ethylene. LSD bar is shown (Appendix D, Tables D.8-D.13).

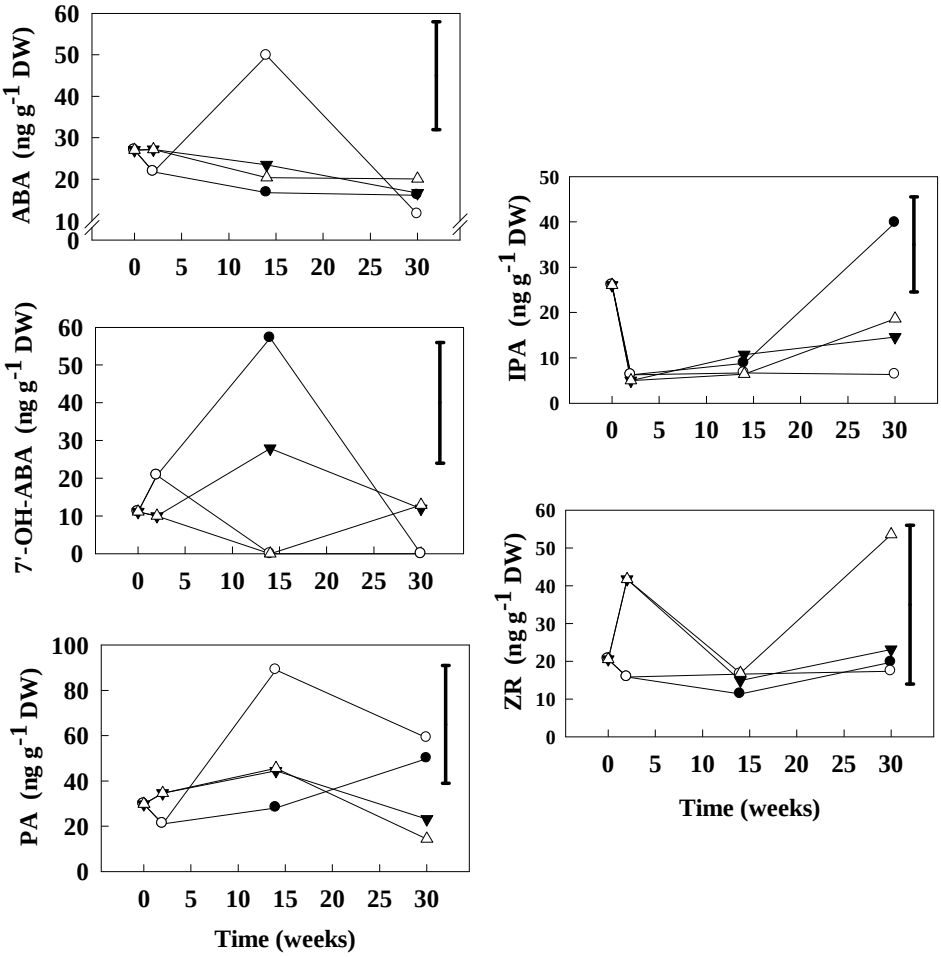

Figure 7.4 ABA, 7'-OH-ABA, PA, IPA and ZR concentration (ng g^{-1} DW) in flesh of 'Marfona' potatoes in year 2010-2011 that were measured after harvest (day 0), after the 24h 1-MCP treatment, at first indication of sprouting and at the end of the experiment (30 weeks). Keys for graph: (●) -1-MCP in continuous air, (○) -1-MCP in continuous ethylene, (▼) +1-MCP in continuous air and (△) +1-MCP in continuous ethylene. LSD bar is shown (Appendix D, Tables D.14-D.18).

7.4 Discussion

According to the results, ABA and its metabolites 7'-OH-ABA and PA and the cytokinins IPA and ZR were measured in 'Marfona' potatoes during three years of study. Additionally, the cytokinin Z and one of the gibberellins GA4 could only be quantified in years 2008-2009 and 2009-2010 respectively for the same variety. Even though the same variety was used during three years of study, the effect of different

environments during cultivation might have played an important role in the number and amount of phytohormones that could be detected in each year.

ABA content decreased during storage in both 'Saturna' and 'Marfona' varieties, however this was treatment-dependent. More specifically, ABA content in ethylene treated 'Saturna' tubers was significantly increased until the time of first indication of sprouting and then subsequently decreased with the onset of dormancy. This is in agreement with Suttle (1995), who demonstrated that ABA content was decreased during storage of potatoes. However, he suggested that there was no threshold point below which sprouting could not occur. ABA content also decreased during storage in ethylene-treated 'Marfona' tubers in all three years of study. The levels of the ABA metabolites (7'-OH-ABA and PA) were decreased during storage; however there was an increase especially in PA in the ethylene treated tubers at the time of first indication of sprouting in all three years. In contrast, 7'-OH-ABA levels were lower under the same treatment. This suggests that ABA was probably metabolised to PA via 7'-OH-ABA (Hirai and Koshimizu, 1983; Schwarz *et al.,* 2003; Galuzsca *et al.,* 2008). According to the authors above, ABA is metabolised to PA and subsequently to DPA; however DPA could not be quantified in the samples tested. According to Suttle (1995), when the potato cv. Russet Burbank tubers were stored at 20°C, ABA was mostly metabolized to DPA, but for tubers stored at 3°C, a transient accumulation of PA and DPA was apparent after only 7 days of storage. 'Marfona' samples were stored at low temperature throughout storage (6°C) and this might explain the fact that DPA could not be quantified in these samples in any of the three years examined.

Both gibberellins and cytokinins have been shown to participate in the termination of tuber dormancy (Hemberg, 1985; Coleman, 1987; Suttle, 2000, Coleman

et al., 2001). More specifically, endogenous levels of IPA and trans-zeatin cytokinins increase during postharvest storage prior to the onset of sprouting (Suttle 1998). Thus, it is thought that cytokinins are responsible for the termination of dormancy in potato tubers. However, differences were shown between treatments and between years during 2008-2011 of study for 'Marfona' potatoes. More specifically, in year 2008-2009 there was an increase for IPA and ZR in air-treated tubers after the time of first indication of sprouting of tubers, while similar results were detected for IPA in year 2010-2011. For GA4, there were differences between treatments but unfortunately not significant ones, so that a conclusion could be drawn.

7.5 Conclusions

Results showed that there were differences between years on the phytohormone content of potato cv. Marfoma samples that were examined. There was a general trend of ABA decreasing and cytokinine content increasing during storage; however this was treatment dependent. More research is needed in order to fully understand the effect of ethylene and 1-MCP on the phytohormone content in different potato cultivars.

CHAPTER EIGHT

GENERAL DISCUSSION

8.1 Effect of ethylene and 1-MCP on tuber physiology and sprouting

Results in Year 1 showed that all cultivars examined can be divided into different groups according to their response to ethylene in terms of sprouting. Sprouting was inhibited in 'Estima', 'Desiree', 'Fianna', 'Russet Burbank' and 'Sylvana' that received a continuous ethylene application during storage compared with the air-treated tubers. Ethylene application after first indication of sprouting was as effective as continuous ethylene in 'Estima', 'Desiree', 'Fianna', 'Russet Burbank' and 'Sylvana' tubers that also had minimal ('Estima', 'Desiree' and 'Fianna') or no sprouts ('Russet Burbank' and 'Sylvana'). 'Russet Burbank' and 'Sylvana' are considered as relatively long dormant varieties and exceptional sprout inhibition was achieved in them, but not in 'Fianna', which is also a long dormant cultivar. In contrast, 'Estima' and 'Desiree' are medium dormant varieties. This is in agreement with the literature and according to Prange *et al.* (1998), 'Russet Burbank' potatoes that were exposed to 4 μL L^{-1} ethylene for 30 weeks at 9°C developed significantly smaller sprouts that those tubers stored in air. In the present study, complete sprout inhibition was recorded in the ethylene-treated 'Russet Burbank' tubers at 6°C for 30 weeks which is in agreement with Prange *et al.* (1998). Sprouting in 'Maris Piper' and 'Marfona' was not inhibited by any of the transition treatments (transfer from air to ethylene and vice versa). However, significantly lower mean total sprouts were recorded in tubers that received ethylene after first indication of sprouting (*viz.* transfer from air to ethylene) than before (*viz.*

transfer from ethylene to air). Year 1 experiments were repeated in Year 2 in combination with 1-MCP and results showed that in terms of sprouting only 'Marfona' and 'Russet Burbank' potatoes had a similar response to the ethylene treatments in Year 1. In contrasty, there were no significant differences between treatments for 'Estima' and 'Saturna' tubers in Year 1. These results are in agreement with those of Prange *et al.* (1998) on 'Russet Burbank' potatoes that were exposed to 4 μL L^{-1} ethylene for 30 weeks at 9°C and developed significantly smaller sprouts than those stored in air. Comparing Years 1 and 2, 'Saturna' potatoes responded similarly to the treatments, since there were no significant differences between treatments in Year 1 and the -1-MCP treatments of Year 2. Additionally, there was no effect of 1-MCP on sprouting in any treatment either in 'Marfona' or 'Estima' potatoes.

8.2 Effect of ethylene and 1-MCP on tuber respiration rate and ethylene production

Respiration rate and ethylene production was only measured in Years 2 and 3. Results in Year 2 showed that there was an effect of +1-MCP application on 'Marfona' and 'Saturna' potatoes at 6 weeks after first indication of sprouting, leading to higher respiration rate of the tubers in all treatments. Higher ethylene production was also detected in the ethylene-treated than air-treated tubers of the same varieties that received a 24h +1-MCP treatment at the time of first indication of sprouting. Similar results were shown for 'Estima' and 'Russet Burbank' tubers, but after 2 weeks storage in ethylene and in air in both +1-MCP and -1-MCP-treated tubers. These results can be explained by the fact that 1-MCP is believed to interact with ethylene receptors and thereby prevent ethylene-dependent responses (Sisler and Serek, 1997, 2003), but should be

applied before ethylene, so that it is allowed to bind first (Watkins, 2006). 1-MCP has been successful in preventing or delaying the ethylene production increase and internal ethylene concentrations associated with the climacteric ripening stage of different agricultural products (Watkins, 2006). It is also believed that 1-MCP binds permanently to receptors present at the time of application and any reverse effects leading to ethylene sensitivity might be due to appearance of new sites (Blankenship and Dole, 2003). However, in this study, and although potatoes are not climacteric products, exposure of tubers to +1-MCP did not suppress the action of ethylene in terms of the increase in the respiration rate or ethylene production at different stages during storage of potatoes; in contrast, +1-MCP exposure enhanced the increase of both respiration rate and ethylene production, suggesting that there might have been a regeneration of new receptors after the beginning of dormancy break of 'Marfona' and 'Saturna' potatoes, that led to the reversion of the 1-MCP effect. This effect took place at different time points during storage and was cultivar-specific.

8.3 Effect of ethylene and 1-MCP on tuber biochemistry

Using ethylene (10 μL L^{-1}) as a sprout suppressing agent and storage of tubers at 6°C resulted in greater sugar concentration in flesh; however this was treatment and cultivar-dependent. Day *et al.* (1978) and Prange *et al.* (1998) previously observed an increase in sugar concentration in ethylene-treated 'Russet Burbank' tubers. Exogenous ethylene treatment of potato tubers can mimic the effect of cold incubation. Bagnaresi *et al.* (2008) have also shown through heterologous microarray experiments that the early events associated with tuber cold sweetening could be identified and ethylene responsive genes were upregulated as a consequence of cold incubation for 4 days at

4°C. Undesirable tissue darkening during frying is caused by high levels of both fructose and glucose in tubers (Stadler *et al.*, 2002) and indeed ethylene-treated tubers have been generally associated with a darker fry colour (Prange *et al.*, 1998; Prange *et al.*, 2005; Daniels-Lake *et al.*, 2005; Daniels-Lake *et al.*, 2007). The changes in sugar content observed in this study varied according to cultivar. The cultivars were grown at different sites and the length of the growing season varies according to the cultivar. Kyriacou *et al.* (2009) demonstrated that tuber sugar accumulation is affected by crop management and there is a subsequent impact on potato processing quality. Variation in tuber sugar composition at harvest reflects the effect of growing season. Sucrose levels are considered to be a possible factor indicating biotic and abiotic stresses on the crop and tuber chemical maturity (Sowokinos, 1978). Differences between cultivars may be explained by differences in the cropping season, as the cultivars studied belong to different groups (viz. maincrop, early, medium early and second early maincrop). Additionally, the genetic diversity among potato cultivars is well documented (Mondal *et al.*, 2007) and may be responsible for different responses to treatments since all studied varieties were of different parentage (British Potato Variety Database, 2009). It is also possible to speculate that variations in the response of potato tubers to ethylene treatments may be related to morphological differences in the skin of the tubers. Higher peel thickness may act as a barrier to ethylene gas to reach the metabolically active meristem tissue where sprouts are initiated and hence limiting its possible role in inducing sugar changes and sprout suppression. Similar hypotheses were proposed by Chope *et al.* (2007) when assessing the response to the ethylene inhibitor 1-MCP and Downes *et al.* (2010) after postharvest application with ethylene and 1-MCP on onions. Spatial differences in sugar content have already been reported for other horticultural

crops (Abayomi and Terry, 2009; Landahl *et al.*, 2009), and in the particular case of potatoes may be connected to the formation of the skin through starch deposition after conversion from translocated sugars (Pringle *et al.*, 2009). In addition, it may be feasible to speculate that spatial differences in sugar content in potato tubers may lead to better understanding of sugar metabolism during storage.

8.4 Effect of ethylene and 1-MCP on phytohormone content

Differences were shown in the type of phytohormones that could be detected in the samples tested during the three year study. Even though the same variety was used during the period, the effect of different environments during cultivation might have played an important role in the number and amount of phytohormones that could be detected in each year. According to the results, ABA and its metabolites 7'-OH-ABA and PA and the cytokinins IPA and ZR were measured in 'Marfona' potatoes during this study. Additionally, the cytokinin Z and one of the gibberellins GA4 could only be quantified in years 2008-2009 and 2009-2010 respectively for the same variety. ABA content in ethylene treated 'Saturna' tubers was significantly increased until the time of first indication of sprouting and then subsequently decreased with the onset of dormancy. Suttle (1995) demonstrated that ABA content was decreased during storage of potatoes, but stated that there was no threshold point below which sprouting could not occur. The levels of ABA and ABA metabolites (7'-OH-ABA and PA) were decreased during storage; however there was an increase especially in PA in the ethylene treated tubers at the time of first indication of sprouting in all three years. In contrast, 7'-OH-ABA levels were lower under the same treatment. ABA was probably metabolised to PA via 7'-OH-ABA (Hirai and Koshimizu, 1983; Schwarz *et al.*, 2003;

Galuzsca *et al.,* 2008). The authors above have demonstrated that ABA is metabolised to PA and subsequently to DPA; however DPA could not be quantified in the samples tested. According to Suttle (1995), when the potato cv. Russet Burbank tubers were stored at 20°C, ABA was mostly metabolized to DPA, but for tubers stored at 3°C, a transient accumulation of PA and DPA was apparent only after 7 days of storage. 'Marfona' samples were stored at low temperature throughout storage (6°C) during 30 weeks and this might explain the fact that DPA could not be quantified in these samples in any of the three years examined.

Gibberellins and cytokinins have been shown to participate in the termination of tuber dormancy (Hemberg, 1985; Coleman, 1987; Suttle, 2000, Coleman *et al.,* 2001). Endogenous levels of IPA and trans-zeatin cytokinins have increased during postharvest storage prior to the onset of sprouting (Suttle 1998). Cytokinins are responsible for the termination of dormancy in potato tuber, but differences were shown between treatments and between years during 2008-2011 of study for 'Marfona' potatoes.

8.5 Project conclusions and future work

Project conclusions are summarized below :

- Storing potatoes under continuous ethylene during storage was as effective in sprout inhibition of tubers as when ethylene was applied at the time of first indication of sprouting and therefore the cost of ethylene usage could be minimized. However, this effect was cultivar dependent.

- A 24h 1-MCP application before storage of tubers in ethylene successfully suppressed the action of ethylene in terms of sugar accumulation in a cultivar dependent manner.

- Both ethylene and 1-MCP had an effect on various phytohormones concentration during three years of study. ABA was found to increase at the time of dormancy break of the tubers, while a combination of ethylene and 1-MCP resulted in the decrease or increase of selected phytohormones during storage

Results of this study showed that the use of ethylene continuously throughout storage may not be essential for all potato cultivars. Thus, using ethylene only at specific timings (e.g. dormany break of some potato cultivars) would reduce cost. Also, in combination with 1-MCP, the effect of sugar accumulation would be suppressed. However, these pracises are cultivar dependent.

Future work includes :

- The examination of the levels of phytohomones during storage at other time points (e.g at the time os transition of the samples between ethylene and air storage).
- Further investigation to understand how ethylene and 1-MCP could elicit the same response during long term storage of tubers of other potato cultivars.

CHAPTER NINE

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APPENDIX A

CHAPTER FOUR

Table A.1 Key-table describing the Genstat structure model used to create the ANOVA tables for Year 2008-2009

Genstat structure: CV * Baseline / (P1 * T1/ (T2*P2))

Outturn	Treatment	Baseline	T1	T2	P1	P2	CV
1	B4Storage	0	0	0	B4 Storage	Before swap	any
2	AIR	1	1	0	AIR P1	Before swap	any
2	ETHY	1	1	0	ETHY P1	Before swap	any
3	AIR	1	2	0	AIR P1	Before swap	any
3	ETHY	1	2	0	ETHY P1	Before swap	any
4	AIR/AIR	1	0	1	AIR P1	AIR P2	any
4	ETHY/ETHY	1	0	1	ETHY P1	ETHY P2	any
4	AIR/ETHY	1	0	1	AIR P1	ETHY P2	any
4	ETHY/AIR	1	0	1	ETHY P1	AIR P2	any
5	AIR/AIR	1	0	2	AIR P1	AIR P2	any
5	ETHY/ETHY	1	0	2	ETHY P1	ETHY P2	any
5	AIR/ETHY	1	0	2	AIR P1	ETHY P2	any
5	ETHY/AIR	1	0	2	ETHY P1	AIR P2	any

Table A.2 ANOVA table for dry weight (g DW 100^{-1} g FW) in flesh for 'King Edward' in experiment 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	2	2.887	1.444	1.02	0.400
Residual	9	12.786	1.421		
Total	11	15.674			

Table A.3 ANOVA table for dry weight (g DW 100^{-1} g FW) in peel for 'King Edward' in experiment 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	2	3.525	1.763	1.10	0.374
Residual	9	14.435	1.604		
Total	11	17.960			

Table A.4 ANOVA table for sucrose concentration (mg g^{-1} DW) in flesh for 'King Edward' potatoes in experiment 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	2	78.224	39.112	4.11	0.054
Residual	9	85.717	9.524		
Total	11	163.940			

Table A.5ANOVA table for glucose concentration (mg g^{-1} DW) in flesh for 'King Edward' potatoes in experiment1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	2	236.87	118.43	10.98	0.004
Residual	9	97.11	10.79		
Total	11	333.98			

Table A.6 ANOVA table for fructose concentration (mg g^{-1} DW) in flesh for 'King Edward' potatoes in experiment1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	2	62.654	31.327	10.55	0.004
Residual	9	26.725	2.969		
Total	11	89.379			

Table A.7 ANOVA table for sucrose concentration in peel (mg g^{-1} DW) for 'King Edward' potatoes in experiment1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	2	203.251	101.625	12.47	0.003
Residual	9	73.368	8.152		
Total	11	276.618			

Table A.8 ANOVA table for glucose concentration in peel (mg g^{-1} DW) for 'King Edward' potatoes in experiment1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	2	140.417	70.208	27.64	<.001
Residual	9	22.865	2.541		
Total	11	163.282			

Table A.9 ANOVA table for fructose concentration in peel (mg g^{-1} DW) for 'King Edward' potatoes in experiment1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	2	71.33	35.66	2.95	0.104
Residual	9	108.91	12.10		
Total	11	180.24			

Table A.10 ANOVA table for firmness (N) for 'King Edward' potatoes in experiment1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	1	5.55	5.55	0.19	0.677
Residual	6	173.62	28.94		
Total	7	179.17			

Table A.11 ANOVA table for apparent elasticity (N mm^{-2}) for 'King Edward' potatoes in experiment1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	1	0.02324	0.02324	0.84	0.396
Residual	6	0.16690	0.02782		
Total	7	0.19014			

Table A.12 ANOVA table for total sprouts of 'King Edward' potatoes in experiment1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	1	162.00	162.00	15.31	0.008
Residual	6	63.50	10.58		
Total	7	225.50			

Table A.13 ANOVA table for sprout length at < 5mm of 'King Edward' potatoes in experiment1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	1	2916.7	2916.7	23.44	0.003
Residual	6	746.6	124.4		
Total	7	3663.3			

Table A.14 ANOVA table for sprout length at 5-10 mm of 'King Edward' potatoes in experiment1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	1	1620.65	1620.65	47.91	<.001
Residual	6	202.95	33.82		
Total	7	1823.60			

Table A.15 ANOVA table for sprout length at > 10 mm of 'King Edward' potatoes in experiment1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1.P2	1	189.0	189.0	1.48	0.269
Residual	6	763.9	127.3		
Total	7	952.9			

Table A.16 ANOVA table for dry weight (g DW 100^{-1} g FW) in flesh for 'Maris Piper', 'Saturna' and 'Mayan Gold' potatoes in experiment 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	2	722.902	361.451	75.45	<.001
BASELINE	1	1.864	1.864	0.39	0.534
CV.BASELINE	2	19.436	9.718	2.03	0.137
BASELINE.P1	1	4.104	4.104	0.86	0.357
BASELINE.T1	1	8.694	8.694	1.81	0.181
CV.BASELINE.P1	2	5.260	2.630	0.55	0.579
CV.BASELINE.T1	2	15.408	7.704	1.61	0.205
BASELINE.P1.T1	1	2.642	2.642	0.55	0.459
BASELINE.T1.T2	1	10.443	10.443	2.18	0.143
BASELINE.T1.P2	1	2.286	2.286	0.48	0.491
CV.BASELINE.P1.T1	2	10.141	5.071	1.06	0.351
CV.BASELINE.T1.T2	2	4.053	2.026	0.42	0.656
BASELINE.P1.T1.T2	1	1.504	1.504	0.31	0.577
CV.BASELINE.T1.P2	2	0.066	0.033	0.01	0.993
BASELINE.P1.T1.P2	1	4.182	4.182	0.87	0.352
BASELINE.T1.T2.P2	1	18.834	18.834	3.93	0.050
CV.BASELINE.P1.T1.T2	2	19.163	9.581	2.00	0.141
CV.BASELINE.P1.T1.P2	2	1.986	0.993	0.21	0.813
CV.BASELINE.T1.T2.P2	2	5.129	2.565	0.54	0.587
BASELINE.P1.T1.T2.P2	1	0.262	0.262	0.05	0.816
CV.BASELINE.P1.T1.T2.P2	2	3.193	1.596	0.33	0.717
Residual	99	474.262	4.791		
Total	131	1335.813			

Table A.17 ANOVA table for dry weight (g DW 100^{-1} g FW) in peel for 'Maris Piper', 'Saturna' and 'Mayan Gold' potatoes in experiment 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	2	194.74	97.37	7.99	<.001
BASELINE	1	0.01	0.01	0.00	0.979
CV.BASELINE	2	19.19	9.59	0.79	0.458
BASELINE.P1	1	6.49	6.49	0.53	0.467
BASELINE.T1	1	19.48	19.48	1.60	0.209
CV.BASELINE.P1	2	5.31	2.66	0.22	0.805
CV.BASELINE.T1	2	32.21	16.10	1.32	0.271
BASELINE.P1.T1	1	1.35	1.35	0.11	0.740
BASELINE.T1.T2	1	4.90	4.90	0.40	0.527
BASELINE.T1.P2	1	10.86	10.86	0.89	0.347
CV.BASELINE.P1.T1	2	1.44	0.72	0.06	0.942
CV.BASELINE.T1.T2	2	138.77	69.38	5.69	0.005
BASELINE.P1.T1.T2	1	0.15	0.15	0.01	0.913
CV.BASELINE.T1.P2	2	18.09	9.05	0.74	0.479
BASELINE.P1.T1.P2	1	1.26	1.26	0.10	0.748
BASELINE.T1.T2.P2	1	5.73	5.73	0.47	0.495
CV.BASELINE.P1.T1.T2	2	30.95	15.48	1.27	0.285
CV.BASELINE.P1.T1.P2	2	30.64	15.32	1.26	0.289
CV.BASELINE.T1.T2.P2	2	2.27	1.14	0.09	0.911
BASELINE.P1.T1.T2.P2	1	1.63	1.63	0.13	0.716
CV.BASELINE.P1.T1.T2.P2	2	14.04	7.02	0.58	0.564
Residual	99	1206.24	12.18		
Total	131	1745.75			

Table A.18 ANOVA table for sucrose concentration (mg g^{-1} DW) in flesh of 'Maris Piper', 'Saturna' and 'Mayan Gold' potatoes in experiment 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	2	1493.09	746.54	53.79	<.001
BASELINE	1	194.35	194.35	14.00	<.001
CV.BASELINE	2	99.61	49.80	3.59	0.031
BASELINE.P1	1	463.87	463.87	33.42	<.001
BASELINE.T1	1	340.46	340.46	24.53	<.001
CV.BASELINE.P1	2	334.57	167.28	12.05	<.001
CV.BASELINE.T1	2	449.50	224.75	16.19	<.001
BASELINE.P1.T1	1	743.08	743.08	53.54	<.001
BASELINE.T1.T2	1	10.00	10.00	0.72	0.398
BASELINE.T1.P2	1	54.06	54.06	3.89	0.051
CV.BASELINE.P1.T1	2	127.23	63.61	4.58	0.012
CV.BASELINE.T1.T2	2	157.15	78.58	5.66	0.005
BASELINE.P1.T1.T2	1	16.42	16.42	1.18	0.279
CV.BASELINE.T1.P2	2	49.50	24.75	1.78	0.173
BASELINE.P1.T1.P2	1	11.68	11.68	0.84	0.361
BASELINE.T1.T2.P2	1	43.99	43.99	3.17	0.078
CV.BASELINE.P1.T1.T2	2	130.73	65.36	4.71	0.011
CV.BASELINE.P1.T1.P2	2	29.58	14.79	1.07	0.348
CV.BASELINE.T1.T2.P2	2	36.75	18.38	1.32	0.271
BASELINE.P1.T1.T2.P2	1	3.80	3.80	0.27	0.602
CV.BASELINE.P1.T1.T2.P2	2	46.51	23.26	1.68	0.192
Residual	99	1374.11	13.88		
Total	131	6210.04			

Table A.19 ANOVA table for glucose concentration (mg g^{-1} DW) in flesh of 'Maris Piper', 'Saturna' and 'Mayan Gold' potatoes in experiment 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	2	609.88	304.94	18.83	<.001
BASELINE	1	506.90	506.90	31.30	<.001
CV.BASELINE	2	26.03	13.01	0.80	0.451
BASELINE.P1	1	121.41	121.41	7.50	0.007
BASELINE.T1	1	264.51	264.51	16.33	<.001
CV.BASELINE.P1	2	83.37	41.68	2.57	0.081
CV.BASELINE.T1	2	63.07	31.54	1.95	0.148
BASELINE.P1.T1	1	3.44	3.44	0.21	0.646
BASELINE.T1.T2	1	209.16	209.16	12.92	<.001
BASELINE.T1.P2	1	133.50	133.50	8.24	0.005
CV.BASELINE.P1.T1	2	71.14	35.57	2.20	0.117
CV.BASELINE.T1.T2	2	138.27	69.14	4.27	0.017
BASELINE.P1.T1.T2	1	41.49	41.49	2.56	0.113
CV.BASELINE.T1.P2	2	24.81	12.41	0.77	0.468
BASELINE.P1.T1.P2	1	0.59	0.59	0.04	0.849
BASELINE.T1.T2.P2	1	16.37	16.37	1.01	0.317
CV.BASELINE.P1.T1.T2	2	69.03	34.51	2.13	0.124
CV.BASELINE.P1.T1.P2	2	193.01	96.50	5.96	0.004
CV.BASELINE.T1.T2.P2	2	5.55	2.77	0.17	0.843
BASELINE.P1.T1.T2.P2	1	1.16	1.16	0.07	0.790
CV.BASELINE.P1.T1.T2.P2	2	73.76	36.88	2.28	0.108
Residual	99	1603.26	16.19		
Total	131	4259.71			

Table A.20 ANOVA table for fructose concentration (mg g^{-1} DW) in flesh of 'Maris Piper', 'Saturna' and 'Mayan Gold' potatoes in experiment 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	2	1397.73	6 98.86	44.21	<.001
BASELINE	1	313.66	313.66	19.84	<.001
CV.BASELINE	2	149.49	74.75	4.73	0.011
BASELINE.P1	1	149.15	149.15	9.44	0.003
BASELINE.T1	1	78.42	78.42	4.96	0.028
CV.BASELINE.P1	2	68.24	34.12	2.16	0.121
CV.BASELINE.T1	2	201.98	100.99	6.39	0.002
BASELINE.P1.T1	1	1.09	1.09	0.07	0.794
BASELINE.T1.T2	1	16.73	16.73	1.06	0.306
BASELINE.T1.P2	1	158.64	158.64	10.04	0.002
CV.BASELINE.P1.T1	2	123.28	61.64	3.90	0.023
CV.BASELINE.T1.T2	2	30.60	15.30	0.97	0.383
BASELINE.P1.T1.T2	1	37.72	37.72	2.39	0.126
CV.BASELINE.T1.P2	2	21.32	10.66	0.67	0.512
BASELINE.P1.T1.P2	1	22.91	22.91	1.45	0.232
BASELINE.T1.T2.P2	1	4.89	4.89	0.31	0.579
CV.BASELINE.P1.T1.T2	2	42.06	21.03	1.33	0.269
CV.BASELINE.P1.T1.P2	2	242.36	121.18	7.67	<.001
CV.BASELINE.T1.T2.P2	2	3.21	1.60	0.10	0.904
BASELINE.P1.T1.T2.P2	1	2.35	2.35	0.15	0.701
CV.BASELINE.P1.T1.T2.P2	2	27.23	13.62	0.86	0.426
Residual	99	1564.93	15.81		
Total	131	4657.99			

Table A.21 ANOVA table for sucrose concentration in peel (mg g^{-1} DW) of 'Maris Piper', 'Saturna' and 'Mayan Gold' potatoes in experiment 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	2	476.59	238.29	11.03	<.001
BASELINE	1	29.73	29.73	1.38	0.244
CV.BASELINE	2	62.53	31.27	1.45	0.240
BASELINE.P1	1	55.79	55.79	2.58	0.111
BASELINE.T1	1	2.19	2.19	0.10	0.751
CV.BASELINE.P1	2	105.53	52.77	2.44	0.092
CV.BASELINE.T1	2	8.86	4.43	0.21	0.815
BASELINE.P1.T1	1	325.94	325.94	15.09	<.001
BASELINE.T1.T2	1	0.33	0.33	0.02	0.902
BASELINE.T1.P2	1	0.02	0.02	0.00	0.978
CV.BASELINE.P1.T1	2	35.38	17.69	0.82	0.444
CV.BASELINE.T1.T2	2	347.49	173.75	8.04	<.001
BASELINE.P1.T1.T2	1	4.21	4.21	0.19	0.660
CV.BASELINE.T1.P2	2	0.98	0.49	0.02	0.978
BASELINE.P1.T1.P2	1	45.26	45.26	2.10	0.151
BASELINE.T1.T2.P2	1	284.40	284.40	13.17	<.001
CV.BASELINE.P1.T1.T2	2	21.52	10.76	0.50	0.609
CV.BASELINE.P1.T1.P2	2	49.25	24.63	1.14	0.324
CV.BASELINE.T1.T2.P2	2	44.49	22.25	1.03	0.361
BASELINE.P1.T1.T2.P2	1	1.75	1.75	0.08	0.777
CV.BASELINE.P1.T1.T2.P2	2	24.03	12.02	0.56	0.575
Residual	99	2138.36	21.60		
Total	131	4064.62			

Table A.22 ANOVA table for glucose concentration in peel (mg g^{-1} DW) of 'Maris Piper', 'Saturna' and 'Mayan Gold' potatoes in experiment 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	2	469.18	234.59	22.52	<.001
BASELINE	1	119.24	119.24	11.45	0.001
CV.BASELINE	2	34.61	17.30	1.66	0.195
BASELINE.P1	1	47.37	47.37	4.55	0.035
BASELINE.T1	1	46.58	46.58	4.47	0.037
CV.BASELINE.P1	2	4.54	2.27	0.22	0.804
CV.BASELINE.T1	2	196.67	98.34	9.44	<.001
BASELINE.P1.T1	1	66.53	66.53	6.39	0.013
BASELINE.T1.T2	1	875.62	875.62	84.07	<.001
BASELINE.T1.P2	1	7.63	7.63	0.73	0.394
CV.BASELINE.P1.T1	2	99.42	49.71	4.77	0.010
CV.BASELINE.T1.T2	2	83.95	41.98	4.03	0.021
BASELINE.P1.T1.T2	1	7.05	7.05	0.68	0.413
CV.BASELINE.T1.P2	2	23.43	11.71	1.12	0.329
BASELINE.P1.T1.P2	1	0.01	0.01	0.00	0.978
BASELINE.T1.T2.P2	1	6.45	6.45	0.62	0.433
CV.BASELINE.P1.T1.T2	2	31.16	15.58	1.50	0.229
CV.BASELINE.P1.T1.P2	2	152.68	76.34	7.33	0.001
CV.BASELINE.T1.T2.P2	2	32.82	16.41	1.58	0.212
BASELINE.P1.T1.T2.P2	1	0.69	0.69	0.07	0.797
CV.BASELINE.P1.T1.T2.P2	2	24.23	12.11	1.16	0.317
Residual	99	1031.12	10.42		
Total	131	3360.97			

Table A.23 ANOVA table for fructose concentration in peel (mg g^{-1} DW) of 'Maris Piper', 'Saturna' and 'Mayan Gold' potatoes in experiment 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	2	625.66	312.83	22.58	<.001
BASELINE	1	9.37	9.37	0.68	0.413
CV.BASELINE	2	179.23	89.62	6.47	0.002
BASELINE.P1	1	22.30	22.30	1.61	0.207
BASELINE.T1	1	71.85	71.85	5.19	0.025
CV.BASELINE.P1	2	58.12	29.06	2.10	0.128
CV.BASELINE.T1	2	252.18	126.09	9.10	<.001
BASELINE.P1.T1	1	76.19	76.19	5.50	0.021
BASELINE.T1.T2	1	528.39	528.39	38.14	<.001
BASELINE.T1.P2	1	76.38	76.38	5.51	0.021
CV.BASELINE.P1.T1	2	134.34	67.17	4.85	0.010
CV.BASELINE.T1.T2	2	42.73	21.37	1.54	0.219
BASELINE.P1.T1.T2	1	40.12	40.12	2.90	0.092
CV.BASELINE.T1.P2	2	37.34	18.67	1.35	0.265
BASELINE.P1.T1.P2	1	1.14	1.14	0.08	0.775
BASELINE.T1.T2.P2	1	0.00	0.00	0.00	0.992
CV.BASELINE.P1.T1.T2	2	42.83	21.41	1.55	0.218
CV.BASELINE.P1.T1.P2	2	240.07	120.03	8.67	<.001
CV.BASELINE.T1.T2.P2	2	49.30	24.65	1.78	0.174
BASELINE.P1.T1.T2.P2	1	1.70	1.70	0.12	0.727
CV.BASELINE.P1.T1.T2.P2	2	35.36	17.68	1.28	0.284
Residual	99	1371.40	13.85		
Total	131	3896.01			

Table A.24 ANOVA table for firmness (N) for 'Maris Piper', 'Saturna' and 'Mayan Gold' at 30 weeks storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	2	2331.32	1165.66	31.02	<.001
P1	1	1.68	1.68	0.04	0.833
P2	1	855.95	855.95	22.78	<.001
CV.P1	2	104.82	52.41	1.39	0.252
CV.P2	2	252.09	126.04	3.35	0.038
P1.P2	1	291.61	291.61	7.76	0.006
CV.P1.P2	2	159.45	79.72	2.12	0.124
Residual	132	4960.80	37.58		
Total	143	8957.71			

Table A.25 ANOVA table for apparent elasticity (N mm^{-2}) for 'Maris Piper', 'Saturna' and 'Mayan Gold' at 30 weeks storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	2	77.757	38.879	20.74	<.001
P1	1	5.266	5.266	2.81	0.096
P2	1	60.547	60.547	32.30	<.001
CV.P1	2	5.883	2.941	1.57	0.212
CV.P2	2	1.257	0.629	0.34	0.716
P1.P2	1	61.949	61.949	33.04	<.001
CV.P1.P2	2	9.214	4.607	2.46	0.090
Residual	132	247.473	1.875		
Total	143	469.347			

Table A.26 ANOVA table for total sprouts for ‘Maris Piper’ and ‘Saturna’ potatoes at 30 weeks storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	1	3100.78	3100.78	48.36	<.001
P1	1	101.53	101.53	1.58	0.220
P2	1	1212.78	1212.78	18.92	<.001
CV.P1	1	1.53	1.53	0.02	0.878
CV.P2	1	639.03	639.03	9.97	0.004
P1.P2	1	2.53	2.53	0.04	0.844
CV.P1.P2	1	0.78	0.78	0.01	0.913
Residual	24	1538.75	64.11		
Total	31	6597.72			

Table A.27 ANOVA table for sprout length < 5mm for ‘Maris Piper’ and ‘Saturna’ potatoes at 30 weeks storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	1	423.4	423.4	0.67	0.421
P1	1	1534.6	1534.6	2.43	0.132
P2	1	3679.5	3679.5	5.82	0.024
CV.P1	1	8.8	8.8	0.01	0.907
CV.P2	1	343.2	343.2	0.54	0.468
P1.P2	1	796.0	796.0	1.26	0.273
CV.P1.P2	1	25.8	25.8	0.04	0.842
Residual	24	15169.4	632.1		
Total	31	21980.7			

Table A.28 ANOVA table for sprout length 5-10 mm for ‘Maris Piper’ and ‘Saturna’ potatoes at 30 weeks storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	1	143.7	143.7	0.31	0.584
P1	1	412.0	412.0	0.88	0.357
P2	1	1036.7	1036.7	2.22	0.149
CV.P1	1	133.5	133.5	0.29	0.598
CV.P2	1	307.5	307.5	0.66	0.425
P1.P2	1	1559.3	1559.3	3.34	0.080
CV.P1.P2	1	452.7	452.7	0.97	0.335
Residual	24	11218.4	467.4		
Total	31	15263.8			

Table A.29 ANOVA table for sprout length >10 mm for ‘Maris Piper’ and ‘Saturna’ potatoes at 30 weeks storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	1	73.5	73.5	0.61	0.443
P1	1	355.5	355.5	2.94	0.099
P2	1	811.0	811.0	6.71	0.016
CV.P1	1	74.2	74.2	0.61	0.441
CV.P2	1	1.0	1.0	0.01	0.928
P1.P2	1	127.4	127.4	1.05	0.315
CV.P1.P2	1	261.9	261.9	2.16	0.154
Residual	24	2903.0	121.0		
Total	31	4607.6			

Table A.30 ANOVA table for total sprouts for 'Mayan Gold' potatoes at 30 weeks storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1	1	0.000	0.000	0.00	1.000
P2	1	4.000	4.000	1.45	0.251
P1.P2	1	9.000	9.000	3.27	0.096
Residual	12	33.000	2.750		
Total	15	46.000			

Table A.31 ANOVA table for small size sprouts for 'Mayan Gold' potatoes at 30 weeks storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1	1	0.562	0.562	0.13	0.728
P2	1	5.062	5.062	1.14	0.306
P1.P2	1	0.562	0.562	0.13	0.728
Residual	12	53.250	4.438		
Total	15	59.438			

Table A.32 ANOVA table for big size sprouts for 'Mayan Gold' potatoes at 30 weeks storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P1	1	0.562	0.562	0.49	0.497
P2	1	0.063	0.063	0.05	0.819
P1.P2	1	5.062	5.062	4.42	0.057
Residual	12	13.750	1.146		
Total	15	19.438			

Table A.33 ANOVA table for dry weight in flesh for 'Marfona', 'Estima', 'Desiree', 'Sylvana', Russet Burbank' and 'Fianna' potatoes in experiment 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	7239.986	1447.997	225.76	<.001
BASELINE	1	1.737	1.737	0.27	0.603
CV.BASELINE	5	17.629	3.526	0.55	0.738
BASELINE.P1	1	8.621	8.621	1.34	0.247
BASELINE.T1	2	28.173	14.086	2.20	0.114
CV.BASELINE.P1	5	21.278	4.256	0.66	0.652
CV.BASELINE.T1	10	73.735	7.374	1.15	0.326
BASELINE.P1.T1	2	5.313	2.656	0.41	0.661
BASELINE.T1.T2	1	10.453	10.453	1.63	0.203
BASELINE.T1.P2	1	3.032	3.032	0.47	0.492
CV.BASELINE.P1.T1	10	30.559	3.056	0.48	0.904
CV.BASELINE.T1.T2	5	57.990	11.598	1.81	0.112
BASELINE.P1.T1.T2	1	0.646	0.646	0.10	0.751
CV.BASELINE.T1.P2	5	24.883	4.977	0.78	0.568
BASELINE.P1.T1.P2	1	3.953	3.953	0.62	0.433
BASELINE.T1.T2.P2	1	0.061	0.061	0.01	0.922
CV.BASELINE.P1.T1.T2	5	101.791	20.358	3.17	0.009
CV.BASELINE.P1.T1.P2	5	41.126	8.225	1.28	0.272
CV.BASELINE.T1.T2.P2	5	19.967	3.993	0.62	0.683
BASELINE.P1.T1.T2.P2	1	1.043	1.043	0.16	0.687
CV.BASELINE.P1.T1.T2.P2	5	10.026	2.005	0.31	0.905
Residual	234	1500.881	6.414		
Total	311	9202.884			

Table A.34 ANOVA table for dry weight in peel for 'Marfona', 'Estima', 'Desiree', 'Sylvana', Russet Burbank' and 'Fianna' potatoes in experiment 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	1552.612	310.522	95.89	<.001
BASELINE	1	5.602	5.602	1.73	0.190
CV.BASELINE	5	30.232	6.046	1.87	0.101
BASELINE.P1	1	0.440	0.440	0.14	0.713
BASELINE.T1	2	53.111	26.556	8.20	<.001
CV.BASELINE.P1	5	34.652	6.930	2.14	0.062
CV.BASELINE.T1	10	87.235	8.723	2.69	0.004
BASELINE.P1.T1	2	4.229	2.114	0.65	0.521
BASELINE.T1.T2	1	3.046	3.046	0.94	0.333
BASELINE.T1.P2	1	0.282	0.282	0.09	0.768
CV.BASELINE.P1.T1	10	45.710	4.571	1.41	0.176
CV.BASELINE.T1.T2	5	89.015	17.803	5.50	<.001
BASELINE.P1.T1.T2	1	6.062	6.062	1.87	0.173
CV.BASELINE.T1.P2	5	44.754	8.951	2.76	0.019
BASELINE.P1.T1.P2	1	4.644	4.644	1.43	0.232
BASELINE.T1.T2.P2	1	5.369	5.369	1.66	0.199
CV.BASELINE.P1.T1.T2	5	66.670	13.334	4.12	0.001
CV.BASELINE.P1.T1.P2	5	34.823	6.965	2.15	0.060
CV.BASELINE.T1.T2.P2	5	36.876	7.375	2.28	0.048
BASELINE.P1.T1.T2.P2	1	0.056	0.056	0.02	0.895
CV.BASELINE.P1.T1.T2.P2	5	32.999	6.600	2.04	0.074
Residual	234	757.772	3.238		
Total	311	2896.193			

Table A.35 ANOVA table for sucrose concentration (mg g^{-1} DW) in flesh of 'Marfona', 'Estima', 'Desiree', 'Sylvana', Russet Burbank' and 'Fianna' potatoes in experiment 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	7208.02	1441.60	75.14	<.001
BASELINE	1	389.19	389.19	20.28	<.001
CV.BASELINE	5	524.27	104.85	5.47	<.001
BASELINE.P1	1	892.28	892.28	46.51	<.001
BASELINE.T1	2	732.95	366.48	19.10	<.001
CV.BASELINE.P1	5	994.32	198.86	10.36	<.001
CV.BASELINE.T1	10	1469.65	146.96	7.66	<.001
BASELINE.P1.T1	2	179.68	89.84	4.68	0.010
BASELINE.T1.T2	1	2165.11	2165.11	112.85	<.001
BASELINE.T1.P2	1	76.95	76.95	4.01	0.046
CV.BASELINE.P1.T1	10	568.12	56.81	2.96	0.002
CV.BASELINE.T1.T2	5	5359.58	1071.92	55.87	<.001
BASELINE.P1.T1.T2	1	83.56	83.56	4.35	0.038
CV.BASELINE.T1.P2	5	133.64	26.73	1.39	0.228
BASELINE.P1.T1.P2	1	6.98	6.98	0.36	0.547
BASELINE.T1.T2.P2	1	22.91	22.91	1.19	0.276
CV.BASELINE.P1.T1.T2	5	2082.96	416.59	21.71	<.001
CV.BASELINE.P1.T1.P2	5	234.95	46.99	2.45	0.035
CV.BASELINE.T1.T2.P2	5	19.43	3.89	0.20	0.961
BASELINE.P1.T1.T2.P2	1	6.92	6.92	0.36	0.549
CV.BASELINE.P1.T1.T2.P2	5	470.28	94.06	4.90	<.001
Residual	234	4489.56	19.19		
Total	311	28111.29			

Table A.36 ANOVA table for glucose concentration (mg g^{-1} DW) in flesh of 'Marfona', 'Estima', 'Desiree', 'Sylvana', Russet Burbank' and 'Fianna' potatoes in experiment 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	52682.38	10536.48	116.23	<.001
BASELINE	1	8145.14	8145.14	89.85	<.001
CV.BASELINE	5	1639.53	327.91	3.62	0.004
BASELINE.P1	1	1474.63	1474.63	16.27	<.001
BASELINE.T1	2	889.91	444.95	4.91	0.008
CV.BASELINE.P1	5	3170.37	634.07	6.99	<.001
CV.BASELINE.T1	10	2309.01	230.90	2.55	0.006
BASELINE.P1.T1	2	2557.83	1278.92	14.11	<.001
BASELINE.T1.T2	1	67.50	67.50	0.74	0.389
BASELINE.T1.P2	1	431.09	431.09	4.76	0.030
CV.BASELINE.P1.T1	10	2208.72	220.87	2.44	0.009
CV.BASELINE.T1.T2	5	3474.57	694.91	7.67	<.001
BASELINE.P1.T1.T2	1	1996.36	1996.36	22.02	<.001
CV.BASELINE.T1.P2	5	268.34	53.67	0.59	0.706
BASELINE.P1.T1.P2	1	204.18	204.18	2.25	0.135
BASELINE.T1.T2.P2	1	31.28	31.28	0.35	0.558
CV.BASELINE.P1.T1.T2	5	3443.78	688.76	7.60	<.001
CV.BASELINE.P1.T1.P2	5	1850.65	370.13	4.08	0.001
CV.BASELINE.T1.T2.P2	5	256.97	51.39	0.57	0.725
BASELINE.P1.T1.T2.P2	1	19.42	19.42	0.21	0.644
CV.BASELINE.P1.T1.T2.P2	5	1864.14	372.83	4.11	0.001
Residual	234	21212.05	90.65		
Total	311	110197.85			

Table A.37 ANOVA table for fructose concentration (mg g^{-1} DW) in flesh of 'Marfona', 'Estima', 'Desiree', 'Sylvana', Russet Burbank' and 'Fianna' potatoes in experiment 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	34120.79	6824.16	165.06	<.001
BASELINE	1	4752.02	4752.02	114.94	<.001
CV.BASELINE	5	1306.66	261.33	6.32	<.001
BASELINE.P1	1	2133.54	2133.54	51.60	<.001
BASELINE.T1	2	235.17	117.58	2.84	0.060
CV.BASELINE.P1	5	1709.63	341.93	8.27	<.001
CV.BASELINE.T1	10	1632.56	163.26	3.95	<.001
BASELINE.P1.T1	2	2020.99	1010.49	24.44	<.001
BASELINE.T1.T2	1	772.93	772.93	18.70	<.001
BASELINE.T1.P2	1	661.38	661.38	16.00	<.001
CV.BASELINE.P1.T1	10	1353.59	135.36	3.27	<.001
CV.BASELINE.T1.T2	5	543.56	108.71	2.63	0.025
BASELINE.P1.T1.T2	1	2103.03	2103.03	50.87	<.001
CV.BASELINE.T1.P2	5	521.09	104.22	2.52	0.030
BASELINE.P1.T1.P2	1	214.33	214.33	5.18	0.024
BASELINE.T1.T2.P2	1	3.40	3.40	0.08	0.774
CV.BASELINE.P1.T1.T2	5	2099.44	419.89	10.16	<.001
CV.BASELINE.P1.T1.P2	5	855.67	171.13	4.14	0.001
CV.BASELINE.T1.T2.P2	5	81.12	16.22	0.39	0.854
BASELINE.P1.T1.T2.P2	1	2.23	2.23	0.05	0.816
CV.BASELINE.P1.T1.T2.P2	5	247.98	49.60	1.20	0.310
Residual	23	49674.42	41.34		
Total	311	67045.53			

Table A.38 ANOVA table for sucrose concentration in peel (mg g^{-1} DW) of 'Marfona', 'Estima', 'Desiree', 'Sylvana', Russet Burbank' and 'Fianna' potatoes in experiment 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	33043.08	6608.62	275.88	<.001
BASELINE	1	2637.56	2637.56	110.11	<.001
CV.BASELINE	5	3753.39	750.68	31.34	<.001
BASELINE.P1	1	488.75	488.75	20.40	<.001
BASELINE.T1	2	479.48	239.74	10.01	<.001
CV.BASELINE.P1	5	660.93	132.19	5.52	<.001
CV.BASELINE.T1	10	1096.29	109.63	4.58	<.001
BASELINE.P1.T1	2	1004.74	502.37	20.97	<.001
BASELINE.T1.T2	1	162.62	162.62	6.79	0.010
BASELINE.T1.P2	1	255.98	255.98	10.69	0.001
CV.BASELINE.P1.T1	10	2785.50	278.55	11.63	<.001
CV.BASELINE.T1.T2	5	2429.68	485.94	20.29	<.001
BASELINE.P1.T1.T2	1	20.56	20.56	0.86	0.355
CV.BASELINE.T1.P2	5	3257.31	651.46	27.20	<.001
BASELINE.P1.T1.P2	1	34.50	34.50	1.44	0.231
BASELINE.T1.T2.P2	1	2.21	2.21	0.09	0.762
CV.BASELINE.P1.T1.T2	5	431.50	86.30	3.60	0.004
CV.BASELINE.P1.T1.P2	5	1400.53	280.11	11.69	<.001
CV.BASELINE.T1.T2.P2	5	245.12	49.02	2.05	0.073
BASELINE.P1.T1.T2.P2	1	36.62	36.62	1.53	0.218
CV.BASELINE.P1.T1.T2.P2	5	1150.82	230.16	9.61	<.001
Residual	234	5605.33	23.95		
Total	311	60982.50			

Table A.39 ANOVA table for glucose concentration in peel (mg g^{-1} DW) of 'Marfona', 'Estima', 'Desiree', 'Sylvana', Russet Burbank' and 'Fianna' potatoes in experiment 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	18169.14	3633.83	102.36	<.001
BASELINE	1	1817.22	1817.22	51.19	<.001
CV.BASELINE	5	561.92	112.38	3.17	0.009
BASELINE.P1	1	150.93	150.93	4.25	0.040
BASELINE.T1	2	70.15	35.08	0.99	0.374
CV.BASELINE.P1	5	1045.83	209.17	5.89	<.001
CV.BASELINE.T1	10	2372.43	237.24	6.68	<.001
BASELINE.P1.T1	2	1604.51	802.25	22.60	<.001
BASELINE.T1.T2	1	828.37	828.37	23.33	<.001
BASELINE.T1.P2	1	319.66	319.66	9.00	0.003
CV.BASELINE.P1.T1	10	1423.22	142.32	4.01	<.001
CV.BASELINE.T1.T2	5	896.96	179.39	5.05	<.001
BASELINE.P1.T1.T2	1	0.76	0.76	0.02	0.884
CV.BASELINE.T1.P2	5	195.21	39.04	1.10	0.361
BASELINE.P1.T1.P2	1	79.70	79.70	2.25	0.135
BASELINE.T1.T2.P2	1	70.20	70.20	1.98	0.161
CV.BASELINE.P1.T1.T2	5	1561.24	312.25	8.80	<.001
CV.BASELINE.P1.T1.P2	5	568.61	113.72	3.20	0.008
CV.BASELINE.T1.T2.P2	5	318.19	63.64	1.79	0.115
BASELINE.P1.T1.T2.P2	1	0.97	0.97	0.03	0.869
CV.BASELINE.P1.T1.T2.P2	5	353.09	70.62	1.99	0.081
Residual	234	8306.97	35.50		
Total	311	40715.27			

Table A.40 ANOVA table for fructose concentration in peel (mg g^{-1} DW) of 'Marfona', 'Estima', 'Desiree', 'Sylvana', Russet Burbank' and 'Fianna' potatoes in experiment 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	17193.47	3438.69	128.58	<.001
BASELINE	1	1449.06	1449.06	54.18	<.001
CV.BASELINE	5	1123.80	224.76	8.40	<.001
BASELINE.P1	1	1188.64	1188.64	44.45	<.001
BASELINE.T1	2	135.80	67.90	2.54	0.081
CV.BASELINE.P1	5	948.55	189.71	7.09	<.001
CV.BASELINE.T1	10	1057.12	105.71	3.95	<.001
BASELINE.P1.T1	2	1762.64	881.32	32.96	<.001
BASELINE.T1.T2	1	1001.94	1001.94	37.47	<.001
BASELINE.T1.P2	1	711.10	711.10	26.59	<.001
CV.BASELINE.P1.T1	10	2228.22	222.82	8.33	<.001
CV.BASELINE.T1.T2	5	307.98	61.60	2.30	0.046
BASELINE.P1.T1.T2	1	265.53	265.53	9.93	0.002
CV.BASELINE.T1.P2	5	1209.10	241.82	9.04	<.001
BASELINE.P1.T1.P2	1	271.73	271.73	10.16	0.002
BASELINE.T1.T2.P2	1	74.62	74.62	2.79	0.096
CV.BASELINE.P1.T1.T2	5	1188.66	237.73	8.89	<.001
CV.BASELINE.P1.T1.P2	5	942.88	188.58	7.05	<.001
CV.BASELINE.T1.T2.P2	5	364.16	72.83	2.72	0.021
BASELINE.P1.T1.T2.P2	1	2.65	2.65	0.10	0.753
CV.BASELINE.P1.T1.T2.P2	5	1079.18	215.84	8.07	<.001
Residual	234	6257.86	26.74		
Total	311	40764.69			

Table A.41 ANOVA table for firmness (N) for 'Marfona', 'Sylvana', 'Russet Burbank' and 'Fianna' potatoes

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	24450.35	4890.07	158.39	<.001
P1	1	39.89	39.89	1.29	0.257
P2	1	0.36	0.36	0.01	0.914
CV.P1	5	869.09	173.82	5.63	<.001
CV.P2	5	111.35	22.27	0.72	0.608
P1.P2	1	53.71	53.71	1.74	0.188
CV.P1.P2	5	412.18	82.44	2.67	0.022
Residual	264	8150.62	30.87		
Total	287	34087.56			

Table A.42 ANOVA table for apparent elasticity (N mm^{-2}) for 'Marfona', 'Sylvana', 'Russet Burbank' and 'Fianna' potatoes

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	207.257	41.451	18.11	<.001
P1	1	0.000	0.000	0.00	0.988
P2	1	8.199	8.199	3.58	0.059
CV.P1	5	31.540	6.308	2.76	0.019
CV.P2	5	9.419	1.884	0.82	0.534
P1.P2	1	3.158	3.158	1.38	0.241
CV.P1.P2	5	126.491	25.298	11.05	<.001
Residual	264	604.223	2.289		
Total	287	990.287			

Table A.43 ANOVA table for firmness (N) for 'Desiree', 'Estima', 'Fianna', 'Marfona' 'Russet Burbank' and 'Sylvana' at 30 weeks storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	24450.35	4890.07	158.39	<.001
P1	1	39.89	39.89	1.29	0.257
P2	1	0.36	0.36	0.01	0.914
CV.P1	5	869.09	173.82	5.63	<.001
CV.P2	5	111.35	22.27	0.72	0.608
P1.P2	1	53.71	53.71	1.74	0.188
CV.P1.P2	5	412.18	82.44	2.67	0.022
Residual	264	8150.62	30.87		
Total	287	34087.56			

Table A.44 ANOVA table for apparent elasticity (N mm^{-2}) for 'Desiree', 'Estima', 'Fianna', 'Marfona' 'Russet Burbank' and 'Sylvana' at 30 weeks storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	207.257	41.451	18.11	<.001
P1	1	0.000	0.000	0.00	0.988
P2	1	8.199	8.199	3.58	0.059
CV.P1	5	31.540	6.308	2.76	0.019
CV.P2	5	9.419	1.884	0.82	0.534
P1.P2	1	3.158	3.158	1.38	0.241
CV.P1.P2	5	126.491	25.298	11.05	<.001
Residual	264	604.223	2.289		
Total	287	990.287			

Table A.45 ANOVA table for sprout length < 5mm for 'Desiree', 'Estima', 'Fianna', 'Marfona' 'Russet Burbank' and 'Sylvana' at 30 weeks storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	35492.4	7098.5	27.38	<.001
P1	1	1609.0	1609.0	6.21	0.015
P2	1	3351.8	3351.8	12.93	<.001
CV.P1	5	1160.7	232.1	0.90	0.489
CV.P2	5	61733.1	12346.6	47.63	<.001
P1.P2	1	12.0	12.0	0.05	0.830
CV.P1.P2	5	4145.2	829.0	3.20	0.012
Residual	72	18663.2	259.2		
Total	95	126167.4			

Table A.46 ANOVA table for sprout length 5-10 mm for 'Desiree', 'Estima', 'Fianna', 'Marfona' 'Russet Burbank' and 'Sylvana' at 30 weeks storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	10606.56	2121.31	22.12	<.001
P1	1	148.60	148.60	1.55	0.217
P2	1	2955.41	2955.41	30.81	<.001
CV.P1	5	1470.39	294.08	3.07	0.014
CV.P2	5	487.40	97.48	1.02	0.414
P1.P2	1	16.36	16.36	0.17	0.681
CV.P1.P2	5	1701.47	340.29	3.55	0.006
Residual	72	6905.43	95.91		
Total	95	24291.62			

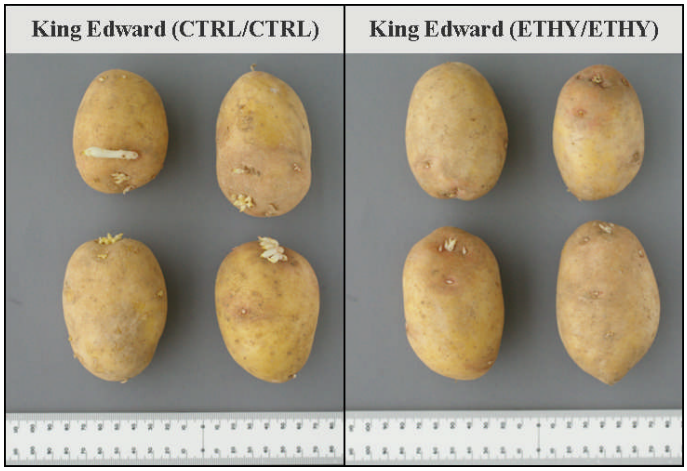
Table A.47 ANOVA table for sprout length >10 mm for ‘Desiree’, ‘Estima’, ‘Fianna’, ‘Marfona’ ‘Russet Burbank’ and ‘Sylvana’ at 30 weeks storage

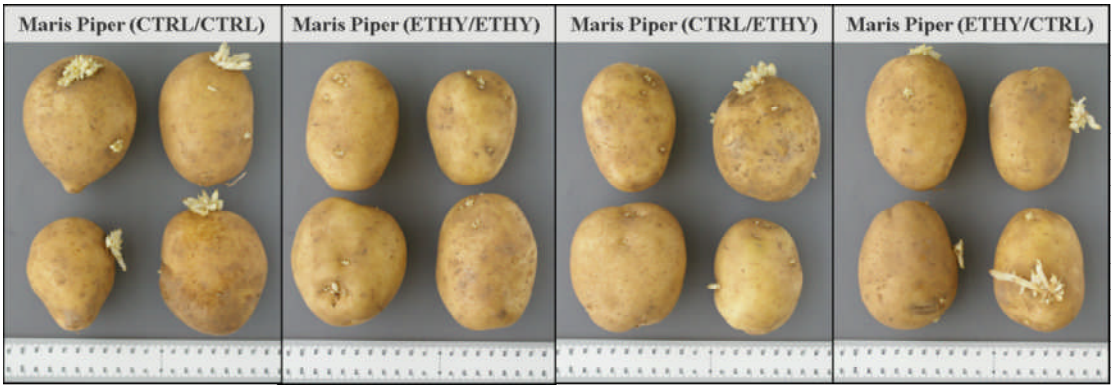
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	2665.47	533.09	5.70	<.001
P1	1	313.86	313.86	3.36	0.071
P2	1	3751.23	3751.23	40.13	<.001
CV.P1	5	412.23	82.45	0.88	0.498
CV.P2	5	2665.47	533.09	5.70	<.001
P1.P2	1	313.86	313.86	3.36	0.071
CV.P1.P2	5	412.23	82.45	0.88	0.498
Residual	72	6730.16	93.47		
Total	95	17264.52			

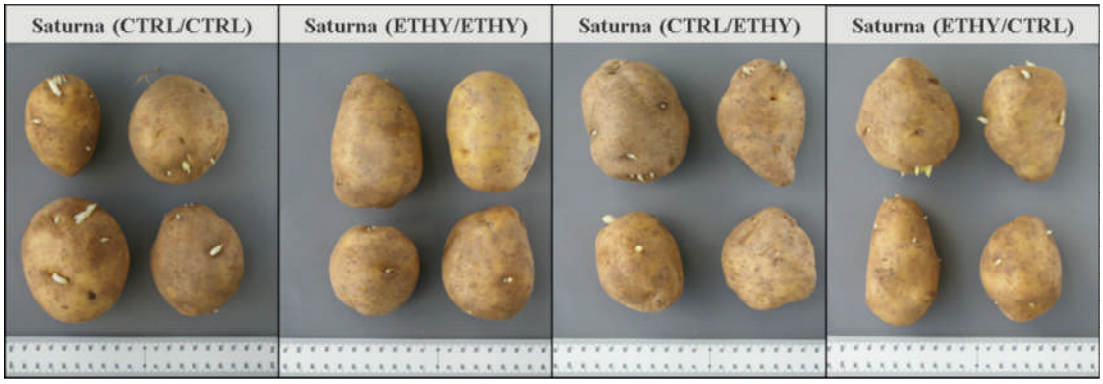
Table A.48 ANOVA table for total sprouts for ‘Desiree’, ‘Estima’, ‘Fianna’, ‘Marfona’ ‘Russet Burbank’ and ‘Sylvana’ at 30 weeks storage

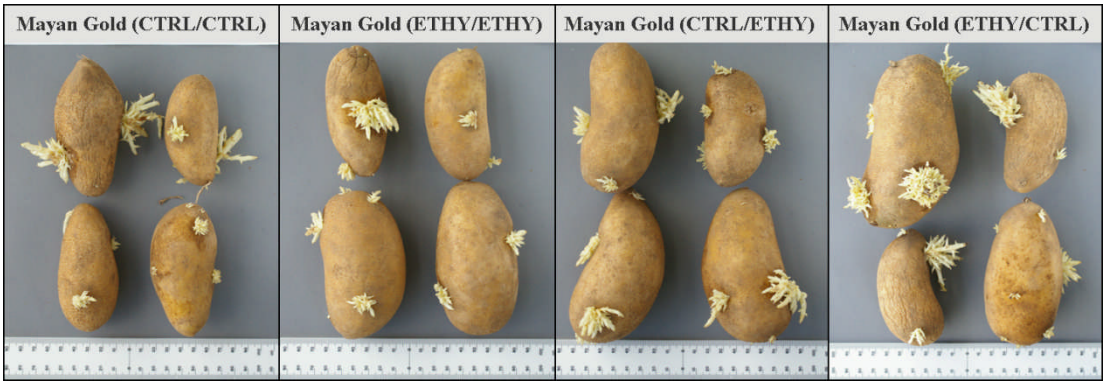
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CV	5	3978.55	795.71	35.67	<.001
P1	1	61.76	61.76	2.77	0.100
P2	1	1881.51	1881.51	84.34	<.001
CV.P1	5	150.55	30.11	1.35	0.254
CV.P2	5	269.55	53.91	2.42	0.044
P1.P2	1	10.01	10.01	0.45	0.505
CV.P1.P2	5	278.80	55.76	2.50	0.038
Residual	72	1606.25	22.31		
Total	95	8236.99			

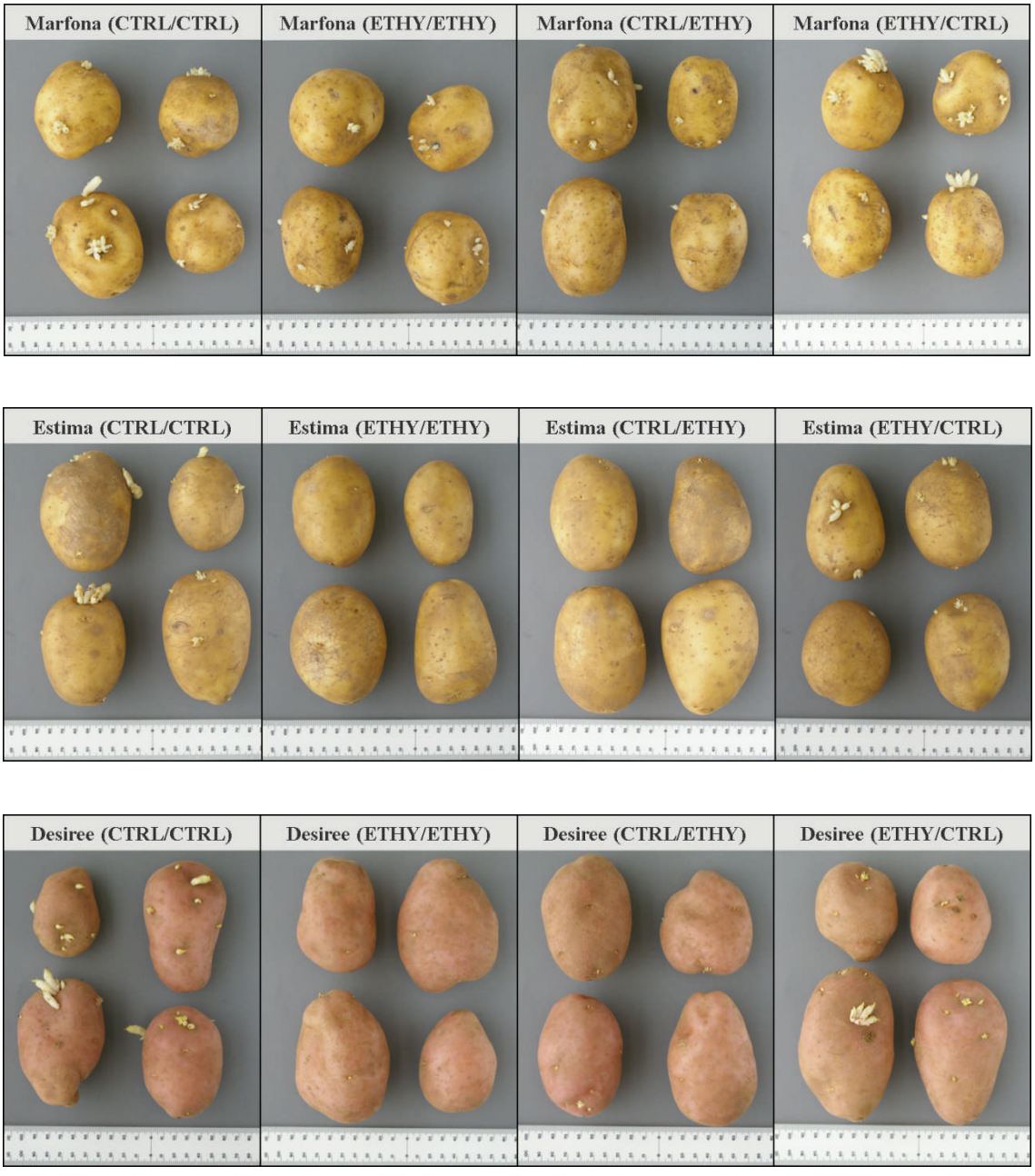
FIGURE A.1. Photos of all ten potato cultivars taken at the end of all experiments at 30 weeks storage.







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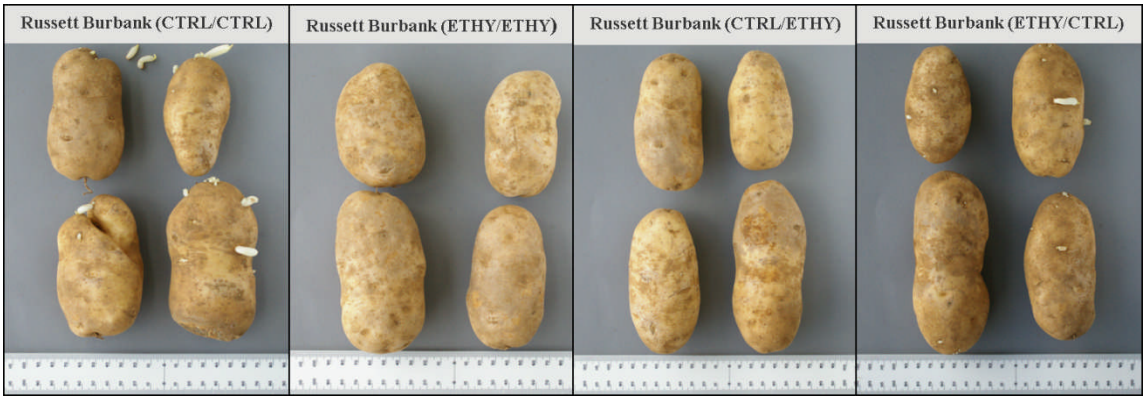
Marfona (ETHY/ETHY)
Marfona (CTRL/ETHY)
Marfona (ETHY/CTRL)
Estima (CTRL/CTRL)
Estima (ETHY/ETHY)
Estima (CTRL/ETHY)
Estima (ETHY/CTRL)
Desiree (CTRL/CTRL)
Desiree (ETHY/ETHY)
Desiree (CTRL/ETHY)
Desiree (ETHY/CTRL)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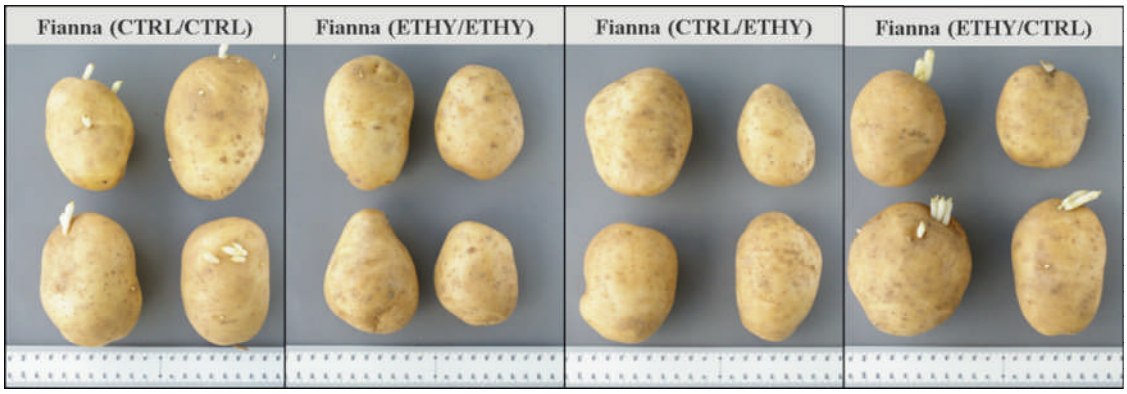
Russett Burbank (ETHY/ETHY)
Russett Burbank (CTRL/ETHY)
Russett Burbank (ETHY/CTRL)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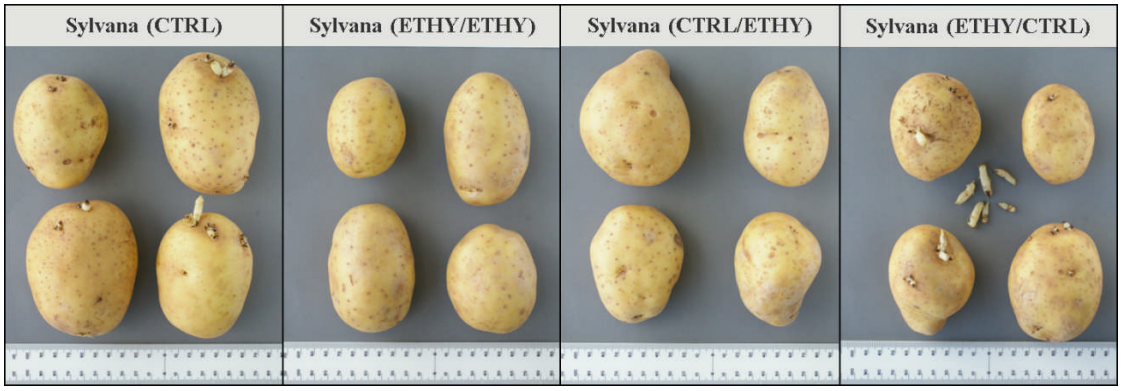
Fianna (ETHY/ETHY)
Fianna (CTRL/ETHY)
Fianna (ETHY/CTRL)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Sylvana (ETHY/ETHY)
Sylvana (CTRL/ETHY)
Sylvana (ETHY/CTRL)

APPENDIX B
CHAPTER FIVE

Table B.1 Key-table describing the Genstat structure model used to create the ANOVA tables for Year 2009-2010 (Experiments 4 & 5)

Genstat Structure: CV*BL1/(Treat*BL_2/(P1*T1/(P3*T2)))

Out	BL1	BL2	BL3	BL4	Treat	P1	P2	P3	T1	T2	CV
1	0	0	0	0	B4 MCP	B4 Storage	B4 2nd MCP	B4 Swap	0	0	any
2	1	0	0	0	Control	B4 Storage	B4 2nd MCP	B4 Swap	0	0	any
2	1	0	0	0	MCP	B4 Storage	B4 2nd MCP	B4 Swap	0	0	any
3	1	1	0	0	Control	CP1	B4 2nd MCP	B4 Swap	1	0	any
3	1	1	0	0	Control	EP1	B4 2nd MCP	B4 Swap	1	0	any
3	1	1	0	0	MCP	CP1	B4 2nd MCP	B4 Swap	1	0	any
3	1	1	0	0	MCP	EP1	B4 2nd MCP	B4 Swap	1	0	any
4	1	1	1	0	Control	CP1	CP2	B4 Swap	2	0	any
4	1	1	1	0	Control	EP1	CP2	B4 Swap	2	0	any
4	1	1	1	0	MCP	CP1	CP2	B4 Swap	2	0	any
4	1	1	1	0	MCP	EP1	CP2	B4 Swap	2	0	any
5	1	1	1	1	Control	CP1	CP2	CP3	2	1	any
5	1	1	1	1	Control	CP1	CP2	EP3	2	1	any
5	1	1	1	1	Control	EP1	CP2	CP3	2	1	any
5	1	1	1	1	Control	EP1	CP2	EP3	2	1	any
5	1	1	1	1	MCP	CP1	CP2	CP3	2	1	any
5	1	1	1	1	MCP	CP1	CP2	EP3	2	1	any
5	1	1	1	1	MCP	EP1	CP2	CP3	2	1	any
5	1	1	1	1	MCP	EP1	CP2	EP3	2	1	any
6	1	1	1	1	Control	CP1	CP2	CP3	2	2	any
6	1	1	1	1	Control	CP1	CP2	EP3	2	2	any
6	1	1	1	1	Control	EP1	CP2	CP3	2	2	any
6	1	1	1	1	Control	EP1	CP2	EP3	2	2	any
6	1	1	1	1	MCP	CP1	CP2	CP3	2	2	any
6	1	1	1	1	MCP	CP1	CP2	EP3	2	2	any
6	1	1	1	1	MCP	EP1	CP2	CP3	2	2	any
6	1	1	1	1	MCP	EP1	CP2	EP3	2	2	any
7	1	1	1	1	Control	CP1	CP2	CP3	2	3	any
7	1	1	1	1	Control	CP1	CP2	EP3	2	3	any
7	1	1	1	1	Control	EP1	CP2	CP3	2	3	any
7	1	1	1	1	Control	EP1	CP2	EP3	2	3	any
7	1	1	1	1	MCP	CP1	CP2	CP3	2	3	any
7	1	1	1	1	MCP	CP1	CP2	EP3	2	3	any
7	1	1	1	1	MCP	EP1	CP2	CP3	2	3	any
7	1	1	1	1	MCP	EP1	CP2	EP3	2	3	any

Table B.2 ANOVA table for respiration rate (mmol Kg^{-1} h^{-1}) for 'Marfona' potatoes in Experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.000222	0.000111	0.02	
REP.*Units* stratum					
BL1	1	0.037087	0.037087	6.95	0.011
BL1.TREAT	1	0.307388	0.307388	57.58	<.001
BL1.BL2	1	0.193628	0.193628	36.27	<.001
BL1.TREAT.BL2	1	0.018710	0.018710	3.50	0.066
BL1.BL2.P1	1	0.002760	0.002760	0.52	0.475
BL1.BL2.T1	1	0.338255	0.338255	63.36	<.001
BL1.TREAT.BL2.P1	1	0.006323	0.006323	1.18	0.281
BL1.TREAT.BL2.T1	1	0.145483	0.145483	27.25	<.001
BL1.BL2.P1.T1	1	0.009102	0.009102	1.70	0.197
BL1.BL2.T1.P3	1	0.000638	0.000638	0.12	0.731
BL1.BL2.T1.T2	2	1.110537	0.555269	104.01	<.001
BL1.TREAT.BL2.P1.T1	1	0.003389	0.003389	0.63	0.429
BL1.TREAT.BL2.T1.P3	1	0.030398	0.030398	5.69	0.020
BL1.BL2.P1.T1.P3	1	0.000458	0.000458	0.09	0.771
BL1.TREAT.BL2.T1.T2	2	1.031507	0.515753	96.60	<.001
BL1.BL2.P1.T1.T2	2	0.000010	0.000005	0.00	0.999
BL1.BL2.T1.P3.T2	2	0.003947	0.001974	0.37	0.693
BL1.TREAT.BL2.P1.T1.P3	1	0.000077	0.000077	0.01	0.905
BL1.TREAT.BL2.P1.T1.T2	2	0.001663	0.000832	0.16	0.856
BL1.TREAT.BL2.T1.P3.T2	2	0.020855	0.010427	1.95	0.151
BL1.BL2.P1.T1.P3.T2	2	0.001637	0.000819	0.15	0.858
BL1.TREAT.BL2.P1.T1.P3.T2	2	0.001598	0.000799	0.15	0.861
Residual	60	0.320331	0.005339		
Total	92	3.586003			

Table B.3 ANOVA table for respiration rate (mmol Kg^{-1} h^{-1}) for 'Estima' potatoes in Experiment 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.002022	0.001011	0.38	
REP.*Units* stratum					
BL1	1	0.122752	0.122752	46.20	<.001
BL1.TREAT	1	0.012159	0.012159	4.58	0.036
BL1.BL2	1	0.026710	0.026710	10.05	0.002
BL1.TREAT.BL2	1	0.000883	0.000883	0.33	0.566
BL1.BL2.P1	1	0.002621	0.002621	0.99	0.324
BL1.BL2_1.T1	2	0.117601	0.058800	22.13	<.001
BL1.TREAT.BL2.P1	1	0.000024	0.000024	0.01	0.924
BL1.TREAT.BL2.T1	2	0.000241	0.000121	0.05	0.956
BL1.BL2.P1.T1	2	0.002541	0.001270	0.48	0.622
BL1.BL2.T1.P3	1	0.018908	0.018908	7.12	0.010
BL1.BL2_1.T1_1.T2_1	2	0.606029	0.303015	114.05	<.001
BL1.TREAT.BL2.P1.T1	2	0.001472	0.000736	0.28	0.759
BL1.TREAT.BL2.T1.P3	1	0.001266	0.001266	0.48	0.492
BL1.BL2.P1.T1.P3	1	0.000018	0.000018	0.01	0.934
BL1.TREAT.BL2.T1.T2	2	0.001492	0.000746	0.28	0.756
BL1.BL2.P1.T1.T2	2	0.031662	0.015831	5.96	0.004
BL1.BL2.T1.P3.T2	2	0.013700	0.006850	2.58	0.083
BL1.TREAT.BL2.P1.T1.P3	1	0.014835	0.014835	5.58	0.021
BL1.TREAT.BL2.P1.T1.T2	2	0.010580	0.005290	1.99	0.144
BL1.TREAT.BL2.T1.P3.T2	2	0.000827	0.000413	0.16	0.856
BL1.BL2.P1.T1.P3.T2	2	0.003727	0.001863	0.70	0.499
BL1.TREAT.BL2.P1.T1.P3.T2	2	0.006921	0.003460	1.30	0.279
Residual	68	0.180659	0.002657		
Total	104	1.179651			

Table B.4 ANOVA table for respiration rate (mmol Kg^{-1} h^{-1}) for 'Saturna' potatoes in Experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.030728	0.015364	3.24	
REP.*Units* stratum					
BL1	1	0.027167	0.027167	5.73	0.020
BL1.TREAT	1	0.208739	0.208739	44.06	<.001
BL1.BL2	1	0.197835	0.197835	41.76	<.001
BL1.TREAT.BL2	1	0.012793	0.012793	2.70	0.106
BL1.BL2.P1	1	0.021141	0.021141	4.46	0.039
BL1.BL2.T1	1	0.458738	0.458738	96.82	<.001
BL1.TREAT.BL2.P1	1	0.010566	0.010566	2.23	0.141
BL1.TREAT.BL2.T1	1	0.103966	0.103966	21.94	<.001
BL1.BL2.P1.T1	1	0.000137	0.000137	0.03	0.866
BL1.BL2.T1.P3	1	0.014404	0.014404	3.04	0.086
BL1.BL2.T1.T2	2	1.291847	0.645924	136.33	<.001
BL1.TREAT.BL2.P1.T1	1	0.000954	0.000954	0.20	0.655
BL1.TREAT.BL2.T1.P3	1	0.007808	0.007808	1.65	0.204
BL1.BL2.P1.T1.P3	1	0.000238	0.000238	0.05	0.824
BL1.TREAT.BL2.T1.T2	2	0.715289	0.357645	75.49	<.001
BL1.BL2.P1.T1.T2	2	0.013787	0.006893	1.45	0.242
BL1.BL2.T1.P3_1.T2	2	0.011927	0.005964	1.26	0.291
BL1.TREAT.BL2.P1.T1.P3	1	0.004496	0.004496	0.95	0.334
BL1.TREAT.BL2.P1.T1.T2	2	0.003441	0.001720	0.36	0.697
BL1.TREAT.BL2.T1.P3.T2	2	0.004182	0.002091	0.44	0.645
BL1.BL2.P1.T1.P3.T2	2	0.003815	0.001908	0.40	0.670
BL1.TREAT.BL2.P1.T1.P3.T2	2	0.003413	0.001706	0.36	0.699
Residual	60	0.284273	0.004738		
Total	92	3.431682			

Table B.5 ANOVA table for respiration rate (mmol Kg^{-1} h^{-1}) for 'Russet Burbank' potatoes in Experiment 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.007520	0.003760	0.84	
REP.*Units* stratum					
BL1	1	0.025431	0.025431	5.67	0.020
BL1.TREAT	1	0.000337	0.000337	0.08	0.785
BL1.BL2	1	0.060585	0.060585	13.51	<.001
BL1.TREAT.BL2	1	0.000187	0.000187	0.04	0.839
BL1.BL2.P1	1	0.015199	0.015199	3.39	0.070
BL1.BL2.T1	2	0.334787	0.167393	37.32	<.001
BL1.TREAT.BL2.P1	1	0.000189	0.000189	0.04	0.838
BL1.TREAT.BL2.T1	2	0.019676	0.009838	2.19	0.119
BL1.BL2.P1.T1	2	0.003156	0.001578	0.35	0.705
BL1.BL2.T1.P3	1	0.000017	0.000017	0.00	0.950
BL1.BL2.T1.T2	2	0.420570	0.210285	46.88	<.001
BL1.TREAT.BL2.P1.T1	2	0.006265	0.003133	0.70	0.501
BL1.TREAT.BL2.T1.P3	1	0.015833	0.015833	3.53	0.065
BL1.BL2.P1.T1.P3	1	0.001248	0.001248	0.28	0.600
BL1.TREAT.BL2.T1.T2	2	0.000791	0.000396	0.09	0.916
BL1.BL2.P1.T1.T2	2	0.010545	0.005272	1.18	0.315
BL1.BL2.T1.P3.T2	2	0.001950	0.000975	0.22	0.805
BL1.TREAT.BL2.P1.T1.P3	1	0.002786	0.002786	0.62	0.433
BL1.TREAT.BL2.P1.T1.T2	2	0.003914	0.001957	0.44	0.648
BL1.TREAT.BL2.T1.P3.T2	2	0.024375	0.012187	2.72	0.073
BL1.BL2.P1.T1.P3.T2	2	0.016042	0.008021	1.79	0.175
BL1.TREAT.BL2.P1.T1.P3.T2	2	0.001525	0.000762	0.17	0.844
Residual	68	0.304990	0.004485		
Total	104	1.277920			

Table B.6 ANOVA table for ethylene production (mmol $Kg^{-1}h^{-1}$) for 'Marfona' potatoes in Experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.3873	0.1936	1.15	
REP.*Units* stratum					
BL1	1	0.1739	0.1739	1.04	0.313
BL1.TREAT	1	1.5835	1.5835	9.44	0.003
BL1.BL2	1	0.4865	0.4865	2.90	0.094
BL1.TREAT.BL2	1	0.1131	0.1131	0.67	0.415
BL1.BL2.P1	1	1.4620	1.4620	8.72	0.004
BL1.BL2.T1	1	19.0752	19.0752	113.76	<.001
BL1.TREAT.BL2.P1	1	0.9427	0.9427	5.62	0.021
BL1.TREAT.BL2.T1	1	24.3891	24.3891	145.45	<.001
BL1.BL2.P1.T1	1	6.6888	6.6888	39.89	<.001
BL1.BL2.T1.P3	1	0.0315	0.0315	0.19	0.666
BL1.BL2.T1.T2	2	1.0408	0.5204	3.10	0.052
BL1.TREAT.BL2.P1.T1	1	7.2012	7.2012	42.95	<.001
BL1.TREAT.BL2.T1.P3	1	0.0458	0.0458	0.27	0.603
BL1.BL2.P1.T1.P3	1	0.0027	0.0027	0.02	0.900
BL1.TREAT.BL2.T1.T2	2	0.9247	0.4624	2.76	0.072
BL1.BL2.P1_1.T1.T2	2	0.0226	0.0113	0.07	0.935
BL1.BL2.T1.P3.T2	2	0.0852	0.0426	0.25	0.776
BL1.TREAT.BL2.P1.T1.P3	1	0.0002	0.0002	0.00	0.975
BL1.TREAT.BL2.P1.T1.T2	2	0.0260	0.0130	0.08	0.925
BL1.TREAT.BL2.T1.P3.T2	2	0.0895	0.0448	0.27	0.767
BL1.BL2.P1.T1.P3.T2	2	0.0027	0.0014	0.01	0.992
BL1.TREAT.BL2.P1.T1.P3.T2	2	0.0022	0.0011	0.01	0.993
Residual	60	10.0610	0.1677		
Total	92	74.8383			

Table B.7 ANOVA table for ethylene production (mmol $Kg^{-1}h^{-1}$) for 'Estima' potatoes in Experiment 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2.381	1.191	0.44	
REP.*Units* stratum					
BL1	1	2.189	2.189	0.82	0.370
BL1.TREAT	1	0.002	0.002	0.00	0.976
BL1_1.BL2_1	1	5.054	5.054	1.88	0.175
BL1.TREAT.BL2	1	0.000	0.000	0.00	0.994
BL1.BL2.P1	1	51.455	51.455	19.17	<.001
BL1.BL2.T1	2	285.738	142.869	53.22	<.001
BL1.TREAT.BL2.P1	1	0.474	0.474	0.18	0.676
BL1.TREAT.BL2.T1	2	9.632	4.816	1.79	0.174
BL1.BL2.P1.T1	2	313.308	156.654	58.35	<.001
BL1.BL2.T1.P3	1	0.269	0.269	0.10	0.753
BL1.BL2.T1.T2	2	10.498	5.249	1.96	0.149
BL1.TREAT.BL2.P1.T1	2	8.451	4.225	1.57	0.215
BL1.TREAT.BL2.T1.P3	1	1.146	1.146	0.43	0.516
BL1.BL2.P1.T1.P3	1	0.007	0.007	0.00	0.960
BL1.TREAT.BL2.T1.T2	2	1.464	0.732	0.27	0.762
BL1.BL2.P1.T1.T2	2	0.065	0.033	0.01	0.988
BL1.BL2.T1.P3.T2	2	0.455	0.227	0.08	0.919
BL1.TREAT.BL2.P1.T1.P3	1	0.040	0.040	0.01	0.904
BL1.TREAT.BL2.P1.T1.T2	2	0.022	0.011	0.00	0.996
BL1.TREAT.BL2.T1.P3.T2	2	2.210	1.105	0.41	0.664
BL1.BL2.P1.T1.P3.T2	2	0.006	0.003	0.00	0.999
BL1.TREAT.BL2.P1.T1.P3.T2	2	0.032	0.016	0.01	0.994
Residual	68	182.560	2.685		
Total	104	877.458			

Table B.8 ANOVA table for ethylene production (mmol $Kg^{-1}h^{-1}$) for 'Saturna' potatoes in Experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.18510	0.09255	1.36	
REP.*Units* stratum					
BL1	1	0.36382	0.36382	5.35	0.024
BL1.TREAT	1	0.83002	0.83002	12.21	<.001
BL1.BL2	1	0.89737	0.89737	13.20	<.001
BL1.TREAT.BL2	1	0.05929	0.05929	0.87	0.354
BL1.BL2.P1	1	4.21037	4.21037	61.92	<.001
BL1.BL2.T1	1	29.77257	29.77257	437.84	<.001
BL1.TREAT.BL2.P1	1	3.84693	3.84693	56.57	<.001
BL1.TREAT.BL2.T1	1	22.62732	22.62732	332.76	<.001
BL1.BL2.P1.T1	1	18.52541	18.52541	272.44	<.001
BL1.BL2.T1.P3	1	0.20746	0.20746	3.05	0.086
BL1.BL2.T1.T2	2	2.29864	1.14932	16.90	<.001
BL1.TREAT.BL2.P1.T1	1	37.86570	37.86570	556.86	<.001
BL1.TREAT.BL2.T1.P3	1	0.18075	0.18075	2.66	0.108
BL1.BL2.P1.T1.P3	1	0.00885	0.00885	0.13	0.720
BL1.TREAT.BL2.T1.T2	2	2.44663	1.22331	17.99	<.001
BL1.BL2.P1.T1.T2	2	0.33004	0.16502	2.43	0.097
BL1.BL2.T1.P3.T2	2	0.34382	0.17191	2.53	0.088
BL1.TREAT.BL2.P1.T1.P3	1	0.01892	0.01892	0.28	0.600
BL1.TREAT.BL2.P1.T1.T2	2	0.25979	0.12989	1.91	0.157
BL1.TREAT.BL2.T1.P3.T2	2	0.38999	0.19500	2.87	0.065
BL1.BL2.P1.T1.P3.T2	2	0.03413	0.01706	0.25	0.779
BL1.TREAT.BL2.P1.T1.P3.T2	2	0.03481	0.01740	0.26	0.775
Residual	60	4.07989	0.06800		
Total	92	129.81762			

Table B.9 ANOVA table for ethylene production (mmol $Kg^{-1}h^{-1}$) for 'Russet Burbank' potatoes in Experiment 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	5.453	2.727	1.32	
REP.*Units* stratum					
BL1	1	4.098	4.098	1.99	0.163
BL1.TREAT	1	15.622	15.622	7.58	0.008
BL1.BL2	1	9.159	9.159	4.44	0.039
BL1.TREAT.BL2	1	0.976	0.976	0.47	0.494
BL1.BL2.P1	1	146.190	146.190	70.95	<.001
BL1.BL2.T1	2	978.518	489.259	237.45	<.001
BL1.TREAT.BL2.P1	1	15.810	15.810	7.67	0.007
BL1.TREAT.BL2.T1	2	99.185	49.593	24.07	<.001
BL1.BL2.P1.T1	2	987.631	493.815	239.66	<.001
BL1.BL2.T1.P3	1	0.131	0.131	0.06	0.802
BL1.BL2.T1.T2	2	0.193	0.096	0.05	0.954
BL1.TREAT.BL2.P1.T1	2	99.915	49.958	24.25	<.001
BL1.TREAT.BL2.T1.P3	1	0.042	0.042	0.02	0.887
BL1.BL2.P1.T1.P3	1	0.103	0.103	0.05	0.824
BL1.TREAT.BL2.T1.T2	2	0.200	0.100	0.05	0.953
BL1.BL2.P1.T1.T2	2	0.126	0.063	0.03	0.970
BL1.BL2.T1.P3.T2	2	0.170	0.085	0.04	0.960
BL1.TREAT.BL2.P1_1.T1.P3	1	0.041	0.041	0.02	0.888
BL1.TREAT.BL2.P1.T1.T2	2	0.026	0.013	0.01	0.994
BL1.TREAT.BL2.T1.P3.T2	2	0.089	0.045	0.02	0.979
BL1.BL2.P1.T1.P3.T2	2	0.270	0.135	0.07	0.937
BL1.TREAT.BL2.P1.T1.P3.T2	2	0.149	0.074	0.04	0.965
Residual	68	140.114	2.061		
Total	104	2504.210			

Table B.10 ANOVA table for sucrose concentration (mg g^{-1} DW) in flesh for 'Marfona' potatoes in experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1.240	0.620	0.19	
REP.*Units* stratum					
BL1	1	106.070	106.070	31.71	<.001
BL1.TREAT	1	270.447	270.447	80.86	<.001
BL1.BL2	1	132.779	132.779	39.70	<.001
BL1.TREAT.BL2	1	24.237	24.237	7.25	0.009
BL1.BL2.P1	1	52.303	52.303	15.64	<.001
BL1.BL2.T1	1	41.858	41.858	12.51	<.001
BL1.TREAT.BL2.P1	1	80.153	80.153	23.96	<.001
BL1.TREAT.BL2.T1	1	6.587	6.587	1.97	0.166
BL1.BL2.P1.T1	1	11.479	11.479	3.43	0.069
BL1.BL2.T1.P3	1	47.771	47.771	14.28	<.001
BL1.BL2.T1.T2	2	54.868	27.434	8.20	<.001
BL1.TREAT.BL2.P1.T1	1	3.597	3.597	1.08	0.304
BL1.TREAT.BL2.T1.P3	1	9.795	9.795	2.93	0.092
BL1.BL2.P1.T1.P3	1	0.560	0.560	0.17	0.684
BL1.TREAT.BL2.T1.T2	2	139.672	69.836	20.88	<.001
BL1.BL2.P1.T1.T2	2	1.546	0.773	0.23	0.794
BL1.BL2.T1.P3.T2	2	0.625	0.312	0.09	0.911
BL1.TREAT.BL2.P1.T1.P3	1	1.270	1.270	0.38	0.540
BL1.TREAT.BL2.P1.T1.T2	2	31.137	15.568	4.65	0.013
BL1.TREAT.BL2.T1.P3.T2	2	11.825	5.912	1.77	0.180
BL1.BL2.P1.T1.P3.T2	2	6.681	3.340	1.00	0.374
BL1.TREAT.BL2.P1.T1.P3.T2	2	4.185	2.092	0.63	0.538
Residual	60	200.684	3.345		
Total	92	1241.367			

Table B.11 ANOVA table for glucose concentration (mg g^{-1} DW) in flesh for 'Marfona' potatoes in experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	356.98	178.49	2.56	
REP.*Units* stratum					
BL1	1	2569.89	2569.89	36.89	<.001
BL1.TREAT	1	3107.36	3107.36	44.61	<.001
BL1.BL2	1	1495.48	1495.48	21.47	<.001
BL1.TREAT.BL2	1	216.47	216.47	3.11	0.083
BL1.BL2.P1	1	695.24	695.24	9.98	0.002
BL1.BL2.T1	1	639.74	639.74	9.18	0.004
BL1.TREAT.BL2.P1	1	620.26	620.26	8.90	0.004
BL1.TREAT.BL2.T1	1	17.69	17.69	0.25	0.616
BL1.BL2.P1.T1	1	0.50	0.50	0.01	0.933
BL1.BL2.T1.P3	1	715.35	715.35	10.27	0.002
BL1.BL2.T1.T2	2	403.58	201.79	2.90	0.063
BL1.TREAT.BL2.P1.T1	1	74.88	74.88	1.07	0.304
BL1.TREAT.BL2.T1.P3	1	89.83	89.83	1.29	0.261
BL1.BL2.P1.T1.P3	1	104.38	104.38	1.50	0.226
BL1.TREAT.BL2.T1.T2	2	1286.99	643.49	9.24	<.001
BL1.BL2.P1_1.T1.T2	2	2.12	1.06	0.02	0.985
BL1.BL2.T1.P3.T2	2	87.58	43.79	0.63	0.537
BL1.TREAT.BL2.P1.T1.P3	1	0.01	0.01	0.00	0.991
BL1.TREAT.BL2.P1.T1.T2	2	112.93	56.46	0.81	0.449
BL1.TREAT.BL2.T1.P3.T2	2	104.62	52.31	0.75	0.476
BL1.BL2.P1.T1.P3.T2	2	55.89	27.95	0.40	0.671
BL1.TREAT.BL2.P1.T1.P3.T2	2	472.69	236.35	3.39	0.040
Residual	60	4179.63	69.66		
Total	92	17410.09			

Table B.12 ANOVA table for fructose concentration (mg g^{-1} DW) in flesh for 'Marfona' potatoes in experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	27.88	13.94	0.41	
REP.*Units* stratum					
BL1	1	2088.58	2088.58	60.94	<.001
BL1.TREAT	1	3390.53	3390.53	98.94	<.001
BL1.BL2	1	836.39	836.39	24.41	<.001
BL1.TREAT_1.BL2	1	290.28	290.28	8.47	0.005
BL1.BL2.P1	1	632.36	632.36	18.45	<.001
BL1.BL2.T1	1	225.17	225.17	6.57	0.013
BL1.TREAT.BL2.P1	1	676.86	676.86	19.75	<.001
BL1.TREAT.BL2.T1	1	36.48	36.48	1.06	0.306
BL1.BL2.P1.T1	1	3.62	3.62	0.11	0.746
BL1.BL2.T1.P3	1	547.61	547.61	15.98	<.001
BL1.BL2.T1.T2	2	204.11	102.06	2.98	0.058
BL1.TREAT.BL2.P1.T1	1	50.71	50.71	1.48	0.229
BL1.TREAT.BL2.T1.P3	1	9.44	9.44	0.28	0.602
BL1.BL2.P1.T1.P3	1	53.98	53.98	1.58	0.214
BL1.TREAT.BL2.T1.T2	2	395.54	197.77	5.77	0.005
BL1.BL2.P1.T1.T2	2	204.45	102.22	2.98	0.058
BL1.BL2.T1.P3.T2	2	20.79	10.40	0.30	0.739
BL1.TREAT.BL2.P1.T1.P3	1	0.40	0.40	0.01	0.915
BL1.TREAT.BL2.P1.T1.T2	2	59.36	29.68	0.87	0.426
BL1.TREAT.BL2.T1.P3.T2	2	86.68	43.34	1.26	0.290
BL1.BL2.P1.T1.P3.T2	2	54.61	27.30	0.80	0.456
BL1.TREAT.BL2.P1.T1.P3.T2	2	272.41	136.21	3.97	0.024
Residual	60	2056.21	34.27		
Total	92	12224.43			

Table B.13 ANOVA table for sucrose concentration (mg g^{-1} DW) in flesh for 'Estima' potatoes in experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	4.424	2.212	1.10	
REP.*Units* stratum					
BL1	1	178.607	178.607	89.17	<.001
BL1.TREAT	1	0.209	0.209	0.10	0.748
BL1.BL2	1	2.944	2.944	1.47	0.230
BL1.TREAT.BL2	1	0.037	0.037	0.02	0.892
BL1.BL2.P1	1	48.286	48.286	24.11	<.001
BL1.BL2.T1	2	33.772	16.886	8.43	<.001
BL1.TREAT.BL2.P1	1	20.044	20.044	10.01	0.002
BL1.TREAT.BL2.T1	2	7.140	3.570	1.78	0.176
BL1.BL2.P1.T1	2	4.120	2.060	1.03	0.363
BL1.BL2.T1.P3	1	4.199	4.199	2.10	0.152
BL1.BL2.T1.T2	2	7.086	3.543	1.77	0.178
BL1.TREAT.BL2.P1.T1	2	0.581	0.290	0.14	0.865
BL1.TREAT.BL2.T1.P3	1	0.962	0.962	0.48	0.491
BL1.BL2.P1.T1.P3	1	0.312	0.312	0.16	0.694
BL1.TREAT.BL2.T1.T2	2	51.426	25.713	12.84	<.001
BL1.BL2.P1.T1.T2	2	7.996	3.998	2.00	0.144
BL1.BL2.T1.P3.T2	2	5.075	2.538	1.27	0.288
BL1.TREAT.BL2.P1.T1.P3	1	4.282	4.282	2.14	0.148
BL1.TREAT.BL2.P1.T1.T2	2	3.844	1.922	0.96	0.388
BL1.TREAT.BL2.T1.P3.T2	2	1.118	0.559	0.28	0.757
BL1.BL2.P1.T1.P3.T2	2	10.745	5.372	2.68	0.076
BL1.TREAT.BL2.P1.T1.P3.T2	2	0.006	0.003	0.00	0.998
Residual	68	136.197	2.003		
Total	104	533.411			

Table B.14 ANOVA table for glucose concentration (mg g^{-1} DW) in flesh for 'Estima' potatoes in experiment 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	202.89	101.45	2.10	
REP.*Units* stratum					
BL1	1	705.61	705.61	14.64	<.001
BL1.TREAT	1	5.00	5.00	0.10	0.748
BL1.BL2	1	44.13	44.13	0.92	0.342
BL1.TREAT.BL2	1	11.08	11.08	0.23	0.633
BL1.BL2.P1	1	274.43	274.43	5.69	0.020
BL1.BL2.T1	2	1124.12	562.06	11.66	<.001
BL1.TREAT.BL2.P1	1	66.53	66.53	1.38	0.244
BL1.TREAT.BL2.T1	2	378.89	189.45	3.93	0.024
BL1.BL2.P1.T1	2	72.55	36.28	0.75	0.475
BL1.BL2.T1.P3	1	170.97	170.97	3.55	0.064
BL1.BL2.T1.T2	2	299.41	149.71	3.11	0.051
BL1.TREAT.BL2.P1.T1	2	39.88	19.94	0.41	0.663
BL1.TREAT.BL2.T1.P3	1	37.73	37.73	0.78	0.379
BL1.BL2.P1.T1.P3	1	5.61	5.61	0.12	0.734
BL1.TREAT.BL2.T1.T2	2	98.30	49.15	1.02	0.366
BL1.BL2.P1.T1.T2	2	102.94	51.47	1.07	0.349
BL1.BL2.T1.P3.T2	2	11.97	5.98	0.12	0.883
BL1.TREAT.BL2.P1.T1.P3	1	138.88	138.88	2.88	0.094
BL1.TREAT.BL2.P1.T1.T2	2	121.66	60.83	1.26	0.290
BL1.TREAT.BL2.T1.P3.T2	2	23.20	11.60	0.24	0.787
BL1.BL2.P1.T1.P3.T2	2	28.11	14.06	0.29	0.748
BL1.TREAT.BL2.P1.T1.P3.T2	2	81.51	40.76	0.85	0.434
Residual	68	3277.68	48.20		
Total	104	7323.09			

Table B.15 ANOVA table for fructose concentration (mg g^{-1} DW) in flesh for 'Estima' potatoes in experiment 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	159.35	79.67	3.11	
REP.*Units* stratum					
BL1	1	835.56	835.56	32.60	<.001
BL1.TREAT	1	163.71	163.71	6.39	0.014
BL1.BL2	1	25.93	25.93	1.01	0.318
BL1.TREAT.BL2	1	16.52	16.52	0.64	0.425
BL1.BL2.P1	1	428.65	428.65	16.72	<.001
BL1.BL2.T1	2	907.16	453.58	17.70	<.001
BL1.TREAT.BL2.P1	1	288.65	288.65	11.26	0.001
BL1.TREAT.BL2.T1	2	144.14	72.07	2.81	0.067
BL1.BL2.P1.T1	2	68.03	34.02	1.33	0.272
BL1.BL2.T1.P3	1	108.84	108.84	4.25	0.043
BL1.BL2.T1.T2	2	409.93	204.96	8.00	<.001
BL1.TREAT.BL2.P1.T1	2	2.01	1.01	0.04	0.961
BL1.TREAT.BL2.T1.P3	1	18.91	18.91	0.74	0.393
BL1.BL2.P1.T1.P3	1	1.53	1.53	0.06	0.808
BL1.TREAT.BL1.T1.T2	2	2.33	1.16	0.05	0.956
BL1.BL2.P1.T1.T2	2	4.68	2.34	0.09	0.913
BL1.BL2.T1.P3.T2	2	18.48	9.24	0.36	0.699
BL1.TREAT.BL2.P1.T1.P3	1	55.82	55.82	2.18	0.145
BL1.TREAT.BL2.P1.T1.T2	2	10.78	5.39	0.21	0.811
BL1.TREAT.BL2.T1.P3.T2	2	3.75	1.87	0.07	0.930
BL1.BL2.P1.T1.P3.T2	2	14.47	7.24	0.28	0.755
BL1.TREAT.BL2.P1.T1.P3.T2	2	4.43	2.22	0.09	0.917
Residual	68	1742.89	25.63		
Total	104	5436.54			

Table B.16 ANOVA table for sucrose concentration (mg g^{-1} DW) in flesh for 'Saturna' potatoes in experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3.303	1.652	0.27	
REP.*Units* stratum					
BL1	1	165.853	165.853	26.75	<.001
BL1.TREAT	1	152.207	152.207	24.55	<.001
BL1.BL2	1	42.592	42.592	6.87	0.011
BL1.TREAT.BL2	1	16.556	16.556	2.67	0.107
BL1.BL2.P1	1	159.159	159.159	25.67	<.001
BL1.BL2.T1	1	21.378	21.378	3.45	0.068
BL1.TREAT.BL2.P1	1	79.147	79.147	12.77	<.001
BL1.TREAT.BL2.T1	1	67.459	67.459	10.88	0.002
BL1.BL2.P1.T1	1	50.944	50.944	8.22	0.006
BL1.BL2.T1.P3	1	10.170	10.170	1.64	0.205
BL1.BL2.T1.T2	2	24.697	12.349	1.99	0.145
BL1.TREAT.BL2.P1.T1	1	68.837	68.837	11.10	0.001
BL1.TREAT.BL2.T1.P3	1	4.057	4.057	0.65	0.422
BL1.BL2.P1.T1.P3	1	2.644	2.644	0.43	0.516
BL1.TREAT.BL2.T1.T2	2	0.634	0.317	0.05	0.950
BL1.BL2.P1.T1.T2	2	3.245	1.622	0.26	0.771
BL1.BL2.T1.P3.T2	2	16.923	8.461	1.36	0.263
BL1.TREAT.BL2.P1.T1.P3	1	20.465	20.465	3.30	0.074
BL1.TREAT.BL2.P1.T1.T2	2	1.658	0.829	0.13	0.875
BL1.TREAT.BL2.T1.P3.T2	2	7.532	3.766	0.61	0.548
BL1.BL2.P1.T1.P3.T2	2	20.716	10.358	1.67	0.197
BL1.TREAT.BL2.P1.T1.P3.T2	2	7.022	3.511	0.57	0.571
Residual	60	371.958	6.199		
Total	92	1319.156			

Table B.17 ANOVA table for glucose concentration (mg g^{-1} DW) in flesh for 'Saturna' potatoes in experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	13.92	6.96	0.53	
REP.*Units* stratum					
BL1	1	32.40	32.40	2.45	0.123
BL1.TREAT	1	39.11	39.11	2.96	0.091
BL1.BL2	1	118.98	118.98	8.99	0.004
BL1.TREAT.BL2	1	5.29	5.29	0.40	0.529
BL1.BL2.P1	1	155.33	155.33	11.74	0.001
BL1.BL2.T1	1	20.66	20.66	1.56	0.216
BL1.TREAT.BL2.P1	1	66.90	66.90	5.06	0.028
BL1.TREAT.BL2.T1	1	5.25	5.25	0.40	0.531
BL1.BL2.P1.T1	1	22.21	22.21	1.68	0.200
BL1.BL2.T1.P3	1	18.29	18.29	1.38	0.244
BL1.BL2.T1.T2	2	4.34	2.17	0.16	0.849
BL1.TREAT.BL2.P1.T1	1	1.79	1.79	0.14	0.714
BL1.TREAT.BL2.T1.P3	1	0.05	0.05	0.00	0.954
BL1.BL2.P1.T1.P3	1	1.13	1.13	0.09	0.771
BL1.TREAT.BL2.T1.T2	2	35.84	17.92	1.35	0.266
BL1.BL2.P1.T1.T2	2	14.95	7.47	0.56	0.571
BL1.BL2.T1.P3.T2	2	57.10	28.55	2.16	0.124
BL1.TREAT.BL2.P1.T1.P3	1	5.50	5.50	0.42	0.521
BL1.TREAT.BL2.P1.T1.T2	2	21.78	10.89	0.82	0.444
BL1.TREAT.BL2.T1.P3.T2	2	2.14	1.07	0.08	0.922
BL1.BL2.P1.T1.P3_T2	2	17.44	8.72	0.66	0.521
BL1.TREAT.BL2.P1.T1.P3.T2	2	18.97	9.49	0.72	0.492
Residual	60	793.82	13.23		
Total	92	1473.20			

Table B.18 ANOVA table for fructose concentration (mg g^{-1} DW) in flesh for 'Saturna' potatoes in experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	12.966	6.483	0.69	
REP.*Units* stratum					
BL1	1	92.865	92.865	9.87	0.003
BL1.TREAT	1	145.946	145.946	15.52	<.001
BL1.BL2	1	201.650	201.650	21.44	<.001
BL1.TREAT.BL2	1	72.896	72.896	7.75	0.007
BL1.BL2.P1	1	152.212	152.212	16.18	<.001
BL1.BL2.T1	1	221.913	221.913	23.59	<.001
BL1.TREAT.BL2.P1	1	121.535	121.535	12.92	<.001
BL1.TREAT.BL2.T1	1	13.794	13.794	1.47	0.231
BL1.BL2.P1.T1	1	22.885	22.885	2.43	0.124
BL1.BL2.T1.P3	1	68.815	68.815	7.32	0.009
BL1.BL2.T1.T2	2	1.588	0.794	0.08	0.919
BL1.TREAT.BL2.P1.T1	1	11.169	11.169	1.19	0.280
BL1.TREAT.BL2.T1.P3	1	1.006	1.006	0.11	0.745
BL1.BL2.P1.T1.P3	1	15.989	15.989	1.70	0.197
BL1.TREAT.BL2.T1.T2	2	33.216	16.608	1.77	0.180
BL1.BL2.P1.T1.T2	2	16.820	8.410	0.89	0.414
BL1.BL2.T1.P3.T2	2	61.989	30.994	3.30	0.044
BL1.TREAT.BL2.P1.T1.P3	1	11.391	11.391	1.21	0.276
BL1.TREAT.BL2.P1.T1.T2	2	41.440	20.720	2.20	0.119
BL1.TREAT.BL2.T1.P3.T2	2	10.394	5.197	0.55	0.578
BL1.BL2.P1.T1.P3.T2	2	36.244	18.122	1.93	0.155
BL1.TREAT.BL2.P1.T1.P3.T2	2	50.658	25.329	2.69	0.076
Residual	60	564.378	9.406		
Total	92	1983.755			

Table B.19 ANOVA table for sucrose concentration (mg g^{-1} DW) in flesh for 'Russet Burbank' potatoes in experiment 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3.2748	1.6374	2.09	
REP.*Units* stratum					
BL1	1	28.4035	28.4035	36.30	<.001
BL1.TREAT	1	28.1613	28.1613	35.99	<.001
BL1.BL2	1	85.3312	85.3312	109.05	<.001
BL1.TREAT.BL2	1	1.0254	1.0254	1.31	0.256
BL1.BL2.P1	1	50.6527	50.6527	64.73	<.001
BL1.BL2.T1	2	42.4888	21.2444	27.15	<.001
BL1.TREAT.BL2.P1	1	37.7712	37.7712	48.27	<.001
BL1.TREAT.BL2.T1	2	11.4217	5.7108	7.30	0.001
BL1.BL2.P1.T1	2	12.1347	6.0674	7.75	<.001
BL1.BL2.T1.P3	1	28.6580	28.6580	36.62	<.001
BL1.BL2.T1.T2	2	5.0694	2.5347	3.24	0.045
BL1.TREAT.BL2.P1.T1	2	14.9172	7.4586	9.53	<.001
BL1.TREAT.BL2.T1.P3	1	0.0263	0.0263	0.03	0.855
BL1.BL2.P1.T1.P3	1	0.1349	0.1349	0.17	0.679
BL1.TREAT.BL2.T1.T2	2	3.4763	1.7382	2.22	0.116
BL1.BL2.P1.T1.T2	2	3.3489	1.6745	2.14	0.126
BL1.BL2.T1.P3.T2	2	1.3765	0.6883	0.88	0.420
BL1.TREAT.BL2.P1.T1.P3	1	0.5763	0.5763	0.74	0.394
BL1.TREAT.BL2.P1.T1.T2	2	2.6002	1.3001	1.66	0.197
BL1.TREAT.BL2.T1.P3.T2	2	0.0713	0.0356	0.05	0.956
BL1.BL2.P1.T1.P3.T2	2	3.6203	1.8101	2.31	0.107
BL1.TREAT.BL2.P1.T1.P3.T2	2	6.7314	3.3657	4.30	0.017
Residual	68	53.2106	0.7825		
Total	104	424.4829			

Table B.20 ANOVA table for glucose concentration (mg g^{-1} DW) in flesh for 'Russet Burbank' potatoes in experiment 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	46.10	23.05	1.78	
REP.*Units* stratum					
BL1	1	112.80	112.80	8.73	0.004
BL1.TREAT	1	251.94	251.94	19.49	<.001
BL1.BL2	1	529.46	529.46	40.95	<.001
BL1.TREAT.BL2	1	7.83	7.83	0.61	0.439
BL1.BL2.P1	1	417.72	417.72	32.31	<.001
BL1.BL2.T1	2	226.25	113.13	8.75	<.001
BL1.TREAT.BL2.P1	1	301.25	301.25	23.30	<.001
BL1.TREAT.BL2.T1	2	196.08	98.04	7.58	0.001
BL1.BL2.P1.T1	2	348.34	174.17	13.47	<.001
BL1.BL2.T1.P3	1	165.40	165.40	12.79	<.001
BL1.BL2.T1.T2	2	8.58	4.29	0.33	0.719
BL1.TREAT.BL2.P1.T1	2	98.53	49.26	3.81	0.027
BL1.TREAT.BL2.T1.P3	1	1.54	1.54	0.12	0.731
BL1.BL2.P1.T1.P3	1	6.01	6.01	0.46	0.498
BL1.TREAT.BL2.T1.T2	2	529.04	264.52	20.46	<.001
BL1.BL2.P1.T1.T2	2	72.33	36.16	2.80	0.068
BL1.BL2.T1.P3.T2	2	9.54	4.77	0.37	0.693
BL1.TREAT.BL2.P1.T1.P3	1	14.57	14.57	1.13	0.292
BL1.TREAT.BL2.P1.T1.T2	2	51.52	25.76	1.99	0.144
BL1.TREAT.BL2.T1.P3.T2	2	76.52	38.26	2.96	0.059
BL1.BL2.P1.T1.P3.T2	2	50.29	25.15	1.95	0.151
BL1.TREAT.BL2.P1.T1.P3.T2	2	3.25	1.63	0.13	0.882
Residual	68	879.12	12.93		
Total	104	4404.03			

Table B.21 ANOVA table for fructose concentration (mg g^{-1} DW) in flesh for 'Russet Burbank' potatoes in experiment 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	6.449	3.225	0.54	
REP.*Units* stratum					
BL1	1	184.981	184.981	30.80	<.001
BL1.TREAT	1	886.632	886.632	147.60	<.001
BL1.BL2	1	344.420	344.420	57.34	<.001
BL1.TREAT.BL2	1	106.374	106.374	17.71	<.001
BL1.BL2.P1	1	922.476	922.476	153.57	<.001
BL1.BL2.T1	2	77.970	38.985	6.49	0.003
BL1.TREAT.BL2.P1	1	832.785	832.785	138.64	<.001
BL1.TREAT.BL2.T1	2	157.200	78.600	13.09	<.001
BL1.BL2.P1.T1	2	163.176	81.588	13.58	<.001
BL1.BL2.T1.P3	1	163.508	163.508	27.22	<.001
BL1.BL2.T1.T2	2	99.610	49.805	8.29	<.001
BL1.TREAT.BL2.P1.T1	2	68.995	34.498	5.74	0.005
BL1.TREAT.BL2.T1.P3	1	4.677	4.677	0.78	0.381
BL1.BL2.P1.T1.P3	1	5.156	5.156	0.86	0.357
BL1.TREAT.BL2.T1.T2	2	144.868	72.434	12.06	<.001
BL1.BL2.P1.T1.T2	2	9.087	4.544	0.76	0.473
BL1.BL2.T1.P3.T2	2	45.132	22.566	3.76	0.028
BL1.TREAT.BL2.P1.T1.P3	1	9.324	9.324	1.55	0.217
BL1.TREAT.BL2.P1.T1.T2	2	29.715	14.858	2.47	0.092
BL1.TREAT.BL2.T1.P3.T2	2	38.212	19.106	3.18	0.048
BL1.BL2.P1.T1.P3.T2	2	74.669	37.334	6.22	0.003
BL1.TREAT.BL2.P1.T1.P3.T2	2	22.016	11.008	1.83	0.168
Residual	68	408.463	6.007		
Total	104	4805.897			

Table B.22 ANOVA table for firmness (N) for 'Marfona' potatoes in experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	116.46	58.23	3.53	
REP.*Units* stratum					
BL1	1	3.36	3.36	0.20	0.654
BL1.TREAT	1	135.93	135.93	8.23	0.006
BL1.BL2	1	9.68	9.68	0.59	0.447
BL1.TREAT.BL2	1	43.09	43.09	2.61	0.112
BL1.BL2.P1	1	52.61	52.61	3.18	0.079
BL1.BL2.T1	1	23.51	23.51	1.42	0.238
BL1.TREAT.BL2.P1	1	75.50	75.50	4.57	0.037
BL1.TREAT.BL2.T1	1	31.77	31.77	1.92	0.171
BL1.BL2.P1.T1	1	12.29	12.29	0.74	0.392
BL1.BL2.T1.P3	1	8.13	8.13	0.49	0.486
BL1.BL2.T1.T2	2	263.15	131.57	7.96	<.001
BL1.TREAT.BL2.P1.T1	1	2.70	2.70	0.16	0.687
BL1.TREAT.BL2.T1.P3	1	44.25	44.25	2.68	0.107
BL1.BL2.P1.T1.P3	1	2.20	2.20	0.13	0.716
BL1.TREAT.BL2.T1.T2	2	48.65	24.32	1.47	0.238
BL1.BL2.P1.T1.T2	2	5.59	2.79	0.17	0.845
BL1.BL2.T1.P3.T2	2	18.80	9.40	0.57	0.569
BL1.TREAT.BL2.P1.T1.P3	1	45.55	45.55	2.76	0.102
BL1.TREAT.BL2.P1.T1.T2	2	11.09	5.54	0.34	0.716
BL1.TREAT.BL2.T1.P3.T2	2	0.95	0.47	0.03	0.972
BL1.BL2.P1.T1.P3.T2	2	44.65	22.33	1.35	0.267
BL1.TREAT.BL2.P1.T1.P3.T2	2	23.66	11.83	0.72	0.493
Residual	60	991.18	16.52		
Total	92	2014.75			

Table B.23 ANOVA table for apparent elasticity (N mm^{-2}) for 'Marfona' potatoes in experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.03523	0.01762	0.48	
REP.*Units* stratum					
BL1	1	0.15005	0.15005	4.06	0.048
BL1.TREAT	1	0.53098	0.53098	14.37	<.001
BL1.BL2	1	0.46381	0.46381	12.55	<.001
BL1.TREAT.BL2	1	0.09287	0.09287	2.51	0.118
BL1.BL2.P1	1	0.02693	0.02693	0.73	0.397
BL1.BL2.T1	1	0.06248	0.06248	1.69	0.199
BL1.TREAT.BL2.P1	1	0.01410	0.01410	0.38	0.539
BL1.TREAT.BL2.T1	1	0.00031	0.00031	0.01	0.927
BL1.BL2.P1.T1	1	0.00492	0.00492	0.13	0.717
BL1.BL2.T1.P3	1	0.18950	0.18950	5.13	0.027
BL1.BL2.T1.T2	2	0.45942	0.22971	6.21	0.004
BL1.TREAT.BL2.P1.T1	1	0.02830	0.02830	0.77	0.385
BL1.TREAT.BL2.T1.P3	1	0.06393	0.06393	1.73	0.193
BL1.BL2.P1.T1.P3	1	0.00565	0.00565	0.15	0.697
BL1.TREAT.BL2.T1.T2	2	0.36829	0.18414	4.98	0.010
BL1.BL2.P1.T1.T2	2	0.06471	0.03236	0.88	0.422
BL1.BL2.T1.P3.T2	2	0.02183	0.01092	0.30	0.745
BL1.TREAT.BL2.P1.T1.P3	1	0.00566	0.00566	0.15	0.697
BL1.TREAT.BL2.P1.T1.T2	2	0.15227	0.07614	2.06	0.136
BL1.TREAT.BL2.T1.P3.T2	2	0.20266	0.10133	2.74	0.073
BL1.BL2.P1.T1.P3.T2	2	0.02253	0.01126	0.30	0.738
BL1.TREAT.BL2.P1.T1.P3.T2	2	0.00143	0.00071	0.02	0.981
Residual	60	2.21771	0.03696		
Total	92	5.18557			

Table B.24 ANOVA table for firmness (N) for 'Estima' potatoes in experiment 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	31.75	15.88	1.25	
REP.*Units* stratum					
BL1	1	35.76	35.76	2.83	0.097
BL1.TREAT	1	14.41	14.41	1.14	0.290
BL1.BL2	1	69.76	69.76	5.51	0.022
BL1.TREAT.BL2	1	0.54	0.54	0.04	0.837
BL1.BL2.P1	1	2.77	2.77	0.22	0.641
BL1.BL2.T1	2	149.36	74.68	5.90	0.004
BL1.TREAT.BL2.P1	1	40.48	40.48	3.20	0.078
BL1.TREAT.BL2.T1	2	5.95	2.97	0.24	0.791
BL1.BL2.P1.T1	2	32.84	16.42	1.30	0.280
BL1.BL2.T1.P3	1	5.12	5.12	0.40	0.527
BL1.BL2.T1.T2	2	156.03	78.01	6.16	0.003
BL1.TREAT.BL2.P1.T1	2	63.01	31.51	2.49	0.090
BL1.TREAT.BL2.T1.P3	1	40.69	40.69	3.21	0.077
BL1.BL2.P1.T1.P3	1	45.76	45.76	3.62	0.061
BL1.TREAT.BL2.T1.T2	2	35.13	17.57	1.39	0.257
BL1.BL2.P1.T1.T2	2	31.83	15.91	1.26	0.291
BL1.BL2.T1.P3.T2	2	7.21	3.60	0.28	0.753
BL1.TREAT.BL2.P1.T1.P3	1	12.89	12.89	1.02	0.316
BL1.TREAT.BL2.P1.T1.T2	2	104.04	52.02	4.11	0.021
BL1.TREAT.BL2.T1.P3.T2	2	187.57	93.78	7.41	0.001
BL1.BL2.P1.T1.P3.T2	2	95.73	47.87	3.78	0.028
BL1.TREAT.BL2.P1.T1.P3.T2	2	7.38	3.69	0.29	0.748
Residual	68	860.65	12.66		
Total	104	2036.66			

Table B.25 ANOVA table for apparent elasticity (N mm^{-2}) for 'Estima' potatoes in experiment 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.06658	0.03329	2.12	
REP.*Units* stratum					
BL1	1	0.11762	0.11762	7.50	0.008
BL1.TREAT	1	0.02002	0.02002	1.28	0.263
BL1.BL2	1	0.49419	0.49419	31.50	<.001
BL1.TREAT.BL2	1	0.00451	0.00451	0.29	0.594
BL1.BL2.P1	1	0.00727	0.00727	0.46	0.498
BL1.BL2.T1	2	0.92012	0.46006	29.33	<.001
BL1.TREAT.BL2.P1	1	0.05557	0.05557	3.54	0.064
BL1.TREAT.BL2.T1	2	0.03878	0.01939	1.24	0.297
BL1.BL2.P1.T1	2	0.01751	0.00875	0.56	0.575
BL1.BL2.T1.P3	1	0.00002	0.00002	0.00	0.973
BL1.BL2.T1.T2	2	0.31223	0.15612	9.95	<.001
BL1.TREAT.BL2.P1.T1	2	0.14943	0.07471	4.76	0.012
BL1.TREAT.BL2.T1.P3	1	0.01147	0.01147	0.73	0.396
BL1.BL2.P1.T1.P3	1	0.00681	0.00681	0.43	0.512
BL1.TREAT.BL2.T1.T2	2	0.01712	0.00856	0.55	0.582
BL1.BL2.P1.T1.T2	2	0.13418	0.06709	4.28	0.018
BL1.BL2.T1.P3.T2	2	0.08230	0.04115	2.62	0.080
BL1.TREAT.BL2.P1.T1.P3	1	0.00279	0.00279	0.18	0.674
BL1.TREAT.BL2.P1.T1.T2	2	0.04313	0.02157	1.37	0.260
BL1.TREAT.BL2.T1.P3.T2	2	0.27263	0.13631	8.69	<.001
BL1.BL2.P1.T1.P3.T2	2	0.00748	0.00374	0.24	0.788
BL1.TREAT.BL2.P1.T1.P3.T2	2	0.02279	0.01140	0.73	0.487
Residual	68	1.06668	0.01569		
Total	104	3.87123			

Table B.26 ANOVA table for firmness (N) for 'Saturna' potatoes in experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	20.36	10.18	0.85	
REP.*Units* stratum					
BL1	1	0.63	0.63	0.05	0.820
BL1.TREAT	1	0.04	0.04	0.00	0.955
BL1.BL2	1	3.54	3.54	0.29	0.590
BL1.TREAT.BL2	1	0.00	0.00	0.00	0.997
BL1.BL2.P1	1	6.77	6.77	0.56	0.456
BL1.BL2.T1	1	46.76	46.76	3.89	0.053
BL1.TREAT.BL2.P1	1	0.01	0.01	0.00	0.980
BL1.TREAT.BL2.T1	1	3.94	3.94	0.33	0.569
BL1.BL2.P1.T1	1	2.69	2.69	0.22	0.638
BL1.BL2.T1.P3	1	7.11	7.11	0.59	0.445
BL1.BL2.T1.T2	2	3.74	1.87	0.16	0.856
BL1.TREAT.BL2.P1.T1	1	10.13	10.13	0.84	0.363
BL1.TREAT.BL2.T1.P3	1	0.28	0.28	0.02	0.880
BL1.BL2.P1.T1.P3	1	0.59	0.59	0.05	0.825
BL1.TREAT.BL2.T1.T2	2	45.86	22.93	1.91	0.158
BL1.BL2.P1.T1.T2	2	0.15	0.07	0.01	0.994
BL1.BL2.T1.P3.	2	46.40	23.20	1.93	0.154
BL1.TREAT.BL2.P1.T1.P3	1	0.34	0.34	0.03	0.866
BL1.TREAT.BL2.P1.T1.T2	2	8.98	4.49	0.37	0.690
BL1.TREAT.BL2.T1.P3.T2	2	5.21	2.61	0.22	0.806
BL1.BL2.P1.T1.P3.T2	2	6.54	3.27	0.27	0.763
BL1.TREAT.BL2.P1.T1.P3.T2	2	16.47	8.23	0.68	0.508
Residual	60	722.17	12.04		
Total	92	958.71			

Table B.27 ANOVA table for apparent elasticity (N mm^{-2}) or 'Saturna' potatoes in experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.01656	0.00828	0.61	
REP.*Units* stratum					
BL1	1	0.01597	0.01597	1.17	0.284
BL1.TREAT	1	0.08035	0.08035	5.88	0.018
BL1.BL2	1	0.02491	0.02491	1.82	0.182
BL1.TREAT.BL2	1	0.01238	0.01238	0.91	0.345
BL1.BL2.P1	1	0.00150	0.00150	0.11	0.742
BL1.BL2.T1	1	0.03294	0.03294	2.41	0.126
BL1.TREAT.BL2.P1	1	0.00427	0.00427	0.31	0.578
BL1.TREAT.BL2.T1	1	0.02496	0.02496	1.83	0.181
BL1.BL2.P1.T1	1	0.00500	0.00500	0.37	0.547
BL1.BL2.T1.P3	1	0.06865	0.06865	5.03	0.029
BL1.BL2.T1.T2	2	0.02804	0.01402	1.03	0.364
BL1.TREAT.BL2.P1.T1	1	0.00890	0.00890	0.65	0.423
BL1.TREAT.BL2.T1.P3	1	0.00633	0.00633	0.46	0.499
BL1.BL2.P1.T1.P3	1	0.00740	0.00740	0.54	0.464
BL1.TREAT.BL2.T1.T2	2	0.17294	0.08647	6.33	0.003
BL1.BL2.P1.T1.T2	2	0.01101	0.00551	0.40	0.670
BL1.BL2.T1.P3.T2	2	0.07956	0.03978	2.91	0.062
BL1.TREAT.BL2.P1.T1.P3	1	0.00319	0.00319	0.23	0.631
BL1.TREAT.BL2.P1.T1.T2	2	0.01699	0.00849	0.62	0.540
BL1.TREAT.BL2.T1.P3.T2	2	0.01447	0.00723	0.53	0.591
BL1.BL2.P1.T1.P3.T2	2	0.01691	0.00846	0.62	0.542
BL1.TREAT.BL2.P1.T1.P3.T2	2	0.02351	0.01176	0.86	0.428
Residual	60	0.81933	0.01366		
Total	92	1.49606			

Table B.28 ANOVA table for firmness (N) for 'Russet Burbank' potatoes in experiment 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	9.993	4.997	0.54	
REP.*Units* stratum					
BL1	1	5.342	5.342	0.57	0.451
BL1.TREAT	1	19.829	19.829	2.13	0.149
BL1.BL2	1	71.914	71.914	7.72	0.007
BL1.TREAT.BL2	1	19.677	19.677	2.11	0.151
BL1.BL2.P1	1	0.610	0.610	0.07	0.799
BL1.BL2.T1	2	295.411	147.706	15.86	<.001
BL1.TREAT.BL2.P1	1	18.226	18.226	1.96	0.166
BL1.TREAT.BL2.T1	2	32.044	16.022	1.72	0.187
BL1.BL2.P1.T1	2	147.882	73.941	7.94	<.001
BL1.BL2.T1.P3	1	13.316	13.316	1.43	0.236
BL1.BL2.T1.T2	2	116.075	58.037	6.23	0.003
BL1.TREAT.BL2.P1.T1	2	27.810	13.905	1.49	0.232
BL1.TREAT.BL2.T1.P3	1	36.518	36.518	3.92	0.052
BL1.BL2.P1.T1.P3	1	20.826	20.826	2.24	0.139
BL1.TREAT.BL2.T1.T2	2	64.318	32.159	3.45	0.037
BL1.BL2.P1.T1.T2	2	92.676	46.338	4.98	0.010
BL1.BL2.T1.P3.T2	2	26.238	13.119	1.41	0.251
BL1.TREAT.BL2.P1.T1.P3	1	7.088	7.088	0.76	0.386
BL1.TREAT.BL2.P1.T1.T2	2	1.088	0.544	0.06	0.943
BL1.TREAT.BL2.T1.P3.T2	2	24.234	12.117	1.30	0.279
BL1.BL2.P1.T1.P3.T2	2	33.741	16.871	1.81	0.171
BL1.TREAT.BL2.P1.T1.P.T2	2	6.125	3.063	0.33	0.721
Residual	68	633.173	9.311		
Total	104	1724.156			

Table B.29 ANOVA table for apparent elasticity (N mm^{-2}) for 'Russet Burbank' potatoes in experiment 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.00556	0.00278	0.22	
REP.*Units* stratum					
BL1	1	0.30996	0.30996	23.97	<.001
BL1.TREAT	1	0.01970	0.01970	1.52	0.221
BL1.BL2	1	0.43318	0.43318	33.50	<.001
BL1.TREAT.BL2	1	0.00105	0.00105	0.08	0.777
BL1.BL2.P1	1	0.00073	0.00073	0.06	0.813
BL1.BL2.T1	2	0.30663	0.15332	11.86	<.001
BL1.TREAT.BL2.P1	1	0.00022	0.00022	0.02	0.896
BL1.TREAT.BL2.T1	2	0.04270	0.02135	1.65	0.199
BL1.BL2.P1.T1	2	0.01405	0.00702	0.54	0.583
BL1.BL2.T1.P3	1	0.01750	0.01750	1.35	0.249
BL1.BL2.T1.T2	2	0.00316	0.00158	0.12	0.885
BL1.TREAT.BL2.P1.T1	2	0.08819	0.04409	3.41	0.039
BL1.TREAT.BL2.T1.P3	1	0.00061	0.00061	0.05	0.829
BL1.BL2.P1.T1.P3	1	0.00417	0.00417	0.32	0.572
BL1.TREAT.BL2.T1.T2	2	0.08094	0.04047	3.13	0.050
BL1.BL2.P1.T1.T2	2	0.18609	0.09305	7.20	0.001
BL1.BL2.T1.P3.T2	2	0.00976	0.00488	0.38	0.687
BL1.TREAT.BL2_1.P1.T1.P3	1	0.00182	0.00182	0.14	0.708
BL1.TREAT.BL2.P1.T1.T2	2	0.14003	0.07002	5.42	0.007
BL1.TREAT.BL2.T1.P3.T2	2	0.00079	0.00039	0.03	0.970
BL1.BL2.P1.T1.P3.T2	2	0.01898	0.00949	0.73	0.484
BL1.TREAT.BL2.P1.T1.P3.T2	2	0.01241	0.00620	0.48	0.621
Residual	68	0.87921	0.01293		
Total	104	2.57743			

Table B.30 ANOVA table for total sprouts at 30 weeks storage for 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank' potatoes in experiments 4 and 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	117.44	58.72	0.62	
REP.*Units* stratum					
CV	3	24298.95	8099.65	86.03	<.001
CV.TREAT	4	1011.38	252.84	2.69	0.039
CV.TREAT.P1	8	487.25	60.91	0.65	0.735
CV.TREAT.P1.P3	16	5849.17	365.57	3.88	<.001
Residual	62	5837.23	94.15		
Total	95	37601.41			

Table B.31 ANOVA table for total sprouts during shelf life for 'Marfona', 'Estima' and 'Saturna' potatoes in experiment 4

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		20.31	10.15	0.40	
REP.*Units* stratum						
CV	2		13722.93	6861.46	269.08	<.001
Day	6		17886.78	2981.13	116.91	<.001
CV.Day	12		6588.20	549.02	21.53	<.001
Day.TREAT	7		1042.96	148.99	5.84	<.001
CV.Day.TREAT	14		3395.53	242.54	9.51	<.001
Day.TREAT.P1	14		462.41	33.03	1.30	0.208
CV.Day.TREAT.P1	28		1763.37	62.98	2.47	<.001
Day.TREAT.P1.P3	28		767.24	27.40	1.07	0.368
CV.Day.TREAT.P1.P3	56		2868.89	51.23	2.01	<.001
Residual	321	(13)	8185.41	25.50		
Total	490	(13)	55526.52			

Table B.32 ANOVA table for total sprouts during shelf life for 'Russet Burbank' potatoes in Experiment 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	642.30	321.15	5.89	
REP.*Units* stratum					
Day	6	51784.06	8630.68	158.31	<.001
Day.TREAT	7	7011.71	1001.67	18.37	<.001
Day.TREAT.P1	14	3300.92	235.78	4.32	<.001
Day.TREAT.P1.P3	28	3555.83	126.99	2.33	<.001
Residual	110	5997.04	54.52		
Total	167	72291.85			

Table B.33 Key-table describing the Genstat structure model used to create the ANOVA tables for Year 2009-2010 (Experimens 6 and 7)

Genstat Structure: CV*T1/(P1*BL_3/(P2*BL_4/(P3*T2)))

Out	BL1	BL2	BL3	BL4	Treat	P1	P2	P3	T1	T2	CV
1	0	0	0	0	B4 MCP	B4 Storage	B4 2nd MCP	B4 Swap	1	0	any
2	1	0	0	0	Control	B4 Storage	B4 2nd MCP	B4 Swap	2	0	any
3	1	1	0	0	Control	CP1	B4 2nd MCP	B4 Swap	0	0	any
3	1	1	0	0	Control	EP1	B4 2nd MCP	B4 Swap	0	0	any
4	1	1	1	0	Control	CP1	CP2	B4 Swap	0	0	any
4	1	1	1	0	Control	CP1	MP2	B4 Swap	0	0	any
4	1	1	1	0	Control	EP1	CP2	B4 Swap	0	0	any
4	1	1	1	0	Control	EP1	MP2	B4 Swap	0	0	any
5	1	1	1	1	Control	CP1	CP2	CP3	1	1	any
5	1	1	1	1	Control	CP1	CP2	EP3	1	1	any
5	1	1	1	1	Control	CP1	MP2	CP3	1	1	any
5	1	1	1	1	Control	CP1	MP2	EP3	1	1	any
5	1	1	1	1	Control	EP1	CP2	CP3	1	1	any
5	1	1	1	1	Control	EP1	CP2	EP3	1	1	any
5	1	1	1	1	Control	EP1	MP2	CP3	1	1	any
5	1	1	1	1	Control	EP1	MP2	EP3	1	1	any
6	1	1	1	1	Control	CP1	CP2	CP3	1	2	any
6	1	1	1	1	Control	CP1	CP2	EP3	1	2	any
6	1	1	1	1	Control	CP1	MP2	CP3	1	2	any
6	1	1	1	1	Control	CP1	MP2	EP3	1	2	any
6	1	1	1	1	Control	EP1	CP2	CP3	1	2	any
6	1	1	1	1	Control	EP1	CP2	EP3	1	2	any
6	1	1	1	1	Control	EP1	MP2	CP3	1	2	any
6	1	1	1	1	Control	EP1	MP2	EP3	1	2	any
7	1	1	1	1	Control	CP1	CP2	CP3	1	3	any
7	1	1	1	1	Control	CP1	CP2	EP3	1	3	any
7	1	1	1	1	Control	CP1	MP2	CP3	1	3	any
7	1	1	1	1	Control	CP1	MP2	EP3	1	3	any
7	1	1	1	1	Control	EP1	CP2	CP3	1	3	any
7	1	1	1	1	Control	EP1	CP2	EP3	1	3	any
7	1	1	1	1	Control	EP1	MP2	CP3	1	3	any
7	1	1	1	1	Control	EP1	MP2	EP3	1	3	any

Table B.34 ANOVA table for respiration rate (mmol Kg^{-1} h^{-1}) for 'Marfona' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	0.000017	0.000008	0.01	
reps.*Units* stratum					
T1	2	0.051376	0.025688	15.33	<.001
T1.P1	1	0.031389	0.031389	18.73	<.001
T1.BL3.P2	1	0.002982	0.002982	1.78	0.187
T1.BL3.BL4	1	0.034588	0.034588	20.64	<.001
T1.P1.BL3.P2	1	0.002036	0.002036	1.21	0.275
T1.P1.BL3.BL4	1	0.013997	0.013997	8.35	0.005
T1.BL3.P2.BL4	1	0.000202	0.000202	0.12	0.730
T1.BL3.BL4.P3	1	0.004099	0.004099	2.45	0.123
T1.BL3.BL4.T2	2	0.419034	0.209517	125.03	<.001
T1.P1.BL3.P2.BL4	1	0.001247	0.001247	0.74	0.392
T1.P1.BL3.BL4.P3	1	0.000064	0.000064	0.04	0.846
T1.BL3.P2.BL4.P3	1	0.007238	0.007238	4.32	0.042
T1.P1.BL3.BL4.T2	2	0.006911	0.003455	2.06	0.136
T1.BL3.P2.BL4.T2	2	0.015098	0.007549	4.50	0.015
T1.BL3.BL4.P3.T2	2	0.011106	0.005553	3.31	0.043
T1.P1.BL3.P2.BL4.P3	1	0.001455	0.001455	0.87	0.355
T1.P1.BL3.P2.BL4.T2	2	0.003203	0.001601	0.96	0.391
T1.P1.BL3.BL4.P3.T2	2	0.004989	0.002494	1.49	0.234
T1.BL3.P2.BL4.P3.T2	2	0.000922	0.000461	0.28	0.760
T1.P1.BL3.P2.BL4.P3.T2	2	0.000404	0.000202	0.12	0.887
Residual	58	0.097194	0.001676		
Total	89	0.709550			

Table B.35 ANOVA table for respiration rate (mmol Kg^{-1} h^{-1}) for 'Estima' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	0.003495	0.001748	0.47	
reps.*Units* stratum					
T1	2	0.127894	0.063947	17.11	<.001
T1.P1	1	0.000284	0.000284	0.08	0.784
T1.BL3	1	0.016534	0.016534	4.42	0.040
T1.P1.BL3	1	0.000846	0.000846	0.23	0.636
T1.BL3.P2	1	0.003232	0.003232	0.86	0.356
T1.BL3.BL4	1	0.053351	0.053351	14.27	<.001
T1.P1.BL3.P2	1	0.005710	0.005710	1.53	0.221
T1.P1.BL3.BL4	1	0.000676	0.000676	0.18	0.672
T1.BL3.P2.BL4	1	0.000990	0.000990	0.26	0.609
T1.BL3.BL4.P3	1	0.029236	0.029236	7.82	0.007
T1.BL3.BL4.T2	2	0.585270	0.292635	78.28	<.001
T1.P1.BL3.P2.BL4	1	0.001044	0.001044	0.28	0.599
T1.P1.BL3.BL4.P3	1	0.000848	0.000848	0.23	0.635
T1.BL3.P2.BL4.P3	1	0.000004	0.000004	0.00	0.973
T1.P1.BL3.BL4.T2	2	0.029708	0.014854	3.97	0.024
T1.BL3.P2.BL4.T2	2	0.000683	0.000341	0.09	0.913
T1.BL3.BL4.P3.T2	2	0.028520	0.014260	3.81	0.027
T1.P1.BL3.P2.BL4.P3	1	0.007811	0.007811	2.09	0.153
T1.P1.BL3.P2.BL4.T2	2	0.009323	0.004662	1.25	0.294
T1.P1.BL3.BL4.P3.T2	2	0.008109	0.004055	1.08	0.344
T1.BL3.P2.BL4.P3.T2	2	0.000828	0.000414	0.11	0.895
T1.P1.BL3.P2.BL4.P3.T2	2	0.002688	0.001344	0.36	0.699
Residual	62	0.231767	0.003738		
Total	95	1.148848			

Table B.36 ANOVA table for respiration rate (mmol Kg^{-1} h^{-1}) for 'Saturna' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	0.000291	0.000146	0.07	
reps.*Units* stratum					
T1	2	0.062970	0.031485	15.89	<.001
T1.P1	1	0.007697	0.007697	3.89	0.053
T1.BL3.P2	1	0.000308	0.000308	0.16	0.695
T1.BL3.BL4	1	0.126570	0.126570	63.90	<.001
T1.P1.BL3.P2	1	0.002036	0.002036	1.03	0.315
T1.P1.BL3.BL4	1	0.001624	0.001624	0.82	0.369
T1.BL3.P2.BL4	1	0.000001	0.000001	0.00	0.984
T1.BL3.BL4.P3	1	0.006749	0.006749	3.41	0.070
T1.BL3.BL4.T2	2	1.052241	0.526121	265.60	<.001
T1.P1.BL3.P2.BL4	1	0.000005	0.000005	0.00	0.959
T1.P1.BL3.BL4.P3	1	0.000692	0.000692	0.35	0.557
T1.BL3.P2.BL4.P3	1	0.015934	0.015934	8.04	0.006
T1.P1.BL3.BL4.T2	2	0.018446	0.009223	4.66	0.013
T1.BL3.P2.BL4.T2	2	0.004785	0.002392	1.21	0.306
T1.BL3.BL4.P3.T2	2	0.002073	0.001037	0.52	0.595
T1.P1.BL3.P2.BL4.P3	1	0.000642	0.000642	0.32	0.571
T1.P1.BL3.P2.BL4.T2	2	0.006897	0.003449	1.74	0.184
T1.P1.BL3_BL4.P3.T2	2	0.006754	0.003377	1.70	0.191
T1.BL3.P2.BL4.P3.T2	2	0.001438	0.000719	0.36	0.697
T1.P1.BL3.P2.BL4.P3.T2	2	0.013699	0.006850	3.46	0.038
Residual	58	0.114889	0.001981		
Total	89	1.446743			

Table B.37 ANOVA table for respiration rate (mmol Kg^{-1} h^{-1}) for 'Russet Burbank' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	0.00661	0.00331	0.22	
reps.*Units* stratum					
T1	2	0.08086	0.04043	2.74	0.072
T1.P1	1	0.06557	0.06557	4.45	0.039
T1.BL3	1	0.03371	0.03371	2.29	0.136
T1.P1.BL3	1	0.00261	0.00261	0.18	0.676
T1.BL3.P2	1	0.01054	0.01054	0.71	0.401
T1.BL3.BL4	1	0.16329	0.16329	11.07	0.001
T1.P1.BL3.P2	1	0.02232	0.02232	1.51	0.223
T1.P1.BL3.BL4	1	0.00251	0.00251	0.17	0.681
T1.BL3.P2.BL4	1	0.00034	0.00034	0.02	0.880
T1.BL3.BL4.P3	1	0.08295	0.08295	5.62	0.021
T1.BL3.BL4.T2	2	0.48773	0.24387	16.53	<.001
T1.P1.BL3.P2.BL4	1	0.00122	0.00122	0.08	0.774
T1.P1.BL3.BL4.P3	1	0.00990	0.00990	0.67	0.416
T1.BL3.P2.BL4.P3	1	0.02497	0.02497	1.69	0.198
T1.P1.BL3.BL4.T2	2	0.06863	0.03432	2.33	0.106
T1.BL3.P2.BL4.T2	2	0.01710	0.00855	0.58	0.563
T1.BL3.BL4.P3.T2	2	0.03659	0.01829	1.24	0.296
T1.P1.BL3.P2.BL4.P3	1	0.00013	0.00013	0.01	0.926
T1.P1.BL3.P2.BL4.T2	2	0.02543	0.01271	0.86	0.427
T1.P1.BL3.BL4.P3.T2	2	0.04880	0.02440	1.65	0.200
T1.BL3.P2.BL4.P3.T2	2	0.00903	0.00451	0.31	0.738
T1.P1.BL3.P2.BL4.P3.T2	2	0.08788	0.04394	2.98	0.058
Residual	62	0.91448	0.01475		
Total	95	2.20321			

Table B.38 ANOVA table for ethylene production (mmol Kg^{-1} h^{-1}) for 'Marfona' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	0.00230	0.00115	0.11	
reps.*Units* stratum					
T1	2	0.11978	0.05989	5.94	0.004
T1.P1	1	0.02155	0.02155	2.14	0.149
T1.BL3.P2	1	0.00532	0.00532	0.53	0.471
T1.BL3.BL4	1	0.36095	0.36095	35.80	<.001
T1.P1.BL3.P2	1	0.00835	0.00835	0.83	0.366
T1.P1.BL3.BL4	1	0.00359	0.00359	0.36	0.553
T1.BL3.P2.BL4	1	0.00089	0.00089	0.09	0.768
T1.BL3.BL4.P3	1	0.04227	0.04227	4.19	0.045
T1.BL3.BL4.T2	2	4.23910	2.11955	210.25	<.001
T1.P1.BL3.P2.BL4	1	0.00139	0.00139	0.14	0.712
T1.P1.BL3.BL4.P3	1	0.00784	0.00784	0.78	0.382
T1.BL3.P2.BL4.P3	1	0.03458	0.03458	3.43	0.069
T1.P1.BL3.BL4.T2	2	0.03274	0.01637	1.62	0.206
T1.BL3.P2.BL4.T2	2	0.00705	0.00352	0.35	0.707
T1.BL3.BL4.P3.T2	2	0.13501	0.06751	6.70	0.002
T1.P1.BL3.P2.BL4.P3	1	0.01626	0.01626	1.61	0.209
T1.P1.BL3.P2.BL4.T2	2	0.01674	0.00837	0.83	0.441
T1.P1.BL3.BL4.P3.T2	2	0.00604	0.00302	0.30	0.742
T1.BL3.P2.BL4.P3.T2	2	0.05183	0.02591	2.57	0.085
T1.P1.BL3.P2.BL4.P3.T2	2	0.02343	0.01172	1.16	0.320
Residual	58	0.58471	0.01008		
Total	89	5.72170			

Table B.39 ANOVA table for ethylene production (mmol Kg^{-1} h^{-1}) for 'Estima' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	0.6484	0.3242	1.31	
reps.*Units* stratum					
T1	2	2.0017	1.0009	4.05	0.022
T1.P1	1	20.7583	20.7583	83.92	<.001
T1.BL3	1	211.8187	211.8187	856.37	<.001
T1.P1.BL3	1	221.3716	221.3716	894.99	<.001
T1_BL3.P2	1	0.0279	0.0279	0.11	0.738
T1.BL3.BL4	1	0.5503	0.5503	2.22	0.141
T1.P1.BL3.P2	1	0.2184	0.2184	0.88	0.351
T1.P1.BL3.BL4	1	0.0523	0.0523	0.21	0.647
T1.BL3.P2.BL4	1	0.0046	0.0046	0.02	0.891
T1.BL3.BL4.P3	1	0.8486	0.8486	3.43	0.069
T1.BL3.BL4.T2	2	5.2896	2.6448	10.69	<.001
T1.P1.BL3.P2.BL4	1	0.0364	0.0364	0.15	0.703
T1.P1.BL3.BL4.P3	1	0.0713	0.0713	0.29	0.593
T1.BL3.P2.BL4.P3	1	0.4459	0.4459	1.80	0.184
T1.P1.BL3.BL4.T2	2	0.6307	0.3154	1.27	0.287
T1.BL3.P2.BL4.T2	2	0.0774	0.0387	0.16	0.856
T1.BL3.BL4.P3.T2	2	1.4219	0.7110	2.87	0.064
T1.P1.BL3.P2.BL4.P3	1	0.1468	0.1468	0.59	0.444
T1.P1.BL3.P2.BL4.T2	2	0.4767	0.2384	0.96	0.387
T1.P1.BL3.BL4.P3.T2	2	0.1838	0.0919	0.37	0.691
T1.BL3.P2.BL4.P3.T2	2	0.9402	0.4701	1.90	0.158
T1.P1.BL3.P2.BL4.P3.T2	2	0.2781	0.1391	0.56	0.573
Residual	62	15.3355	0.2473		
Total	95	483.6352			

Table B.40 ANOVA table for ethylene production (mmol Kg^{-1} h^{-1}) for 'Saturna' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	0.09235	0.04617	0.70	
reps.*Units* stratum					
T1	2	0.47124	0.23562	3.56	0.035
T1.P1	1	0.15028	0.15028	2.27	0.137
T1.BL3.P2	1	0.00045	0.00045	0.01	0.935
T1.BL3.BL4	1	0.07631	0.07631	1.15	0.287
T1.P1.BL3.P2	1	0.08826	0.08826	1.33	0.253
T1.P1.BL3.BL4	1	0.75039	0.75039	11.34	0.001
T1.BL3.P2.BL4	1	0.17923	0.17923	2.71	0.105
T1.BL3.BL4.P3	1	0.46416	0.46416	7.01	0.010
T1.BL3.BL4.T2	2	9.31640	4.65820	70.39	<.001
T1.P1.BL3.P2.BL4	1	0.96657	0.96657	14.61	<.001
T1.P1.BL3.BL4.P3	1	0.01853	0.01853	0.28	0.599
T1.BL3.P2.BL4.P3	1	0.03973	0.03973	0.60	0.442
T1.P1.BL3.BL4.T2	2	0.88051	0.44025	6.65	0.003
T1.BL3.P2.BL4.T2	2	0.02580	0.01290	0.19	0.823
T1.BL3.BL4.P3.T2	2	1.15727	0.57863	8.74	<.001
T1.P1.BL3.P2.BL4.P3	1	0.00912	0.00912	0.14	0.712
T1.P1.BL3.P2.BL4.T2	2	0.01407	0.00703	0.11	0.899
T1.P1.BL3.BL4.P3.T2	2	0.16077	0.08039	1.21	0.304
T1.BL3.P2.BL4.P3.T2	2	0.02647	0.01323	0.20	0.819
T1.P1.BL3.P2.BL4.P3.T2	2	0.00822	0.00411	0.06	0.940
Residual	58	3.83830	0.06618		
Total	89	18.73444			

Table B.41 ANOVA table for ethylene production (mmol Kg^{-1} h^{-1}) for 'Russet Burbank' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	2.414	1.207	0.52	
reps.*Units* stratum					
T1	2	7.796	3.898	1.69	0.193
T1.P1	1	116.303	116.303	50.44	<.001
T1.BL3	1	871.217	871.217	377.84	<.001
T1.P1.BL3	1	878.245	878.245	380.89	<.001
T1.BL3.P2	1	5.402	5.402	2.34	0.131
T1.BL3.BL4	1	1.736	1.736	0.75	0.389
T1.P1.BL3.P2	1	5.676	5.676	2.46	0.122
T1.P1.BL3.BL4	1	1.276	1.276	0.55	0.460
T1.BL3.P2.BL4	1	0.900	0.900	0.39	0.534
T1.BL3.BL4.P3	1	1.737	1.737	0.75	0.389
T1.BL3.BL4.T2	2	18.760	9.380	4.07	0.022
T1.P1.BL3.P2.BL4	1	0.946	0.946	0.41	0.524
T1.P1.BL3.BL4.P3	1	1.935	1.935	0.84	0.363
T1.BL3.P2.BL4.P3	1	0.565	0.565	0.25	0.622
T1.P1.BL3.BL4.T2	2	16.850	8.425	3.65	0.032
T1.BL3.P2.BL4.T2	2	11.894	5.947	2.58	0.084
T1.BL3.BL4.P3.T2	2	3.251	1.626	0.70	0.498
T1.P1.BL3.P2.BL4.P3	1	0.751	0.751	0.33	0.570
T1.P1.BL3.P2.BL4.T2	2	12.959	6.479	2.81	0.068
T1.P1.BL3.BL4.P3.T2	2	4.076	2.038	0.88	0.418
T1.BL3.P2.BL4.P3.T2	2	1.201	0.601	0.26	0.772
T1.P1.BL3.P2.BL4.P3.T2	2	1.267	0.633	0.27	0.761
Residual	62	142.959	2.306		
Total	95	2110.117			

Table B.42 ANOVA table for sucrose concentration (mg g^{-1} DW) in flesh for 'Marfona' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	0.700	0.350	0.09	
reps.*Units* stratum					
T1	2	292.408	146.204	39.20	<.001
T1.P1	1	356.981	356.981	95.70	<.001
T1.BL3.P2	1	13.467	13.467	3.61	0.062
T1.BL3.BL4	1	87.135	87.135	23.36	<.001
T1.P1.BL3.P2	1	7.339	7.339	1.97	0.166
T1.P1.BL3.BL4	1	0.614	0.614	0.16	0.686
T1.BL3.P2.BL4	1	29.500	29.500	7.91	0.007
T1.BL3.BL4.P3	1	59.766	59.766	16.02	<.001
T1.BL3.BL4.T2	2	9.264	4.632	1.24	0.296
T1.P1.BL3.P2.BL4	1	36.828	36.828	9.87	0.003
T1.P1.BL3.BL4.P3	1	0.033	0.033	0.01	0.925
T1.BL3.P2.BL4.P3	1	5.339	5.339	1.43	0.236
T1.P1.BL3.BL4.T2	2	35.109	17.555	4.71	0.013
T1.BL3.P2.BL4.T2	2	15.960	7.980	2.14	0.127
T1.BL3.BL4.P1.T2	2	4.379	2.190	0.59	0.559
T1.P1.BL3.P2.BL4.P3	1	2.867	2.867	0.77	0.384
T1.P1.BL3.P2.BL4.T2	2	33.700	16.850	4.52	0.015
T1.P1.BL3.BL4.P3.T2	2	8.134	4.067	1.09	0.343
T1.BL3.P2.BL4.P3.T2	2	9.605	4.803	1.29	0.284
T1.P1.BL3.P2.BL4.P3.T2	2	4.662	2.331	0.62	0.539
Residual	58	216.349	3.730		
Total	89	1230.139			

Table B.43 ANOVA table for glucose concentration (mg g^{-1} DW) in flesh for 'Marfona' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	70.28	35.14	0.50	
reps.*Units* stratum					
T1	2	5239.38	2619.69	36.92	<.001
T1.P1	1	3611.07	3611.07	50.89	<.001
T1.BL3.P2	1	3.44	3.44	0.05	0.827
T1.BL3.BL4	1	494.94	494.94	6.98	0.011
T1.P1.BL3.P2	1	77.79	77.79	1.10	0.299
T1.P1.BL3.BL4	1	8.97	8.97	0.13	0.723
T1.BL3.P2.BL4	1	1.35	1.35	0.02	0.891
T1.BL3.BL4.P3	1	143.94	143.94	2.03	0.160
T1.BL3.BL4.T2	2	82.95	41.47	0.58	0.561
T1.P1.BL3.P2.BL4	1	40.52	40.52	0.57	0.453
T1.P1.BL3.BL4.P3	1	6.58	6.58	0.09	0.762
T1.BL3.P2.BL4.P3	1	27.78	27.78	0.39	0.534
T1.P1.BL3.BL4.T2	2	338.98	169.49	2.39	0.101
T1.BL3.P2.BL4.T2	2	68.12	34.06	0.48	0.621
T1.BL3.BL4_P3.T2	2	33.69	16.84	0.24	0.789
T1.P1.BL3.P2.BL4.P3	1	60.04	60.04	0.85	0.361
T1.P1.BL3.P2.BL4.T2	2	63.17	31.58	0.45	0.643
T1.P1.BL3.BL4.P3.T2	2	177.65	88.82	1.25	0.294
T1.BL3.P2.BL4.P3.T2	2	0.55	0.28	0.00	0.996
T1.P1.BL3.P2.BL4.P3.T2	2	315.63	157.81	2.22	0.117
Residual	58	4115.52	70.96		
Total	89	14982.33			

Table B.44 ANOVA table for fructose concentration (mg g^{-1} DW) in flesh for 'Marfona' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	25.04	12.52	0.32	
reps.*Units* stratum					
T1	2	4135.74	2067.87	52.74	<.001
T1.P1	1	4394.02	4394.02	112.07	<.001
T1.BL3.P2	1	49.61	49.61	1.27	0.265
T1.BL3.BL4	1	182.46	182.46	4.65	0.035
T1.P1.BL3.P2	1	228.73	228.73	5.83	0.019
T1.P1.BL3.BL4	1	0.15	0.15	0.00	0.951
T1.BL3.P2.BL4	1	20.63	20.63	0.53	0.471
T1.BL3.BL4.P3	1	435.50	435.50	11.11	0.002
T1.BL3.BL4.T2	2	128.92	64.46	1.64	0.202
T1.P1.BL3.P2.BL4	1	31.45	31.45	0.80	0.374
T1.P1.BL3.BL4.P3	1	1.13	1.13	0.03	0.866
T1.BL3.P2.BL4.P3	1	0.29	0.29	0.01	0.932
T1.P1.BL3.BL4.T2	2	220.31	110.15	2.81	0.068
T1.BL3.P2.BL4.T2	2	122.53	61.26	1.56	0.218
T1.BL3.BL4.P3.T2	2	38.05	19.02	0.49	0.618
T1.P1.BL3.P2.BL4.P3	1	47.83	47.83	1.22	0.274
T1.P1.BL3.P2.BL4.T2	2	123.17	61.59	1.57	0.217
T1.P1.BL3.BL4.P3.T2	2	118.08	59.04	1.51	0.230
T1.BL3.P2.BL4.P3.T2	2	60.63	30.31	0.77	0.466
T1.P1.BL3.P2.BL4.P3.T2	2	187.83	93.92	2.40	0.100
Residual	58	2274.15	39.21		
Total	89	12826.25			

Table B.45 ANOVA table for sucrose concentration (mg g^{-1} DW) in flesh for 'Estima' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	4.189	2.094	1.02	
reps.*Units* stratum					
T1	2	199.374	99.687	48.36	<.001
T1.P1	1	95.639	95.639	46.39	<.001
T1.BL3	1	4.621	4.621	2.24	0.139
T1.P1.BL3	1	0.961	0.961	0.47	0.497
T1.BL3.P2	1	22.793	22.793	11.05	0.001
T1.BL3.BL4	1	27.725	27.725	13.45	<.001
T1.P1.BL3.P2	1	2.790	2.790	1.35	0.249
T1.P1.BL3.BL4	1	2.741	2.741	1.33	0.253
T1.BL3.P2.BL4	1	3.385	3.385	1.64	0.205
T1.BL3.BL4.P3	1	12.476	12.476	6.05	0.017
T1.BL3.BL4.T2	2	85.643	42.822	20.77	<.001
T1.P1.BL3.P2.BL4	1	0.064	0.064	0.03	0.860
T1.P1.BL3.BL4.P3	1	0.157	0.157	0.08	0.783
T1.BL3.P2.BL4.P3	1	0.253	0.253	0.12	0.728
T1.P1.BL3.BL4.T2	2	18.335	9.168	4.45	0.016
T1.BL3.P2.BL4.T2	2	1.506	0.753	0.37	0.695
T1.BL3.BL4.P3.T2	2	16.324	8.162	3.96	0.024
T1.P1.BL3.P2.BL4.P3	1	9.146	9.146	4.44	0.039
T1.P1.BL3.P2.BL4.T2	2	17.146	8.573	4.16	0.020
T1.P1.BL3.BL4.P3.T2	2	7.047	3.524	1.71	0.189
T1.BL3.P2.BL4.P3.T2	2	4.168	2.084	1.01	0.370
T1.P1.BL3.P2.BL4.P3.T2	2	2.654	1.327	0.64	0.529
Residual	62	127.814	2.062		
Total	95	666.952			

Table B.46 ANOVA table for glucose concentration (mg g^{-1} DW) in flesh for 'Estima' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	301.28	150.64	2.51	
reps.*Units* stratum					
T1	2	839.08	419.54	6.99	0.002
T1.P1	1	551.33	551.33	9.18	0.004
T1.BL3	1	397.02	397.02	6.61	0.013
T1.P1.BL3	1	9.98	9.98	0.17	0.685
T1.BL3.P2	1	265.79	265.79	4.43	0.039
T1.BL3.BL4	1	896.82	896.82	14.93	<.001
T1.P1.BL3.P2	1	0.10	0.10	0.00	0.968
T1.P1.BL3.BL4	1	118.40	118.40	1.97	0.165
T1.BL3.P2.BL4	1	128.82	128.82	2.15	0.148
T1.BL3.BL4.P3	1	398.92	398.92	6.64	0.012
T1.BL3.BL4.T2	2	495.41	247.70	4.12	0.021
T1.P1.BL3.P2.BL4	1	1.99	1.99	0.03	0.856
T1.P1.BL3.BL4.P3	1	16.74	16.74	0.28	0.599
T1.BL3.P2.BL4.P3	1	0.57	0.57	0.01	0.923
T1.P1.BL3.BL4.T2	2	149.77	74.88	1.25	0.294
T1.BL3.P2.BL4.T2	2	63.37	31.68	0.53	0.593
T1.BL3.BL4.P3_1.T2	2	10.06	5.03	0.08	0.920
T1.P1.BL3.P2.BL4.P3	1	332.87	332.87	5.54	0.022
T1.P1.BL3.P2.BL4.T2	2	55.11	27.56	0.46	0.634
T1.P1.BL3.BL4.P3.T2	2	14.98	7.49	0.12	0.883
T1.BL3.P2.BL4.P3.T2	2	30.36	15.18	0.25	0.777
T1.P1.BL3.P2.BL4.P3.T2	2	95.22	47.61	0.79	0.457
Residual	62	3723.44	60.06		
Total	95	8897.40			

Table B.47 ANOVA table for fructose concentration (mg g^{-1} DW) in flesh for 'Estima' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	99.94	49.97	1.69	
reps.*Units* stratum					
T1	2	1008.00	504.00	17.02	<.001
T1.P1	1	1569.62	1569.62	52.99	<.001
T1.BL3	1	408.71	408.71	13.80	<.001
T1.P1.BL3	1	4.58	4.58	0.15	0.695
T1.BL3.P2	1	98.71	98.71	3.33	0.073
T1.BL3.BL4	1	534.92	534.92	18.06	<.001
T1.P1.BL3.P2	1	8.38	8.38	0.28	0.597
T1.P1.BL3.BL4	1	37.47	37.47	1.27	0.265
T1.BL3.P2.BL4	1	22.17	22.17	0.75	0.390
T1.BL3.BL4.P3	1	274.43	274.43	9.27	0.003
T1.BL3.BL4.T2	2	280.53	140.27	4.74	0.012
T1.P1.BL3.P2.BL4	1	2.57	2.57	0.09	0.770
T1.P1.BL3.BL4.P3	1	13.35	13.35	0.45	0.504
T1.BL3.P2.BL4.P3	1	3.19	3.19	0.11	0.744
T1.P1.BL3.BL4.T2	2	16.83	8.42	0.28	0.754
T1.BL3.P2.BL4.T2	2	25.13	12.56	0.42	0.656
T1.BL3.BL4.P3.T2	2	36.08	18.04	0.61	0.547
T1.P1.BL3.P2.BL4.P3	1	152.79	152.79	5.16	0.027
T1.P1.BL3.P2.BL4.T2	2	37.58	18.79	0.63	0.534
T1.P1.BL3.BL4.P3.T2	2	1.91	0.95	0.03	0.968
T1.BL3.P2.BL4.P3.T2	2	13.90	6.95	0.23	0.792
T1.P1.BL3.P2.BL4.P3.T2	2	11.90	5.95	0.20	0.818
Residual	62	1836.33	29.62		
Total	95	6499.01			

Table B.48 ANOVA table for sucrose concentration (mg g^{-1} DW) in flesh for 'Saturna' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	14.746	7.373	0.82	
reps.*Units* stratum					
T1	2	308.328	154.164	17.09	<.001
T1.P1	1	502.959	502.959	55.76	<.001
T1.BL3.P2	1	3.243	3.243	0.36	0.551
T1.BL3.BL4	1	136.331	136.331	15.11	<.001
T1.P1.BL3.P2	1	0.836	0.836	0.09	0.762
T1.P1.BL3.BL4	1	239.670	239.670	26.57	<.001
T1.BL3.P2.BL4	1	1.348	1.348	0.15	0.701
T1.BL3.BL4.P3	1	33.641	33.641	3.73	0.058
T1.BL3.BL4.T2	2	27.141	13.570	1.50	0.231
T1.P1.BL3.P2.BL4	1	0.002	0.002	0.00	0.988
T1.P1.BL3.BL4.P3	1	12.672	12.672	1.40	0.241
T1.BL3.P2.BL4.P3	1	21.393	21.393	2.37	0.129
T1.P1.BL3.BL4.T2	2	48.303	24.151	2.68	0.077
T1.BL3.P2.BL4.T2	2	26.442	13.221	1.47	0.239
T1.BL3.BL4.P3.T2	2	22.261	11.131	1.23	0.299
T1.P1.BL3.P2.BL4.P3	1	41.702	41.702	4.62	0.036
T1.P1.BL3.P2.BL4.T2	2	58.101	29.050	3.22	0.047
T1.P1.BL3.BL4.P3.T2	2	7.186	3.593	0.40	0.673
T1.BL3.P2.BL4.P3.T2	2	14.698	7.349	0.81	0.448
T1.P1.BL3.P2.BL4.P3.T2	2	7.784	3.892	0.43	0.652
Residual	58	523.147	9.020		
Total	89	2051.936			

Table B.49 ANOVA table for glucose concentration (mg g^{-1} DW) in flesh for 'Saturna' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	29.81	14.90	1.28	
reps.*Units* stratum					
T1	2	135.59	67.79	5.81	0.005
T1.P1	1	331.37	331.37	28.40	<.001
T1.BL3.P2	1	0.78	0.78	0.07	0.797
T1.BL3.BL4	1	45.91	45.91	3.93	0.052
T1.P1.BL3.P2	1	5.95	5.95	0.51	0.478
T1.P1.BL3.BL4	1	35.27	35.27	3.02	0.087
T1.BL3.P2.BL4	1	0.00	0.00	0.00	0.986
T1.BL3.BL4.P3	1	16.80	16.80	1.44	0.235
T1.BL3.BL4.T2	2	36.68	18.34	1.57	0.216
T1.P1.BL3.P2.BL4	1	0.01	0.01	0.00	0.973
T1.P1.BL3.BL4.P3	1	13.29	13.29	1.14	0.290
T1.BL3.P2.BL4.P3	1	0.15	0.15	0.01	0.909
T1.P1.BL3.BL4.T2	2	42.35	21.18	1.81	0.172
T1.BL3.P2.BL4.T2	2	0.56	0.28	0.02	0.976
T1.BL3.BL4.P3.T2	2	43.75	21.87	1.87	0.163
T1.P1.BL3.P2.BL4.P3	1	0.06	0.06	0.00	0.945
T1.P1.BL3.P2.BL4.T2	2	56.80	28.40	2.43	0.097
T1.P1.BL3.BL4.P3.T2	2	38.59	19.29	1.65	0.200
T1.BL3.P2.BL4.P3.T2	2	11.27	5.63	0.48	0.620
T1.P1.BL3.P2.BL4.P3.T2	2	5.01	2.50	0.21	0.808
Residual	58	676.85	11.67		
Total	89	1526.84			

Table B.50 ANOVA table for fructose concentration (mg g^{-1} DW) in flesh for 'Saturna' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	41.50	20.75	2.06	
reps.*Units* stratum					
T1	2	397.76	198.88	19.73	<.001
T1.P1	1	494.57	494.57	49.07	<.001
T1.BL3.P2	1	4.35	4.35	0.43	0.514
T1.BL3.BL4	1	311.34	311.34	30.89	<.001
T1.P1.BL3.P2	1	1.26	1.26	0.13	0.725
T1.P1.BL3.BL4	1	45.42	45.42	4.51	0.038
T1.BL3.P2.BL4	1	0.93	0.93	0.09	0.762
T1.BL3.BL4.P3	1	64.68	64.68	6.42	0.014
T1.BL3.BL4.T2	2	69.36	34.68	3.44	0.039
T1.P1.BL3.P2.BL4	1	1.92	1.92	0.19	0.664
T1.P1.BL3.BL4.P3	1	26.95	26.95	2.67	0.107
T1.BL3.P2.BL4.P3	1	1.58	1.58	0.16	0.694
T1.P1.BL3.BL4.T2	2	70.54	35.27	3.50	0.037
T1.BL3.P2.BL4.T2	2	11.66	5.83	0.58	0.564
T1.BL3.BL4.P3.T2	2	87.11	43.55	4.32	0.018
T1.P1.BL3.P2.BL4.P3	1	4.76	4.76	0.47	0.495
T1.P1.BL3.P2.BL4.T2	2	13.89	6.94	0.69	0.506
T1.P1.BL3.BL4.P3.T2	2	76.14	38.07	3.78	0.029
T1.BL3.P2.BL4.P3.T2	2	3.88	1.94	0.19	0.825
T1.P1.BL3.P2.BL4.P3.T2	2	20.28	10.14	1.01	0.372
Residual	58	584.58	10.08		
Total	89	2334.45			

Table B.51 ANOVA table for sucrose concentration (mg g^{-1} DW) in flesh for 'Russet Burbank' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps1 stratum	2	0.722	0.361	0.31	
reps.*Units* stratum					
T1	2	91.394	45.697	39.54	<.001
T1.P1	1	113.095	113.095	97.86	<.001
T1.BL3	1	1.023	1.023	0.88	0.351
T1.P1.BL3	1	28.580	28.580	24.73	<.001
T1.BL3.P2	1	0.357	0.357	0.31	0.580
T1.BL3.BL4	1	38.442	38.442	33.26	<.001
T1.P1.BL3.P2	1	1.116	1.116	0.97	0.330
T1.P1.BL3.BL4	1	0.627	0.627	0.54	0.464
T1.BL3.P2.BL4	1	0.079	0.079	0.07	0.795
T1.BL3.BL4.P3	1	29.462	29.462	25.49	<.001
T1.BL3.BL4.T2	2	22.662	11.331	9.80	<.001
T1.P1.BL3.P2.BL4	1	1.714	1.714	1.48	0.228
T1.P1.BL3.BL4.P3	1	0.527	0.527	0.46	0.502
T1.BL3.P2.BL4.P3	1	0.056	0.056	0.05	0.827
T1.P1.BL3.BL4.T2	2	16.185	8.092	7.00	0.002
T1.BL3.P2.BL4.T2	2	2.000	1.000	0.87	0.426
T1.BL3.BL4.P3.T2	2	10.030	5.015	4.34	0.017
T1.P1.BL3.P2.BL4.P3	1	0.160	0.160	0.14	0.711
T1.P1.BL3.P2.BL4.T2	2	0.577	0.288	0.25	0.780
T1.P1.BL3.BL4.P3.T2	2	2.364	1.182	1.02	0.366
T1.BL3.P2.BL4.P3.T2	2	5.597	2.798	2.42	0.097
T1.P1.BL3.P2.BL4.P3.T2	2	7.564	3.782	3.27	0.045
Residual	62	71.651	1.156		
Total	95	445.984			

Table B.52 ANOVA table for glucose concentration (mg g^{-1} DW) in flesh for 'Russet Burbank' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	3.74	1.87	0.13	
reps.*Units* stratum					
T1	2	567.54	283.77	19.94	<.001
T1.P1	1	911.77	911.77	64.08	<.001
T1.BL3	1	0.49	0.49	0.03	0.853
T1.P1.BL3	1	126.72	126.72	8.91	0.004
T1.BL3.P2	1	10.04	10.04	0.71	0.404
T1.BL3.BL4	1	335.01	335.01	23.55	<.001
T1.P1.BL3.P2	1	17.30	17.30	1.22	0.274
T1.P1.BL3.BL4	1	268.60	268.60	18.88	<.001
T1.BL3.P2.BL4	1	1.96	1.96	0.14	0.712
T1.BL3.BL4.P3	1	238.34	238.34	16.75	<.001
T1.BL3.BL4.T2	2	430.76	215.38	15.14	<.001
T1.P1.BL3.P2.BL4	1	61.39	61.39	4.31	0.042
T1.P1.BL3.BL4.P3	1	4.69	4.69	0.33	0.568
T1.BL3.P2.BL4.P3	1	1.78	1.78	0.13	0.724
T1.P1.BL3.BL4.T2	2	140.41	70.20	4.93	0.010
T1.BL3.P2.BL4.T2	2	30.65	15.32	1.08	0.347
T1.BL3.BL4.P3.T2	2	115.73	57.87	4.07	0.022
T1.P1.BL3.P2.BL4.P3	1	16.84	16.84	1.18	0.281
T1.P1.BL3.P2.BL4.T2	2	91.74	45.87	3.22	0.047
T1.P1.BL3.BL4.P3.T2	2	11.76	5.88	0.41	0.663
T1.BL3.P2.BL4.P3.T2	2	0.22	0.11	0.01	0.992
T1.P1.BL3.P2.BL4.P3.T2	2	22.55	11.27	0.79	0.457
Residual	62	882.13	14.23		
Total	95	4292.16			

Table B.53 ANOVA table for fructose concentration (mg g^{-1} DW) in flesh for 'Russet Burbank' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	1.71	0.86	0.07	
reps.*Units* stratum					
T1	2	771.81	385.90	32.74	<.001
T1.P1	1	2776.47	2776.47	235.58	<.001
T1.BL3	1	0.40	0.40	0.03	0.855
T1.P1.BL3	1	67.87	67.87	5.76	0.019
T1.BL3.P2	1	2.94	2.94	0.25	0.619
T1.BL3.BL4	1	193.82	193.82	16.45	<.001
T1.P1.BL3.P2	1	9.09	9.09	0.77	0.383
T1.P1.BL3.BL4	1	213.95	213.95	18.15	<.001
T1.BL3.P2.BL4	1	2.55	2.55	0.22	0.644
T1.BL3.BL4.P3	1	163.86	163.86	13.90	<.001
T1.BL3.BL4.T2	2	269.29	134.65	11.42	<.001
T1.P1.BL3.P2.BL4	1	14.46	14.46	1.23	0.272
T1.P1.BL3.BL4.P3	1	2.09	2.09	0.18	0.675
T1.BL3.P2.BL4.P3	1	4.62	4.62	0.39	0.534
T1.P1.BL3.BL4.T2	2	5.04	2.52	0.21	0.808
T1.BL3.P2.BL4.T2	2	28.16	14.08	1.19	0.310
T1.BL3.BL4.P3.T2	2	115.11	57.55	4.88	0.011
T1.P1.BL3.P2.BL4.P3	1	15.05	15.05	1.28	0.263
T1.P1.BL3.P2.BL4.T2	2	54.92	27.46	2.33	0.106
T1.P1.BL3.BL4.P3.T2	2	34.92	17.46	1.48	0.235
T1.BL3.P2.BL4.P3.T2	2	1.80	0.90	0.08	0.926
T1.P1.BL3.P2.BL4.P3.T2	2	53.62	26.81	2.27	0.111
Residual	62	730.71	11.79		
Total	95	5534.27			

Table B.54 ANOVA table for firmness (N) for 'Marfona' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	4.41	2.20	0.14	
reps.*Units* stratum					
T1	2	3.71	1.86	0.12	0.889
T1.P1	1	0.63	0.63	0.04	0.843
T1.BL3.P2	1	159.08	159.08	10.08	0.002
T1.BL3.BL4	1	28.92	28.92	1.83	0.181
T1.P1.BL3.P2	1	4.96	4.96	0.31	0.577
T1.P1.BL3.BL4	1	1.36	1.36	0.09	0.770
T1.BL3.P2.BL4	1	26.09	26.09	1.65	0.204
T1.BL3.BL4.P3	1	3.15	3.15	0.20	0.657
T1.BL3.BL4.T2	2	52.35	26.17	1.66	0.199
T1.P1.BL3.P2.BL4	1	15.88	15.88	1.01	0.320
T1.P1.BL3.BL4.P3	1	0.95	0.95	0.06	0.807
T1.BL3.P2.BL4.P3	1	31.08	31.08	1.97	0.166
T1.P1.BL3.BL4.T2	2	22.61	11.30	0.72	0.493
T1.BL3.P2.BL4.T2	2	5.67	2.84	0.18	0.836
T1.BL3.BL4.P3.T2	2	5.16	2.58	0.16	0.850
T1.P1.BL3.P2.BL4.P3	1	52.71	52.71	3.34	0.073
T1.P1.BL3.P2.BL4.T2	2	17.63	8.82	0.56	0.575
T1.P1.BL3.BL4.P3.T2	2	7.53	3.76	0.24	0.789
T1.BL3.P2.BL4.P3.T2	2	30.36	15.18	0.96	0.388
T1.P1.BL3.P2.BL4.P3.T2	2	9.24	4.62	0.29	0.747
Residual	58	915.41	15.78		
Total	89	1398.87			

Table B.55 ANOVA table for apparent elasticity (N mm^{-2}) for 'Marfona' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	0.04698	0.02349	0.62	
reps.*Units* stratum					
T1	2	0.21406	0.10703	2.82	0.068
T1.P1	1	0.00117	0.00117	0.03	0.861
T1.BL3.P2	1	0.10549	0.10549	2.78	0.101
T1.BL3.BL4	1	0.14503	0.14503	3.82	0.055
T1.P1.BL3.P2	1	0.00634	0.00634	0.17	0.684
T1.P1.BL3.BL4	1	0.06329	0.06329	1.67	0.202
T1.BL3.P2.BL4	1	0.02208	0.02208	0.58	0.449
T1.BL3.BL4.P3	1	0.11318	0.11318	2.98	0.089
T1.BL3.BL4.T2	2	0.58438	0.29219	7.70	0.001
T1.P1.BL3.P2.BL4	1	0.02355	0.02355	0.62	0.434
T1.P1.BL3.BL4.P3	1	0.02318	0.02318	0.61	0.438
T1.BL3.P2.BL4.P3	1	0.12372	0.12372	3.26	0.076
T1.P1.BL3.BL4.T2	2	0.22681	0.11341	2.99	0.058
T1.BL3.P2.BL4.T2	2	0.01257	0.00628	0.17	0.848
T1.BL3.BL4.P3.T2	2	0.09570	0.04785	1.26	0.291
T1.P1.BL3.P2.BL4.P3	1	0.00000	0.00000	0.00	0.992
T1.P1.BL3.P2.BL4.T2	2	0.02546	0.01273	0.34	0.716
T1.P1.BL3.BL4.P3.T2	2	0.00038	0.00019	0.00	0.995
T1.BL3.P2.BL4.P3.T2	2	0.09768	0.04884	1.29	0.284
T1.P1.BL3.P2.BL4.P3.T2	2	0.03909	0.01955	0.52	0.600
Residual	58	2.20019	0.03793		
Total	89	4.17033			

Table B.56 ANOVA table for firmness (N) for 'Estima' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	9.32	4.66	0.39	
reps.*Units* stratum					
T1	2	78.86	39.43	3.29	0.044
T1.P1	1	0.00	0.00	0.00	0.997
T1.BL3	1	61.69	61.69	5.14	0.027
T1.P1.BL3	1	4.03	4.03	0.34	0.564
T1.BL3.P2	1	18.96	18.96	1.58	0.213
T1.BL3.BL4	1	1.22	1.22	0.10	0.751
T1.P1.BL3.P2	1	20.42	20.42	1.70	0.197
T1.P1.BL3.BL4	1	0.14	0.14	0.01	0.914
T1.BL3.P2.BL4	1	1.65	1.65	0.14	0.712
T1.BL3.BL4.P3	1	2.96	2.96	0.25	0.621
T1.BL3.BL4.T2	2	88.64	44.32	3.69	0.031
T1.P1.BL3.P2.BL4	1	12.54	12.54	1.04	0.311
T1.P1.BL3.BL4.P3	1	1.98	1.98	0.17	0.686
T1.BL3.P2.BL4.P3	1	34.06	34.06	2.84	0.097
T1.P1.BL3.BL4.T2	2	9.89	4.95	0.41	0.664
T1.BL3.P2.BL4.T2	2	3.08	1.54	0.13	0.880
T1.BL3.BL4.P3.T2	2	21.89	10.94	0.91	0.407
T1.P1.BL3.P2.BL4.P3	1	3.12	3.12	0.26	0.612
T1.P1.BL3.P2.BL4.T2	2	4.42	2.21	0.18	0.832
T1.P1.BL3.BL4.P3.T2	2	50.81	25.41	2.12	0.129
T1.BL3.P2.BL4.P3.T2	2	104.41	52.21	4.35	0.017
T1.P1.BL3.P2.BL4.P3.T2	2	20.19	10.10	0.84	0.436
Residual	62	744.16	12.00		
Total	95	1298.46			

Table B.57 ANOVA table for apparent elasticity (N mm^{-2}) for 'Estima' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	0.00208	0.00104	0.06	
reps.*Units* stratum					
T1	2	0.43019	0.21509	12.87	<.001
T1.P1	1	0.03385	0.03385	2.02	0.160
T1.BL3	1	0.72477	0.72477	43.36	<.001
T1.P1.BL3	1	0.04390	0.04390	2.63	0.110
T1.BL3.P2	1	0.00369	0.00369	0.22	0.640
T1.BL3.BL4	1	0.11695	0.11695	7.00	0.010
T1.P1.BL3.P2	1	0.00014	0.00014	0.01	0.927
T1.P1.BL3.BL4	1	0.00710	0.00710	0.42	0.517
T1.BL3.P2.BL4	1	0.03130	0.03130	1.87	0.176
T1.BL3.BL4.P3	1	0.00454	0.00454	0.27	0.604
T1.BL3.BL4.T2	2	0.40072	0.20036	11.99	<.001
T1.P1.BL3.P2.BL4	1	0.00975	0.00975	0.58	0.448
T1.P1.BL3.BL4.P3	1	0.00000	0.00000	0.00	0.990
T1.BL3.P2.BL4.P3	1	0.00126	0.00126	0.08	0.785
T1.P1.BL3.BL4.T2	2	0.08242	0.04121	2.47	0.093
T1.BL3.P2.BL4.T2	2	0.02145	0.01073	0.64	0.530
T1.BL3.BL4.P3.T2	2	0.03603	0.01802	1.08	0.347
T1.P1.BL3.P2.BL4.P3	1	0.00097	0.00097	0.06	0.810
T1.P1.BL3.P2.BL4.T2	2	0.09549	0.04774	2.86	0.065
T1.P1.BL3.BL4.P3.T2	2	0.01707	0.00853	0.51	0.603
T1.BL3.P2.BL4.P3.T2	2	0.17093	0.08546	5.11	0.009
T1.P1.BL3.P2.BL4.P3.T2	2	0.03871	0.01935	1.16	0.321
Residual	62	1.03630	0.01671		
Total	95	3.30960			

Table B.58 ANOVA table for firmness (N) for 'Saturna' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	59.41	29.71	1.21	
reps.*Units* stratum					
T1	2	1.52	0.76	0.03	0.970
T1.P1	1	7.49	7.49	0.30	0.583
T1.BL3.P2	1	1.93	1.93	0.08	0.780
T1.BL3.BL4	1	7.28	7.28	0.30	0.589
T1.P1.BL3.P2	1	0.05	0.05	0.00	0.964
T1.P1.BL3.BL4	1	0.00	0.00	0.00	0.996
T1.BL3.P2.BL4	1	4.64	4.64	0.19	0.665
T1.BL3.BL4.P3	1	0.42	0.42	0.02	0.897
T1.BL3.BL4.T2	2	75.20	37.60	1.53	0.225
T1.P1.BL3.P2.BL4	1	2.45	2.45	0.10	0.753
T1.P1.BL3.BL4.P3	1	58.79	58.79	2.39	0.127
T1.BL3.P2.BL4.P3	1	14.74	14.74	0.60	0.442
T1.P1.BL3.BL4.T2	2	5.07	2.53	0.10	0.902
T1.BL3.P2.BL4.T2	2	3.60	1.80	0.07	0.930
T1.BL3.BL4.P3.T2	2	69.88	34.94	1.42	0.250
T1.P1.BL3.P2.BL4.P3	1	61.63	61.63	2.51	0.119
T1.P1.BL3.P2.BL4.T2	2	14.78	7.39	0.30	0.741
T1.P1.BL3.BL4.P3.T2	2	97.74	48.87	1.99	0.146
T1.BL3.P2.BL4.P3.T2	2	96.29	48.15	1.96	0.150
T1.P1.BL3.P2.BL4.P3.T2	2	62.94	31.47	1.28	0.286
Residual	58	1426.02	24.59		
Total	89	2071.88			

Table B.59 ANOVA table for apparent elasticity (N mm^{-2}) for 'Saturna' potatoes in Experiment 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	0.2765	0.1383	0.42	
reps.*Units* stratum					
T1	2	0.0118	0.0059	0.02	0.982
T1.P1	1	0.3151	0.3151	0.96	0.330
T1.BL3.P2	1	0.4632	0.4632	1.42	0.239
T1.BL3.BL4	1	0.0174	0.0174	0.05	0.818
T1.P1.BL3.P2	1	0.2859	0.2859	0.88	0.353
T1.P1.BL3.BL4	1	0.1234	0.1234	0.38	0.541
T1.BL3.P2.BL4	1	0.0431	0.0431	0.13	0.718
T1.BL3.BL4.P3	1	0.8128	0.8128	2.49	0.120
T1.BL3.BL4.T2	2	0.3141	0.1571	0.48	0.621
T1.P1.BL3.P2.BL4	1	0.1074	0.1074	0.33	0.569
T1.P1.BL3.BL4.P3	1	0.3428	0.3428	1.05	0.310
T1.BL3.P2.BL4.P3	1	0.3136	0.3136	0.96	0.331
T1.P1.BL3.BL4.T2	2	0.7098	0.3549	1.09	0.344
T1.BL3.P2.BL4.T2	2	1.1146	0.5573	1.71	0.191
T1.BL3.BL4.P3.T2	2	0.5008	0.2504	0.77	0.469
T1.P1.BL3.P2.BL4.P3	1	0.1962	0.1962	0.60	0.441
T1.P1.BL3.P2.BL4.T2	2	0.4913	0.2457	0.75	0.476
T1.P1.BL3.BL4.P3.T2	2	0.6005	0.3002	0.92	0.405
T1.BL3.P2.BL4.P3.T2	2	0.7368	0.3684	1.13	0.331
T1.P1.BL3.P2.BL4.P3.T2	2	0.8499	0.4249	1.30	0.280
Residual	58	18.9474	0.3267		
Total	89	27.5746			

Table B.60 ANOVA table for firmness (N) for 'Russet Burbank' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	13.980	6.990	0.74	
reps.*Units* stratum					
T1	2	7.853	3.927	0.41	0.663
T1.P1	1	1.437	1.437	0.15	0.699
T1.BL3	1	14.147	14.147	1.49	0.227
T1.P1.BL3	1	27.901	27.901	2.94	0.092
T1.BL3.P2	1	55.893	55.893	5.88	0.018
T1.BL3.BL4	1	22.689	22.689	2.39	0.127
T1.P1.BL3.P2	1	1.085	1.085	0.11	0.737
T1.P1.BL3.BL4	1	0.283	0.283	0.03	0.864
T1.BL3.P2.BL4	1	56.430	56.430	5.94	0.018
T1.BL3.BL4.P3	1	0.921	0.921	0.10	0.757
T1.BL3.BL4.T2	2	84.032	42.016	4.42	0.016
T1.P1.BL3.P2.BL4	1	1.375	1.375	0.14	0.705
T1.P1.BL3.BL4.P3	1	15.827	15.827	1.67	0.202
T1.BL3.P2.BL4.P3	1	11.247	11.247	1.18	0.281
T1.P1.BL3.BL4.T2	2	52.303	26.151	2.75	0.072
T1.BL3.P2.BL4.T2	2	92.646	46.323	4.88	0.011
T1.BL3.BL4.P3.T2	2	29.062	14.531	1.53	0.225
T1.P1.BL3.P2.BL4.P3	1	10.547	10.547	1.11	0.296
T1.P1.BL3.P2.BL4.T2	2	11.917	5.958	0.63	0.537
T1.P1.BL3.BL4.P3.T2	2	2.133	1.066	0.11	0.894
T1.BL3.P2.BL4.P3.T2	2	21.879	10.939	1.15	0.323
T1.P1.BL3.P2.BL4.P3.T2	2	17.225	8.613	0.91	0.409
Residual	62	589.074	9.501		
Total	95	1141.884			

Table B.61 ANOVA table for apparent elasticity (N mm^{-2}) for 'Russet Burbank' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	0.00473	0.00237	0.13	
reps.*Units* stratum					
T1	2	0.60526	0.30263	17.08	<.001
T1.P1	1	0.00294	0.00294	0.17	0.685
T1.BL3	1	0.25597	0.25597	14.44	<.001
T1.P1.BL3	1	0.03412	0.03412	1.93	0.170
T1.BL3.P2	1	0.01119	0.01119	0.63	0.430
T1.BL3.BL4	1	0.00953	0.00953	0.54	0.466
T1.P1.BL3.P2	1	0.00107	0.00107	0.06	0.807
T1.P1.BL3.BL4	1	0.00056	0.00056	0.03	0.860
T1.BL3.P2.BL4	1	0.00989	0.00989	0.56	0.458
T1.BL3.BL4.P3	1	0.00000	0.00000	0.00	0.997
T1.BL3.BL4.T2	2	0.10537	0.05269	2.97	0.058
T1.P1.BL3.P2.BL4	1	0.01833	0.01833	1.03	0.313
T1.P1.BL3.BL4.P3	1	0.00877	0.00877	0.49	0.484
T1.BL3.P2.BL4.P3	1	0.01149	0.01149	0.65	0.424
T1.P1.BL3.BL4.T2	2	0.54896	0.27448	15.49	<.001
T1.BL3.P2.BL4.T2	2	0.01616	0.00808	0.46	0.636
T1.BL3.BL4.P3.T2	2	0.01654	0.00827	0.47	0.629
T1.P1.BL3.P2.BL4.P3	1	0.01334	0.01334	0.75	0.389
T1.P1.BL3.P2.BL4.T2	2	0.00916	0.00458	0.26	0.773
T1.P1.BL3.BL4.P3.T2	2	0.00882	0.00441	0.25	0.780
T1.BL3.P2.BL4.P3.T2	2	0.00331	0.00166	0.09	0.911
T1.P1.BL3.P2.BL4.P3.T2	2	0.01428	0.00714	0.40	0.670
Residual	62	1.09870	0.01772		
Total	95	2.80848			

Table B.62 ANOVA table for total sprouts at 30 weeks storage for 'Marfona', 'Estima', 'Saturna' and 'Russet Burbank' potatoes in Experiment 6 and 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
reps stratum	2	125.1	62.6	0.46	
reps.*Units* stratum					
CV	3	20354.6	6784.9	49.46	<.001
CV.P1	4	842.9	210.7	1.54	0.200
CV.P1.P3	8	3559.7	445.0	3.24	0.003
Residual	78	10699.5	137.2		
Total	95	35581.8			

Table B.63 ANOVA table for total sprouts during shelf life for 'Marfona', 'Estima' and 'Saturna' potatoes in experiments 6 and 7

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		54.25	27.12	0.66	
REP.*Units* stratum						
CV	2		19823.05	9911.52	241.95	<.001
Day	6		22243.04	3707.17	90.50	<.001
CV.Day	12		5553.07	462.76	11.30	<.001
Day.P1	7		309.90	44.27	1.08	0.375
CV.Day.P1	14		1009.98	72.14	1.76	0.042
Day.P1.P3	14		498.60	35.61	0.87	0.593
CV.Day.P1.P3	28		1149.25	41.04	1.00	0.465
Residual	397	(21)	16262.86	40.96		
Total	482	(21)	65415.27			

Table B.64 ANOVA table for total sprouts during shelf life for 'Russet Burbank' potatoes in Experiment 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	335.80	167.90	2.28	
REP.*Units* stratum					
Day	6	59563.57	9927.26	135.04	<.001
Day.P1	7	482.50	68.93	0.94	0.480
Day.P1.P3	14	1148.67	82.05	1.12	0.349
Residual	138	10144.87	73.51		
Total	167	71675.40			

APPENDIX C

CHAPTER SIX

Table C.1 Key-table describing the Genstat structure model used to create the ANOVA tables for Year 2010-2011(Experiment 8)

ContTreated/(ContMCP1*OUT23/(ContETHY1*ContMCP2*out34/ContETHY2))

Out	ContTreated	ContMCP1	OUT23	ContEthy1	ContMCP2	Out34	ContETHY2
1	C	B4MCP1	C	B4 EMCP2	B4 EMCP2	C	B4 ETHY2
2	T	C MCP	C	B4 EMCP2	B4 EMCP2	C	B4 ETHY2
2	T	P MCP	C	B4 EMCP2	B4 EMCP2	C	B4 ETHY2
3	T	C MCP	T	PE	P MCP2	C	B4 ETHY2
3	T	C MCP	T	PE	C MCP2	C	B4 ETHY2
3	T	C MCP	T	CE	P MCP2	C	B4 ETHY2
3	T	C MCP	T	CE	C MCP2	C	B4 ETHY2
3	T	P MCP	T	PE	P MCP2	C	B4 ETHY2
3	T	P MCP	T	PE	C MCP2	C	B4 ETHY2
3	T	P MCP	T	CE	P MCP2	C	B4 ETHY2
3	T	P MCP	T	CE	C MCP2	C	B4 ETHY2
4	T	C MCP	T	PE	P MCP2	T	P ETHY2
4	T	C MCP	T	PE	P MCP2	T	C ETHY2
4	T	C MCP	T	PE	C MCP2	T	P ETHY2
4	T	C MCP	T	PE	C MCP2	T	C ETHY2
4	T	C MCP	T	CE	P MCP2	T	P ETHY2
4	T	C MCP	T	CE	P MCP2	T	C ETHY2
4	T	C MCP	T	CE	C MCP2	T	P ETHY2
4	T	C MCP	T	CE	C MCP2	T	C ETHY2
4	T	P MCP	T	PE	P MCP2	T	P ETHY2
4	T	P MCP	T	PE	P MCP2	T	C ETHY2
4	T	P MCP	T	PE	C MCP2	T	P ETHY2
4	T	P MCP	T	PE	C MCP2	T	C ETHY2
4	T	P MCP	T	CE	P MCP2	T	P ETHY2
4	T	P MCP	T	CE	P MCP2	T	C ETHY2
4	T	P MCP	T	CE	C MCP2	T	P ETHY2
4	T	P MCP	T	CE	C MCP2	T	C ETHY2

Table C.2 ANOVA table for ethylene production (mmol Kg^{-1} h^{-1}) for 'Marfona' potatoes in Experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.0636	0.0318	0.22	
rep.*Units* stratum					
BL1	1	0.3811	0.3811	2.61	0.113
BL1.MCP1	1	0.0107	0.0107	0.07	0.788
BL1.BL2	1	0.8987	0.8987	6.14	0.016
BL1.MCP1.BL2	1	0.0009	0.0009	0.01	0.938
BL1.BL2.ETHY1	1	0.0063	0.0063	0.04	0.836
BL1.BL2.MCP2	1	0.0011	0.0011	0.01	0.932
BL1.BL2.BL3	1	5.8418	5.8418	39.94	<.001
BL1.MCP1.BL2.ETHY1	1	0.0150	0.0150	0.10	0.750
BL1.MCP1.BL2.MCP2	1	0.2570	0.2570	1.76	0.191
BL1.BL2.ETHY1.MCP2	1	0.0333	0.0333	0.23	0.635
BL1.MCP1.BL2.BL3	1	0.0058	0.0058	0.04	0.843
BL1.BL2.ETHY1.BL3	1	0.0031	0.0031	0.02	0.884
BL1.BL2.MCP2.BL3	1	0.0005	0.0005	0.00	0.952
BL1.BL2.BL3.ETHY2	1	13.3569	13.3569	91.32	<.001
BL1.MCP1.BL2.ETHY1.MCP2	1	0.0047	0.0047	0.03	0.858
BL1.MCP1.BL2.ETHY1.BL3	1	0.0075	0.0075	0.05	0.822
BL1.MCP1.BL2.MCP2.BL3	1	0.1285	0.1285	0.88	0.353
BL1.BL2.ETHY1.MCP2.BL3	1	0.0166	0.0166	0.11	0.737
BL1.MCP1.BL2.BL3.ETHY2	1	0.2553	0.2553	1.75	0.192
BL1.BL2.ETHY1.BL3.ETHY2	1	0.1713	0.1713	1.17	0.284
BL1.BL2.MCP2.BL3.ETHY2	1	0.1150	0.1150	0.79	0.379
BL1.MCP1.BL2.ETHY1.MCP2.BL3	1	0.0024	0.0024	0.02	0.899
BL1.MCP1.BL2.ETHY1.BL3.ETHY2	1	0.0524	0.0524	0.36	0.552
BL1.MCP1.BL2.MCP2.BL3.ETHY2	1	0.0121	0.0121	0.08	0.775
BL1.BL2.ETHY1.MCP2.BL3.ETHY2	1	0.0226	0.0226	0.15	0.696
BL1.MCP1.BL2.ETHY1.MCP2.BL3.ETHY2	1	0.3795	0.3795	2.59	0.113
Residual	52	7.6060	0.1463		
Total	80	29.6498			

Table C.3 ANOVA table for respiration rate (CO_2) (mmol Kg^{-1} h^{-1}) for 'Marfona' potatoes in Experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.011287	0.005644	1.69	
rep.*Units* stratum					
BL1	1	0.002370	0.002370	0.71	0.403
BL1.MCP1	1	0.000496	0.000496	0.15	0.701
BL1.BL2	1	0.001627	0.001627	0.49	0.488
BL1.MCP1.BL2	1	0.000731	0.000731	0.22	0.642
BL1.BL2.ETHY1	1	0.000745	0.000745	0.22	0.638
BL1.BL2.MCP2	1	0.000627	0.000627	0.19	0.666
BL1.BL2.BL3	1	0.039922	0.039922	11.97	0.001
BL1.MCP1.BL2.ETHY1	1	0.012073	0.012073	3.62	0.063
BL1.MCP1.BL2.MCP2	1	0.003704	0.003704	1.11	0.297
BL1.BL2.ETHY1.MCP2	1	0.001373	0.001373	0.41	0.524
BL1.MCP1.BL2.BL3	1	0.000000	0.000000	0.00	0.999
BL1.BL2.ETHY1.BL3	1	0.000001	0.000001	0.00	0.988
BL1.BL2.MCP2.BL3	1	0.001719	0.001719	0.52	0.476
BL1.BL2.BL3.ETHY2	1	0.011946	0.011946	3.58	0.064
BL1.MCP1.BL2.ETHY1.MCP2	1	0.000510	0.000510	0.15	0.697
BL1.MCP1.BL2.ETHY1.BL3	1	0.007742	0.007742	2.32	0.134
BL1.MCP1.BL2.MCP2.BL3	1	0.003355	0.003355	1.01	0.320
BL1.BL2.ETHY1.MCP2.BL3	1	0.000113	0.000113	0.03	0.854
BL1.MCP1.BL2.BL3.ETHY2	1	0.000404	0.000404	0.12	0.729
BL1.BL2.ETHY1.BL3.ETHY2	1	0.014896	0.014896	4.47	0.039
BL1.BL2.MCP2.BL3.ETHY2	1	0.002458	0.002458	0.74	0.394
BL1.MCP1.BL2.ETHY1.MCP2.BL3	1	0.000690	0.000690	0.21	0.651
BL1.MCP1.BL2.ETHY1.BL3.ETHY2	1	0.000915	0.000915	0.27	0.603
BL1.MCP1.BL2.MCP2.BL3.ETHY2	1	0.002276	0.002276	0.68	0.412
BL1.BL2.ETHY1.MCP2.BL3.ETHY2	1	0.000074	0.000074	0.02	0.883
BL1.MCP1.BL2.ETHY1.MCP2.BL3.ETHY2	1	0.000572	0.000572	0.17	0.680
Residual	52	0.173378	0.003334		
Total	80	0.296006			

Table C.4 ANOVA table for ethylene production (mmol Kg^{-1} h^{-1}) for 'Estima' potatoes in Experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.40949	0.20474	3.29	
rep.*Units* stratum					
BL1	1	0.06581	0.06581	1.06	0.309
BL1.MCP1	1	0.00159	0.00159	0.03	0.874
BL1.BL2	1	0.15138	0.15138	2.43	0.125
BL1.MCP1.BL2	1	0.00013	0.00013	0.00	0.963
BL1.BL2.ETHY1	1	0.13075	0.13075	2.10	0.153
BL1.BL2.MCP2	1	0.72838	0.72838	11.69	0.001
BL1.BL2.BL3	1	0.98395	0.98395	15.79	<.001
BL1.MCP1.BL2.ETHY1	1	0.00191	0.00191	0.03	0.862
BL1.MCP1.BL2.MCP2	1	0.01832	0.01832	0.29	0.590
BL1.BL2.ETHY1.MCP2	1	0.26329	0.26329	4.23	0.045
BL1.MCP1.BL2.BL3	1	0.00086	0.00086	0.01	0.907
BL1.BL2.ETHY1.BL3	1	0.06537	0.06537	1.05	0.310
BL1.BL2.MCP2.BL3	1	0.36419	0.36419	5.85	0.019
BL1.BL2.BL3.ETHY2	1	2.45533	2.45533	39.41	<.001
BL1.MCP1.BL2.ETHY1.MCP2	1	0.28663	0.28663	4.60	0.037
BL1.MCP1.BL2.ETHY1.BL3	1	0.00095	0.00095	0.02	0.902
BL1.MCP1.BL2.MCP2.BL3	1	0.00916	0.00916	0.15	0.703
BL1.BL2.ETHY1.MCP2.BL3	1	0.13165	0.13165	2.11	0.152
BL1.MCP1.BL2.BL3.ETHY2	1	0.00009	0.00009	0.00	0.970
BL1.BL2.ETHY1.BL3.ETHY2	1	0.13126	0.13126	2.11	0.153
BL1.BL2.MCP2.BL3.ETHY2	1	0.93066	0.93066	14.94	<.001
BL1.MCP1.BL2.ETHY1.MCP2.BL3	1	0.14331	0.14331	2.30	0.135
BL1.MCP1.BL2.ETHY1.BL3.ETHY2	1	0.00058	0.00058	0.01	0.923
BL1.MCP1.BL2.MCP2.BL3.ETHY2	1	0.03805	0.03805	0.61	0.438
BL1.BL2.ETHY1.MCP2.BL3.ETHY2	1	0.22781	0.22781	3.66	0.061
BL1.MCP1.BL2.ETHY1.MCP2.BL3.ETHY2	1	0.48583	0.48583	7.80	0.007
Residual	52	3.23960	0.06230		
Total	80	11.26634			

Table C.5 ANOVA table for respiration rate (CO_2) (mmol Kg^{-1} h^{-1}) for 'Estima' potatoes in Experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.006561	0.003280	0.85	
rep.*Units* stratum					
BL1	1	0.000135	0.000135	0.03	0.853
BL1.MCP1	1	0.001978	0.001978	0.51	0.478
BL1.BL2	1	0.003749	0.003749	0.97	0.329
BL1.MCP1.BL2	1	0.000383	0.000383	0.10	0.754
BL1.BL2.ETHY1	1	0.001884	0.001884	0.49	0.488
BL1.BL2.MCP2	1	0.005668	0.005668	1.47	0.231
BL1.BL2.BL3	1	0.045022	0.045022	11.65	0.001
BL1.MCP1.BL2.ETHY1	1	0.001877	0.001877	0.49	0.489
BL1.MCP1.BL2.MCP2	1	0.005548	0.005548	1.44	0.236
BL1.BL2.ETHY1.MCP2	1	0.002920	0.002920	0.76	0.389
BL1.MCP1.BL2.BL3	1	0.000000	0.000000	0.00	0.992
BL1.BL2.ETHY1.BL3	1	0.001594	0.001594	0.41	0.524
BL1.BL2.MCP2.BL3	1	0.001327	0.001327	0.34	0.560
BL1.BL2.BL3.ETHY2	1	0.053045	0.053045	13.72	<.001
BL1.MCP1.BL2.ETHY1.MCP2	1	0.007461	0.007461	1.93	0.171
BL1.MCP1.BL2.ETHY1.BL3	1	0.002445	0.002445	0.63	0.430
BL1.MCP1.BL2.MCP2.BL3	1	0.001745	0.001745	0.45	0.505
BL1.BL2.ETHY1.MCP2.BL3	1	0.003614	0.003614	0.93	0.338
BL1.MCP1.BL2.BL3.ETHY2	1	0.000023	0.000023	0.01	0.938
BL1.BL2.ETHY1.BL3.ETHY2	1	0.008005	0.008005	2.07	0.156
BL1.BL2.MCP2.BL3.ETHY2	1	0.023431	0.023431	6.06	0.017
BL1.MCP1.BL2.ETHY1.MCP2.BL3	1	0.005576	0.005576	1.44	0.235
BL1.MCP1.BL2.ETHY1.BL3.ETHY2	1	0.018939	0.018939	4.90	0.031
BL1.MCP1.BL2.MCP2.BL3.ETHY2	1	0.017274	0.017274	4.47	0.039
BL1.BL2.ETHY1.MCP2.BL3.ETHY2	1	0.000001	0.000001	0.00	0.990
BL1.MCP1.BL2.ETHY1.MCP2.BL3.ETHY2	1	0.006274	0.006274	1.62	0.208
Residual	52	0.201025	0.003866		
Total	80	0.427507			

Table C.6 ANOVA table for sucrose concentration (mg g^{-1} DW) in flesh for 'Marfona' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	2.307	1.154	0.48	
rep.*Units* stratum					
BL1	1	3.844	3.844	1.59	0.213
BL1.MCP1	1	225.265	225.265	93.24	<.001
BL1.BL2	1	13.893	13.893	5.75	0.020
BL1.MCP1.BL2	1	16.720	16.720	6.92	0.011
BL1.BL2.ETHY1	1	194.646	194.646	80.57	<.001
BL1.BL2.MCP2	1	3.802	3.802	1.57	0.215
BL1.BL2.BL3	1	785.726	785.726	325.23	<.001
BL1.MCP1.BL2.ETHY1	1	123.651	123.651	51.18	<.001
BL1.MCP1.BL2.MCP2	1	5.677	5.677	2.35	0.131
BL1.BL2.ETHY1.MCP2	1	0.464	0.464	0.19	0.663
BL1.MCP1.BL2.BL3	1	5.354	5.354	2.22	0.143
BL1.BL2.ETHY1.BL3	1	36.846	36.846	15.25	<.001
BL1.BL2.MCP2.BL3	1	2.164	2.164	0.90	0.348
BL1.BL2.BL3.ETHY2	1	391.886	391.886	162.21	<.001
BL1.MCP1.BL2.ETHY1.MCP2	1	1.467	1.467	0.61	0.439
BL1.MCP1.BL2.ETHY1.BL3	1	22.944	22.944	9.50	0.003
BL1.MCP1.BL2.MCP2.BL3	1	0.005	0.005	0.00	0.963
BL1.BL2.ETHY1.MCP2.BL3	1	2.278	2.278	0.94	0.336
BL1.MCP1.BL2.BL3.ETHY2	1	2.015	2.015	0.83	0.365
BL1.BL2.ETHY1.BL3.ETHY2	1	11.594	11.594	4.80	0.033
BL1.BL2.MCP2.BL3.ETHY2	1	4.846	4.846	2.01	0.163
BL1.MCP1.BL2.ETHY1.MCP2.BL3	1	0.232	0.232	0.10	0.758
BL1.MCP1.BL2.ETHY1.BL3.ETHY2	1	2.358	2.358	0.98	0.328
BL1.MCP1.BL2.MCP2.BL3.ETHY2	1	0.035	0.035	0.01	0.905
BL1.BL2.ETHY1.MCP2.BL3.ETHY2	1	4.703	4.703	1.95	0.169
BL1.MCP1.BL2.ETHY1.MCP2.BL3.ETHY2	1	7.179	7.179	2.97	0.091
Residual	52	125.628	2.416		
Total	80	1997.527			

Table C.7 ANOVA table for glucose concentration (mg g^{-1} DW) in flesh for 'Marfona' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	285.99	143.00	3.70	
rep.*Units* stratum					
BL1	1	3661.32	3661.32	94.68	<.001
BL1.MCP1	1	1286.24	1286.24	33.26	<.001
BL1.BL2	1	5543.50	5543.50	143.35	<.001
BL1.MCP1.BL2	1	80.36	80.36	2.08	0.155
BL1.BL2.ETHY1	1	1527.27	1527.27	39.49	<.001
BL1.BL2.MCP2	1	0.08	0.08	0.00	0.963
BL1.BL2.BL3	1	6382.44	6382.44	165.04	<.001
BL1.MCP1.BL2.ETHY1	1	1337.69	1337.69	34.59	<.001
BL1.MCP1.BL2.MCP2	1	11.62	11.62	0.30	0.586
BL1.BL2.ETHY1.MCP2	1	141.33	141.33	3.65	0.061
BL1.MCP1.BL2.BL3	1	20.40	20.40	0.53	0.471
BL1.BL2.ETHY1.BL3	1	71.03	71.03	1.84	0.181
BL1.BL2.MCP2.BL3	1	40.54	40.54	1.05	0.311
BL1.BL2.BL3.ETHY2	1	1337.20	1337.20	34.58	<.001
BL1.MCP1.BL2.ETHY1.MCP2	1	467.74	467.74	12.10	0.001
BL1.MCP1.BL2.ETHY1.BL3	1	5.64	5.64	0.15	0.704
BL1.MCP1.BL2.MCP2.BL3	1	59.16	59.16	1.53	0.222
BL1.BL2.ETHY1.MCP2.BL3	1	201.91	201.91	5.22	0.026
BL1.MCP1.BL2.BL3.ETHY2	1	13.14	13.14	0.34	0.563
BL1.BL2.ETHY1.BL3.ETHY2	1	0.45	0.45	0.01	0.915
BL1.BL2.MCP2.BL3.ETHY2	1	235.15	235.15	6.08	0.017
BL1.MCP1.BL2.ETHY1.MCP2.BL3	1	187.04	187.04	4.84	0.032
BL1.MCP1.BL2.ETHY1.BL3.ETHY2	1	661.51	661.51	17.11	<.001
BL1.MCP1.BL2.MCP2.BL3.ETHY2	1	174.18	174.18	4.50	0.039
BL1.BL2.ETHY1.MCP2.BL3.ETHY2	1	187.96	187.96	4.86	0.032
BL1.MCP1.BL2.ETHY1.MCP2.BL3.ETHY2	1	205.88	205.88	5.32	0.025
Residual	52	2010.92	38.67		
Total	80	0.427507			

Table C.8 ANOVA table for fructose concentration (mg g^{-1} DW) in flesh for 'Marfona' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	241.65	120.83	4.98	
rep.*Units* stratum					
BL1	1	2997.16	2997.16	123.62	<.001
BL1.MCP1	1	2847.30	2847.30	117.44	<.001
BL1.BL2	1	4603.88	4603.88	189.89	<.001
BL1.MCP1.BL2	1	222.21	222.21	9.17	0.004
BL1.BL2.ETHY1	1	2278.06	2278.06	93.96	<.001
BL1.BL2.MCP2	1	10.30	10.30	0.42	0.517
BL1.BL2.BL3	1	4035.18	4035.18	166.43	<.001
BL1.MCP1.BL2.ETHY1	1	2077.20	2077.20	85.67	<.001
BL1.MCP1.BL2.MCP2	1	9.84	9.84	0.41	0.527
BL1.BL2.ETHY1.MCP2	1	200.14	200.14	8.25	0.006
BL1.MCP1.BL2.BL3	1	2.50	2.50	0.10	0.749
BL1.BL2.ETHY1.BL3	1	5.18	5.18	0.21	0.646
BL1.BL2.MCP2.BL3	1	6.02	6.02	0.25	0.620
BL1.BL2.BL3.ETHY2	1	841.83	841.83	34.72	<.001
BL1.MCP1.BL2.ETHY1.MCP2	1	393.97	393.97	16.25	<.001
BL1.MCP1.BL2.ETHY1.BL3	1	9.58	9.58	0.40	0.532
BL1.MCP1.BL2.MCP2.BL3	1	28.11	28.11	1.16	0.287
BL1.BL2.ETHY1.MCP2.BL3	1	186.14	186.14	7.68	0.008
BL1.MCP1.BL2.BL3.ETHY2	1	11.49	11.49	0.47	0.494
BL1.BL2.ETHY1.BL3.ETHY2	1	4.56	4.56	0.19	0.666
BL1.BL2.MCP2.BL3.ETHY2	1	157.86	157.86	6.51	0.014
BL1.MCP1.BL2.ETHY1.MCP2.BL3	1	173.79	173.79	7.17	0.010
BL1.MCP1.BL2.ETHY1.BL3.ETHY2	1	399.01	399.01	16.46	<.001
BL1.MCP1.BL2.MCP2.BL3.ETHY2	1	150.40	150.40	6.20	0.016
BL1.BL2.ETHY1.MCP2.BL3.ETHY2	1	217.29	217.29	8.96	0.004
BL1.MCP1.BL2.ETHY1.MCP2.BL3.ETHY2	1	194.19	194.19	8.01	0.007
Residual	52	1260.75	24.25		
Total	80	23565.59			

Table C.9 ANOVA table for sucrose concentration (mg g^{-1} DW) in flesh for 'Estima' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	2.392	1.196	0.17	
rep.*Units* stratum					
BL1	1	64.071	64.071	9.29	0.004
BL1.MCP1	1	83.972	83.97	12.18	<.001
BL1.BL2	1	277.841	277.841	40.29	<.001
BL1.MCP1.BL2	1	2.827	2.827	0.41	0.525
BL1.BL2.ETHY1	1	52.738	52.738	7.65	0.008
BL1.BL2.MCP2	1	14.315	14.315	2.08	0.156
BL1.BL2.BL3	1	0.388	0.388	0.06	0.813
BL1.MCP1.BL2.ETHY1	1	48.932	48.932	7.10	0.010
BL1.MCP1.BL2.MCP2	1	0.017	0.017	0.00	0.961
BL1.BL2.ETHY1.MCP2	1	1.083	1.083	0.16	0.694
BL1.MCP1.BL2.BL3	1	2.268	2.268	0.33	0.569
BL1.BL2.ETHY1.BL3	1	0.467	0.467	0.07	0.796
BL1.BL2.MCP2.BL3	1	6.246	6.246	0.91	0.346
BL1.BL2.BL3.ETHY2	1	2.225	2.225	0.32	0.572
BL1.MCP1.BL2.ETHY1.MCP2	1	0.043	0.043	0.01	0.937
BL1.MCP1.BL2.ETHY1.BL3	1	0.006	0.006	0.00	0.976
BL1.MCP1.BL2.MCP2.BL3	1	11.036	11.036	1.60	0.211
BL1.BL2.ETHY1.MCP2.BL3	1	1.304	1.304	0.19	0.665
BL1.MCP1.BL2.BL3.ETHY2	1	23.588	23.588	3.42	0.070
BL1.BL2.ETHY1.BL3.ETHY2	1	1.281	1.281	0.19	0.668
BL1.BL2.MCP2.BL3.ETHY2	1	0.215	0.215	0.03	0.860
BL1.MCP1.BL2.ETHY1.MCP2.BL3	1	0.000	0.000	0.00	0.996
BL1.MCP1.BL2.ETHY1.BL3.ETHY2	1	7.311	7.311	1.06	0.308
BL1.MCP1.BL2.MCP2.BL3.ETHY2	1	2.231	2.231	0.32	0.572
BL1.BL2.ETHY1.MCP2.BL3.ETHY2	1	8.621	8.621	1.25	0.269
BL1.MCP1.BL2.ETHY1.MCP2.BL3.ETHY2	1	0.003	0.003	0.00	0.984
Residual	52	358.585	6.896		
Total	80	974.006			

Table C.10 ANOVA table for glucose concentration (mg g^{-1} DW) in flesh for 'Estima' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	121.17	60.59	1.64	
rep.*Units* stratum					
BL1	1	2347.59	2347.59	63.56	<.001
BL1.MCP1	1	31.25	31.25	0.85	0.362
BL1.BL2	1	4727.97	4727.97	128.01	<.001
BL1.MCP1.BL2	1	0.70	0.70	0.02	0.891
BL1.BL2.ETHY1	1	629.29	629.29	17.04	<.001
BL1.BL2.MCP2	1	30.96	30.96	0.84	0.364
BL1.BL2.BL3	1	5362.64	5362.64	145.20	<.001
BL1.MCP1.BL2.ETHY1	1	1.69	1.69	0.05	0.831
BL1.MCP1.BL2.MCP2	1	267.70	267.70	7.25	0.010
BL1.BL2.ETHY1.MCP2	1	4.21	4.21	0.11	0.737
BL1.MCP1.BL2.BL3	1	410.86	410.86	11.12	0.002
BL1.BL2.ETHY1.BL3	1	38.32	38.32	1.04	0.313
BL1.BL2.MCP2.BL3	1	0.02	0.02	0.00	0.983
BL1.BL2.BL3.ETHY2	1	108.38	108.38	2.93	0.093
BL1.MCP1.BL2.ETHY1.MCP2	1	74.34	74.34	2.01	0.162
BL1.MCP1.BL2.ETHY1.BL3	1	314.34	314.34	8.51	0.005
BL1.MCP1.BL2.MCP2.BL3	1	278.19	278.19	7.53	0.008
BL1.BL2.ETHY1.MCP2.BL3	1	8.15	8.15	0.22	0.641
BL1.MCP1.BL2.BL3.ETHY2	1	15.85	15.85	0.43	0.515
BL1.BL2.ETHY1.BL3.ETHY2	1	4.16	4.16	0.11	0.739
BL1.BL2.MCP2.BL3.ETHY2	1	0.83	0.83	0.02	0.882
BL1.MCP1.BL2.ETHY1.MCP2.BL3	1	41.84	41.84	1.13	0.292
BL1.MCP1.BL2.ETHY1.BL3.ETHY2	1	37.99	37.99	1.03	0.315
BL1.MCP1.BL2.MCP2.BL3.ETHY2	1	51.77	51.77	1.40	0.242
BL1.BL2.ETHY1.MCP2.BL3.ETHY2	1	109.91	109.91	2.98	0.090
BL1.MCP1.BL2.ETHY1.MCP2.BL3.ETHY2	1	0.38	0.38	0.01	0.919
Residual	52	1920.56	36.93		
Total	80	16941.08			

Table C.11 ANOVA table for fructose concentration (mg g^{-1} DW) in flesh for 'Estima' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	110.83	55.41	3.46	
rep.*Units* stratum					
BL1	1	1643.64	1643.64	102.50	<.001
BL1.MCP1	1	698.52	698.52	43.56	<.001
BL1.BL2	1	3380.60	3380.60	210.83	<.001
BL1.MCP1.BL2	1	58.30	58.30	3.64	0.062
BL1.BL2.ETHY1	1	1208.10	1208.10	75.34	<.001
BL1.BL2.MCP2	1	25.42	25.42	1.59	0.214
BL1.BL2.BL3	1	3378.38	3378.38	210.69	<.001
BL1.MCP1.BL2.ETHY1	1	168.01	168.01	10.48	0.002
BL1.MCP1.BL2.MCP2	1	52.82	52.82	3.29	0.075
BL1.BL2.ETHY1.MCP2	1	28.63	28.63	1.79	0.187
BL1.MCP1.BL2.BL3	1	171.92	171.92	10.72	0.002
BL1.BL2.ETHY1.BL3	1	20.67	20.67	1.29	0.261
BL1.BL2.MCP2.BL3	1	6.83	6.83	0.43	0.517
BL1.BL2.BL3.ETHY2	1	206.63	206.63	12.89	<.001
BL1.MCP1.BL2.ETHY1.MCP2	1	61.09	61.09	3.81	0.056
BL1.MCP1.BL2.ETHY1.BL3	1	135.05	135.05	8.42	0.005
BL1.MCP1.BL2.MCP2.BL3	1	120.26	120.26	7.50	0.008
BL1.BL2.ETHY1.MCP2.BL3	1	5.41	5.41	0.34	0.564
BL1.MCP1.BL2.BL3.ETHY2	1	1.09	1.09	0.07	0.795
BL1.BL2.ETHY1.BL3.ETHY2	1	0.32	0.32	0.02	0.888
BL1.BL2.MCP2.BL3.ETHY2	1	25.68	25.68	1.60	0.211
BL1.MCP1.BL2.ETHY1.MCP2.BL3	1	28.60	28.60	1.78	0.188
BL1.MCP1.BL2.ETHY1.BL3.ETHY2	1	15.43	15.43	0.96	0.331
BL1.MCP1.BL2.MCP2.BL3.ETHY2	1	38.70	38.70	2.41	0.126
BL1.BL2.ETHY1.MCP2.BL3.ETHY2	1	42.96	42.96	2.68	0.108
BL1.MCP1.BL2.ETHY1.MCP2.BL3.ETHY2	1	0.49	0.49	0.03	0.862
Residual	52	833.82	16.04		
Total	80	12468.19			

Table C.12 ANOVA table for sprout length < 5 mm at 30 weeks storage for 'Marfona' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	62.54	31.27	0.41	
rep.*Units* stratum					
MCP1	1	42.19	42.19	0.55	0.463
ETHY1	1	13.02	13.02	0.17	0.683
MCP2	1	3.52	3.52	0.05	0.832
ETHY2	1	2366.02	2366.02	30.96	<.001
MCP1.ETHY1	1	46.02	46.02	0.60	0.444
MCP1.MCP2	1	93.52	93.52	1.22	0.277
ETHY1.MCP2	1	99.19	99.19	1.30	0.264
MCP1.ETHY2	1	1.69	1.69	0.02	0.883
ETHY1.ETHY2	1	6.02	6.02	0.08	0.781
MCP2.ETHY2	1	25.52	25.52	0.33	0.568
MCP1.ETHY1.MCP2	1	105.02	105.02	1.37	0.250
MCP1.ETHY1.ETHY2	1	117.19	117.19	1.53	0.225
MCP1.MCP2.ETHY2	1	46.02	46.02	0.60	0.444
ETHY1.MCP2.ETHY2	1	77.52	77.52	1.01	0.322
MCP1.ETHY1.MCP2.ETHY2	1	99.19	99.19	1.30	0.264
Residual	30	2292.79	76.43		
Total	47	5496.98			

Table C.13 ANOVA table for sprout length 5-10 mm at 30 weeks storage for 'Marfona' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	48.29	24.15	1.70	
rep.*Units* stratum					
MCP1	1	67.69	67.69	4.76	0.037
ETHY1	1	1.02	1.02	0.07	0.791
MCP2	1	4.69	4.69	0.33	0.570
ETHY2	1	368.52	368.52	25.93	<.001
MCP1.ETHY1	1	7.52	7.52	0.53	0.473
MCP1.MCP2	1	13.02	13.02	0.92	0.346
ETHY1.MCP2	1	35.02	35.02	2.46	0.127
MCP1.ETHY2	1	67.69	67.69	4.76	0.037
ETHY1.ETHY2	1	1.02	1.02	0.07	0.791
MCP2.ETHY2	1	4.69	4.69	0.33	0.570
MCP1.ETHY1.MCP2	1	67.69	67.69	4.76	0.037
MCP1.ETHY1.ETHY2	1	7.52	7.52	0.53	0.473
MCP1.MCP2.ETHY2	1	13.02	13.02	0.92	0.346
ETHY1.MCP2.ETHY2	1	35.02	35.02	2.46	0.127
MCP1.ETHY1.MCP2.ETHY2	1	67.69	67.69	4.76	0.037
Residual	30	426.38	14.21		
Total	47	1236.48			

Table C.14 ANOVA table for sprout length > 10 mm at 30 weeks storage for 'Marfona' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	10.292	5.146	0.68	
rep.*Units* stratum					
MCP1	1	10.083	10.083	1.34	0.257
ETHY1	1	18.750	18.750	2.48	0.125
MCP2	1	10.083	10.083	1.34	0.257
ETHY2	1	120.333	120.333	15.95	<.001
MCP1.ETHY1	1	5.333	5.333	0.71	0.407
MCP1.MCP2	1	0.000	0.000	0.00	1.000
ETHY1.MCP2	1	0.333	0.333	0.04	0.835
MCP1.ETHY2	1	10.083	10.083	1.34	0.257
ETHY1.ETHY2	1	18.750	18.750	2.48	0.125
MCP2.ETHY2	1	10.083	10.083	1.34	0.257
MCP1.ETHY1.MCP2	1	0.750	0.750	0.10	0.755
MCP1.ETHY1.ETHY2	1	5.333	5.333	0.71	0.407
MCP1.MCP2.ETHY2	1	0.000	0.000	0.00	1.000
ETHY1.MCP2.ETHY2	1	0.333	0.333	0.04	0.835
MCP1.ETHY1.MCP2.ETHY2	1	0.750	0.750	0.10	0.755
Residual	30	226.375	7.546		
Total	47	447.667			

Table C.15 ANOVA table for sprout length < 5 mm at 30 weeks storage for 'Estima' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	4.50	2.25	0.13	
rep.*Units* stratum					
MCP1	1	1.33	1.33	0.08	0.780
ETHY1	1	33.33	33.33	1.98	0.170
MCP2	1	5.33	5.33	0.32	0.578
ETHY2	1	352.08	352.08	20.90	<.001
MCP1.ETHY1	1	18.75	18.75	1.11	0.300
MCP1.MCP2	1	6.75	6.75	0.40	0.532
ETHY1.MCP2	1	30.08	30.08	1.79	0.192
MCP1.ETHY2	1	56.33	56.33	3.34	0.077
ETHY1.ETHY2	1	8.33	8.33	0.49	0.487
MCP2.ETHY2	1	5.33	5.33	0.32	0.578
MCP1.ETHY1.MCP2	1	16.33	16.33	0.97	0.333
MCP1.ETHY1.ETHY2	1	2.08	2.08	0.12	0.728
MCP1.MCP2.ETHY2	1	24.08	24.08	1.43	0.241
ETHY1.MCP2.ETHY2	1	10.08	10.08	0.60	0.445
MCP1.ETHY1.MCP2.ETHY2	1	27.00	27.00	1.60	0.215
Residual	30	505.50	16.85		
Total	47	1107.25			

Table C.16 ANOVA table for sprout length 5-10 mm at 30 weeks storage for 'Estimaa' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	15.500	7.750	4.12	
rep.*Units* stratum					
MCP1	1	22.688	22.688	12.05	0.002
ETHY1	1	35.021	35.021	18.60	<.001
MCP2	1	11.021	11.021	5.85	0.022
ETHY2	1	67.688	67.688	35.94	<.001
MCP1.ETHY1	1	13.021	13.021	6.91	0.013
MCP1.MCP2	1	1.021	1.021	0.54	0.467
ETHY1.MCP2	1	7.521	7.521	3.99	0.055
MCP1.ETHY2	1	22.688	22.688	12.05	0.002
ETHY1.ETHY2	1	35.021	35.021	18.60	<.001
MCP2.ETHY2	1	11.021	11.021	5.85	0.022
MCP1.ETHY1.MCP2	1	0.521	0.521	0.28	0.603
MCP1.ETHY1.ETHY2	1	13.021	13.021	6.91	0.013
MCP1.MCP2.ETHY2	1	1.021	1.021	0.54	0.467
ETHY1.MCP2.ETHY2	1	7.521	7.521	3.99	0.055
MCP1.ETHY1.MCP2.ETHY2	1	0.521	0.521	0.28	0.603
Residual	30	56.500	1.883		
Total	47	321.312			

Table C.17 ANOVA table for sprout length > 10 mm at 30 weeks storage for 'Estima' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.1250	0.0625	0.19	
rep.*Units* stratum					
MCP1	1	4.6875	4.6875	14.24	<.001
ETHY1	1	31.6875	31.6875	96.27	<.001
MCP2	1	4.6875	4.6875	14.24	<.001
ETHY2	1	31.6875	31.6875	96.27	<.001
MCP1.ETHY1	1	4.6875	4.6875	14.24	<.001
MCP1.MCP2	1	1.6875	1.6875	5.13	0.031
ETHY1.MCP2	1	4.6875	4.6875	14.24	<.001
MCP1.ETHY2	1	4.6875	4.6875	14.24	<.001
ETHY1.ETHY2	1	31.6875	31.6875	96.27	<.001
MCP2.ETHY2	1	4.6875	4.6875	14.24	<.001
MCP1.ETHY1.MCP2	1	1.6875	1.6875	5.13	0.031
MCP1.ETHY1.ETHY2	1	4.6875	4.6875	14.24	<.001
MCP1.MCP2.ETHY2	1	1.6875	1.6875	5.13	0.031
ETHY1.MCP2.ETHY2	1	4.6875	4.6875	14.24	<.001
MCP1.ETHY1.MCP2.ETHY2	1	1.6875	1.6875	5.13	0.031
Residual	30	9.8750	0.3292		
Total	47	149.3125			

Table C.18 ANOVA table for dry weight (g DW 100^{-1} g FW) for 'Marfona' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	5.172	2.586	2.37	
rep.*Units* stratum					
BL1	1	0.494	0.494	0.45	0.504
BL1.MCP1	1	0.123	0.123	0.11	0.739
BL1.BL2	1	2.398	2.398	2.20	0.144
BL1.MCP1.BL2	1	0.233	0.233	0.21	0.646
BL1.BL2.ETHY1	1	1.730	1.730	1.58	0.214
BL1.BL2.MCP2	1	0.313	0.313	0.29	0.594
BL1.BL2.BL3	1	0.053	0.053	0.05	0.826
BL1.MCP1.BL2.ETHY1	1	0.557	0.557	0.51	0.478
BL1.MCP1.BL2.MCP2	1	0.043	0.043	0.04	0.843
BL1.BL2.ETHY1.MCP2	1	9.569	9.569	8.76	0.005
BL1.MCP1.BL2.BL3	1	1.235	1.235	1.13	0.292
BL1.BL2.ETHY1.BL3	1	0.697	0.697	0.64	0.428
BL1.BL2.MCP2.BL3	1	0.214	0.214	0.20	0.660
BL1.BL2.BL3.ETHY2	1	0.015	0.015	0.01	0.906
BL1.MCP1.BL2.ETHY1.MCP2	1	0.631	0.631	0.58	0.450
BL1.MCP1.BL2.ETHY1.BL3	1	0.317	0.317	0.29	0.592
BL1.MCP1.BL2.MCP2.BL3	1	0.360	0.360	0.33	0.568
BL1.BL2.ETHY1.MCP2.BL3	1	3.117	3.117	2.85	0.097
BL1.MCP1.BL2.BL3.ETHY2	1	0.001	0.001	0.00	0.983
BL1.BL2.ETHY1.BL3.ETHY2	1	1.125	1.125	1.03	0.315
BL1.BL2.MCP2.BL3.ETHY2	1	1.340	1.340	1.23	0.273
BL1.MCP1.BL2.ETHY1.MCP2.BL3	1	0.186	0.186	0.17	0.682
BL1.MCP1.BL2.ETHY1.BL3.ETHY2	1	1.941	1.941	1.78	0.188
BL1.MCP1.BL2.MCP2.BL3.ETHY2	1	0.132	0.132	0.12	0.729
BL1.BL2.ETHY1.MCP2.BL3.ETHY2	1	5.471	5.471	5.01	0.030
BL1.MCP1.BL2.ETHY1.MCP2.BL3.ETHY2	1	4.275	4.275	3.91	0.053
Residual	52	56.796	1.092		
Total	80	98.540			

Table C.19 ANOVA table for dry weight (g DW 100^{-1} g FW) for 'Estima' potatoes in experiment 8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.819	0.409	0.27	
rep.*Units* stratum					
BL1	1	0.123	0.123	0.08	0.777
BL1.MCP1	1	0.292	0.292	0.19	0.662
BL1.BL2	1	0.092	0.092	0.06	0.806
BL1.MCP1.BL2	1	2.426	2.426	1.60	0.211
BL1.BL2.ETHY1	1	0.024	0.024	0.02	0.900
BL1.BL2.MCP2	1	0.695	0.695	0.46	0.501
BL1.BL2.BL3	1	0.085	0.085	0.06	0.813
BL1.MCP1.BL2.ETHY1	1	1.150	1.150	0.76	0.387
BL1.MCP1.BL2.MCP2	1	0.289	0.289	0.19	0.664
BL1.BL2.ETHY1.MCP2	1	0.053	0.053	0.03	0.852
BL1.MCP1.BL2.BL3	1	0.988	0.988	0.65	0.423
BL1.BL2.ETHY1.BL3	1	0.164	0.164	0.11	0.743
BL1.BL2.MCP2.BL3	1	2.431	2.431	1.61	0.211
BL1.BL2.BL3.ETHY2	1	0.587	0.587	0.39	0.536
BL1.MCP1.BL2.ETHY1.MCP2	1	0.395	0.395	0.26	0.612
BL1.MCP1.BL2.ETHY1.BL3	1	0.545	0.545	0.36	0.551
BL1.MCP1.BL2.MCP2.BL3	1	0.719	0.719	0.48	0.493
BL1.BL2.ETHY1.MCP2.BL3	1	0.002	0.002	0.00	0.973
BL1.MCP1.BL2.BL3.ETHY2	1	10.425	10.425	6.89	0.011
BL1.BL2.ETHY1.BL3.ETHY2	1	2.352	2.352	1.55	0.218
BL1.BL2.MCP2.BL3.ETHY2	1	0.000	0.000	0.00	0.994
BL1.MCP1.BL2.ETHY1.MCP2.BL3	1	2.818	2.818	1.86	0.178
BL1.MCP1.BL2.ETHY1.BL3.ETHY2	1	0.190	0.190	0.13	0.725
BL1.MCP1.BL2.MCP2.BL3.ETHY2	1	0.126	0.126	0.08	0.774
BL1.BL2.ETHY1.MCP2.BL3.ETHY2	1	6.153	6.153	4.07	0.049
BL1.MCP1.BL2.ETHY1.MCP2.BL3.ETHY2	1	0.550	0.550	0.36	0.549
Residual	52	78.657	1.513		
Total	80	113.152			

APPENDIX D

CHAPTER SEVEN

Table D.1 ANOVA table for ABA concentration (ng g^{-1} DW) in 'Saturna' tubers in Year 2008-2009

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
BASELINE	1	32.5	32.5	0.07	0.796
BASELINE.P1	1	309.6	309.6	0.66	0.428
BASELINE.T1	1	25.2	25.2	0.05	0.820
BASELINE.P1.T1	1	136.1	136.1	0.29	0.598
BASELINE.T1.T2	1	8546.7	8546.7	18.13	<.001
BASELINE.T1.P2	1	253.8	253.8	0.54	0.473
BASELINE.P1.T1.T2	1	252.5	252.5	0.54	0.474
BASELINE.P1.T1.P2	1	1750.9	1750.9	3.71	0.070
BASELINE.T1.T2.P2	1	396.6	396.6	0.84	0.371
BASELINE.P1.T1.T2.P2	1	661.6	661.6	1.40	0.252
Residual	18 (4)	8486.7	471.5		
Total	28 (4)	18430.5			

Table D.2 ANOVA table for ABA concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2008-2009

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BASELINE	1	219.6	219.6	0.35	0.557
BASELINE.TREATMENT	1	700.9	700.9	1.13	0.297
BASELINE.T1	3	9458.9	3153.0	5.09	0.006
BASELINE.TREATMENT.T1	3	8035.4	2678.5	4.32	0.013
Residual	27	16732.8	619.7		
Total	35	35147.6			

Table D.3 ANOVA table for 7'-OH-ABA concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2008-2009

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
BASELINE	1	211.223	211.223	25.25	0.002
BASELINE.TREATMENT	1	92.213	92.213	11.03	0.013
BASELINE.T1	3	2090.636	696.879	83.32	<.001
BASELINE.TREATMENT.T1	3	81.638	27.213	3.25	0.090
Residual	7(20)	58.547	8.364		
Total	15(20)	1094.726			

Table D.4 ANOVA table for PA concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2008-2009

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BASELINE	1	98.9	98.9	0.57	0.456
BASELINE.TREATMENT	1	174.0	174.0	1.00	0.325
BASELINE.T1	3	4206.7	1402.2	8.09	<.001
BASELINE.TREATMENT.T1	3	935.4	311.8	1.80	0.171
Residual	27	4677.5	173.2		
Total	35	10092.6			

Table D.5 ANOVA table for Z concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2008-2009

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
BASELINE	1	3649.	3649.	3.61	0.087
BASELINE.TREATMENT	1	4670.	4670.	4.62	0.057
BASELINE.T1	3	3307.	1102.	1.09	0.397
BASELINE.TREATMENT.T1	3	7238.	2413.	2.39	0.130
Residual	10(17)	10107.	1011.		
Total	18(17)	17409.			

Table D.6 ANOVA table for ZR concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2008-2009

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
BASELINE	1		9.50	9.50	0.55	0.465
BASELINE.TREATMENT	1		55.81	55.81	3.24	0.084
BASELINE.T1	3		200.33	66.78	3.87	0.021
BASELINE.TREATMENT.T1	3		109.37	36.46	2.11	0.123
Residual	26	(1)	448.16	17.24		
Total	34	(1)	819.52			

Table D.7 ANOVA table for IPA concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2008-2009

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
BASELINE	1		132.2	132.2	0.50	0.486
BASELINE.TREATMENT	1		1438.4	1438.4	5.45	0.029
BASELINE.T1	3		6748.4	2249.5	8.52	<.001
BASELINE.TREATMENT.T1	3		4870.2	1623.4	6.15	0.003
Residual	22	(5)	5806.2	263.9		
Total	30	(5)	18783.3			

Table D.8 ANOVA table for ABA concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2009-2010

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	63.82	31.91	0.49	
REP.*Units* stratum					
BL1	1	432.48	432.48	6.66	0.014
BL1.TREAT	1	284.86	284.86	4.39	0.043
BL1.BL2	1	963.31	963.31	14.83	<.001
BL1.TREAT.BL2	1	119.38	119.38	1.84	0.184
BL1.BL2.P1	1	172.45	172.45	2.66	0.112
BL1.BL2.T1	3	4549.69	1516.56	23.35	<.001
BL1.TREAT.BL2.P1	1	14.88	14.88	0.23	0.635
BL1.TREAT.BL2.T1	3	1620.08	540.03	8.31	<.001
BL1.BL2.P1.T1	3	64.85	21.62	0.33	0.802
BL1.TREAT.BL2.P1.T1	3	459.58	153.19	2.36	0.088
Residual	36	2338.33	64.95		
Total	56	11083.72			

Table D.9 ANOVA table for 7'-OH-ABA concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2009-2010

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		477.77	238.88	4.10	
REP.*Units* stratum						
BL1	1		24.31	24.31	0.42	0.529
BL1.TREAT	1		2346.28	2346.28	40.32	<.001
BL1.BL2	1		358.35	358.35	6.16	0.026
BL1.TREAT.BL2	1		65.73	65.73	1.13	0.306
BL1.BL2.P1	1		807.52	807.52	13.88	0.002
BL1.BL2.T1	3		803.51	267.84	4.60	0.019
BL1.TREAT.BL2.P1	1		3146.25	3146.25	54.06	<.001
BL1.TREAT.BL2.T1	3		340.02	113.34	1.95	0.168
BL1.BL2.P1.T1	3		3686.72	1228.91	21.12	<.001
BL1.TREAT.BL2.P1.T1	3		187.53	62.51	1.07	0.392
Residual	14 (22)		814.72	58.19		
Total	34 (22)		8092.78			

Table D.10 ANOVA table for PA concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2009-2010

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3546.	1773.	0.66	
REP.*Units* stratum					
BL1	1	3198.	3198.	1.19	0.282
BL1.TREAT	1	8246.	8246.	3.07	0.088
BL1.BL2	1	616.	616.	0.23	0.635
BL1.TREAT.BL2	1	366.	366.	0.14	0.714
BL1.BL2.P1	1	9530.	9530.	3.55	0.068
BL1.BL2.T1	3	4929.	1643.	0.61	0.611
BL1.TREAT.BL2.P1	1	5214.	5214.	1.94	0.172
BL1.TREAT.BL2.T1	3	3206.	1069.	0.40	0.755
BL1.BL2.P1.T1	3	488.	163.	0.06	0.980
BL1.TREAT.BL2.P1.T1	3	7180.	2393.	0.89	0.455
Residual	36	96582.	2683.		
Total	56	143100.			

Table D.11 ANOVA table for GA_4 concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2009-2010

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	166.9	83.5	0.31	
REP.*Units* stratum					
BL1	1	123.1	123.1	0.46	0.503
BL1.TREAT	1	190.0	190.0	0.71	0.407
BL1.BL2	1	263.5	263.5	0.98	0.329
BL1.TREAT.BL2	1	3.4	3.4	0.01	0.911
BL1.BL2.P1	1	3.9	3.9	0.01	0.905
BL1.BL2.T1	3	1899.4	633.1	2.35	0.089
BL1.TREAT.BL2.P1	1	15.9	15.9	0.06	0.809
BL1.TREAT.BL2.T1	3	2052.4	684.1	2.54	0.072
BL1.BL2.P1.T1	3	477.4	159.1	0.59	0.625
BL1.TREAT.BL2.P1.T1	3	881.1	293.7	1.09	0.366
Residual	36	9700.5	269.5		
Total	56	15777.7			

Table D.12 ANOVA table for IPA concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2009-2010

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2	984.9	492.5	4.01	
REP.*Units* stratum					
BL1	1	11.0	11.0	0.09	0.769
BL1.TREAT	1	1146.5	1146.5	9.33	0.009
BL1.BL2	1	144.9	144.9	1.18	0.296
BL1.TREAT.BL2	1	190.0	190.0	1.55	0.234
BL1.BL2.P1	1	174.2	174.2	1.42	0.253
BL1.BL2.T1	3	831.2	277.1	2.26	0.127
BL1.TREAT.BL2.P1	1	350.7	350.7	2.86	0.113
BL1.TREAT.BL2.T1	3	404.2	134.7	1.10	0.383
BL1.BL2.P1.T1	3	404.1	134.7	1.10	0.383
BL1.TREAT.BL2.P1.T1	3	769.6	256.5	2.09	0.148
Residual	14 (22)	1719.5	122.8		
Total	34 (22)	4262.4			

Table D.13 ANOVA table for ZR concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2009-2010

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	354.7	177.4	0.77	
REP.*Units* stratum					
BL1	1	3.6	3.6	0.02	0.901
BL1.TREAT	1	595.3	595.3	2.58	0.117
BL1.BL2	1	323.1	323.1	1.40	0.245
BL1.TREAT.BL2	1	67.5	67.5	0.29	0.592
BL1.BL2.P1	1	65.2	65.2	0.28	0.599
BL1.BL2.T1	3	1143.9	381.3	1.65	0.195
BL1.TREAT.BL2.P1	1	350.4	350.4	1.52	0.226
BL1.TREAT.BL2.T1	3	702.8	234.3	1.01	0.398
BL1.BL2.P1.T1	3	748.9	249.6	1.08	0.370
BL1.TREAT.BL2.P1.T1	3	598.0	199.3	0.86	0.470
Residual	36	8322.3	231.2		
Total	56	13275.8			

Table D.14 ANOVA table for ABA concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2010-2011

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	62.8	31.4	0.13	
REP.*Units* stratum					
ContTreated	1	57.1	57.1	0.24	0.629
ContTreated.ContMCP1	1	21.1	21.1	0.09	0.769
ContTreated.OUT23	1	33.1	33.1	0.14	0.713
ContTreated.ContMCP1.OUT23	1	92.8	92.8	0.39	0.539
ContTreated.OUT23.ContETHY1	1	307.6	307.6	1.30	0.268
ContTreated.OUT23.TIME	1	783.0	783.0	3.30	0.084
ContTreated.ContMCP1.OUT23.ContETHY1	1	296.5	296.5	1.25	0.277
ContTreated.ContMCP1.OUT23.TIME	1	374.2	374.2	1.58	0.224
ContTreated.OUT23.ContETHY1.TIME	1	362.4	362.4	1.53	0.231
ContTreated.ContMCP1.OUT23.ContETHY1.TIME	1	730.4	730.4	3.08	0.095
Residual	20	4747.5	237.4		
Total	32	7868.4			

Table D.15 ANOVA table for 7'-OH-ABA concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2010-2011

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1429.9	714.9	2.32	
REP.*Units* stratum					
ContTreated	1	24.0	24.0	0.08	0.787
ContTreated.ContMCP1	1	69.1	69.1	0.22	0.647
ContTreated.OUT23	1	13.9	13.9	0.05	0.837
ContTreated.ContMCP1.OUT23	1	113.0	113.0	0.37	0.560
ContTreated.OUT23.ContETHY1	1	2657.6	2657.6	8.61	0.017
ContTreated.OUT23.TIME	1	1360.2	1360.2	4.41	0.065
ContTreated.ContMCP1.OUT23.ContETHY1	1	339.7	339.7	1.10	0.321
ContTreated.ContMCP1.OUT23.TIME	1	1095.8	1095.8	3.55	0.092
ContTreated.OUT23.ContETHY1.TIME	1	2769.9	2769.9	8.97	0.015
ContTreated.ContMCP1.OUT23.ContETHY1.TIME	1	301.2	301.2	0.98	0.349
Residual	9(11)	2777.7	308.6		
Total	21(11)	9779.0			

Table D.16 ANOVA table for PA concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2010-2011

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1130.	565.	0.49	
REP.*Units* stratum					
ContTreated	1	345.	345.	0.30	0.590
ContTreated.ContMCP1	1	2160.	2160.	1.89	0.185
ContTreated.OUT23	1	1278.	1278.	1.12	0.304
ContTreated.ContMCP1.OUT23	1	1739.	1739.	1.52	0.233
ContTreated.OUT23.ContETHY1	1	1463.	1463.	1.28	0.272
ContTreated.OUT23.TIME	1	1379.	1379.	1.20	0.286
ContTreated.ContMCP1.OUT23.ContETHY1	1	2257.	2257.	1.97	0.176
ContTreated.ContMCP1.OUT23.TIME	1	738.	738.	0.65	0.432
ContTreated.OUT23.ContETHY1.TIME	1	1422.	1422.	1.24	0.279
ContTreated.ContMCP1.OUT23.ContETHY1.TIME	1	655.	655.	0.57	0.459
Residual	19 (1)	21744.	1144.		
Total	31 (1)	36090.			

Table D.17 ANOVA table for IPA concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2010-2011

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2	593.8	296.9	2.25	
REP.*Units* stratum					
ContTreated	1	506.9	506.9	3.85	0.081
ContTreated.ContMCP1	1	47.4	47.4	0.36	0.563
ContTreated.OUT23	1	336.7	336.7	2.56	0.144
ContTreated.ContMCP1.OUT23	1	3.2	3.2	0.02	0.879
ContTreated.OUT23.ContETHY1	1	484.4	484.4	3.68	0.087
ContTreated.OUT23.TIME	1	820.5	820.5	6.23	0.034
ContTreated.ContMCP1.OUT23.ContETHY1	1	466.4	466.4	3.54	0.093
ContTreated.ContMCP1.OUT23.TIME	1	78.3	78.3	0.59	0.461
ContTreated.OUT23.ContETHY1.TIME	1	199.7	199.7	1.52	0.250
ContTreated.ContMCP1.OUT23.ContETHY1.TIME	1	594.7	594.7	4.51	0.063
Residual	9 (11)	1186.0	131.8		
Total	21 (11)	2830.5			

Table D.18 ANOVA table for ZR concentration (ng g^{-1} DW) in 'Marfona' potatoes in Year 2010-2011

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2	710.0	355.0	0.54	
REP.*Units* stratum					
ContTreated	1	18.8	18.8	0.03	0.867
ContTreated.ContMCP1	1	1440.6	1440.6	2.20	0.154
ContTreated.OUT23	1	241.7	241.7	0.37	0.550
ContTreated.ContMCP1.OUT23	1	272.5	272.5	0.42	0.526
ContTreated.OUT23.ContETHY1	1	856.9	856.9	1.31	0.266
ContTreated.OUT23.TIME	1	641.4	641.4	0.98	0.334
ContTreated.ContMCP1.OUT23.ContETHY1	1	659.6	659.6	1.01	0.328
ContTreated.ContMCP1.OUT23.TIME	1	202.1	202.1	0.31	0.585
ContTreated.OUT23.ContETHY1.TIME	1	163.5	163.5	0.25	0.623
ContTreated.ContMCP1.OUT23.ContETHY1.TIME	1	489.2	489.2	0.75	0.398
Residual	19(1)	12413.3	653.3		
Total	31(1)	18012.7			

APPENDIX E

FINAL REPORT

Understanding the fundamental role of ethylene in potato storage

SUTTON BRIDGE CROP STORAGE RESEARCH

AHDB - Potato Council
East Bank, Sutton Bridge
Spalding, Lincs. PE12 9YD
Tel: 01406 351444 Fax: 01406 351125
email: sbcsr@potato.org.uk

Study Director: Dr Glyn Harper
Report Authors: Graeme Stroud and Glyn Harper

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Contents

1. Summary

Ethylene is used as a sprout suppressant with 4% of the total Great Britain tonnage treated in 2008 (Garthwaite *et al.* 2010). The main appeal to the potato industry is the absence of a deposited residue. However, there is limited understanding of how ethylene works and its use is currently limited to low temperature, pre-pack potato storage.

The aim of this study was to broaden the understanding of the application of ethylene as a sprout suppressant. A range of cultivars and application timings were tested and periodically assessed for sugars and plant growth regulators at Cranfield University and physical sprouting at Sutton Bridge Crop Storage Research (formerly Sutton Bridge Experimental Unit).

Crops were divided into two experimental stores, one with no added ethylene and the other with ethylene supplied at 10 ppm. There were four treatments: two were full term storage under the regimes in these stores. The other treatments were reciprocal swaps between the two stores, triggered by 10% sprout eye movement in the untreated crop.

Ethylene reduced sprouting in all varieties. Excellent sprout inhibition was observed in Russet Burbank and Sylvana, both relatively long dormant varieties, and good sprout inhibition in Desiree, Estima, Fianna and Maris Piper. The least inhibition was observed in the very short dormant *Solanum phureja* cultivar, Mayan Gold. Although sprout inhibition appeared more pronounced in long dormant cultivars there were exceptions, notably Marfona, which is long dormant but in which sprouting was only weakly inhibited by ethylene.

Previous studies have found that ethylene reduces the dormant period of a potato. However, in this study, no correlation was discerned between ethylene use and observed dormancy in any variety.

After 30 weeks' storage, there was little difference in sprout length between 'full term ethylene treatment' and 'treatment since dormancy break'. This suggested that initiating ethylene treatment at dormancy break, as measured by 10% eye movement, was as effective as treating with ethylene throughout the storage period. However, in the long dormant varieties, Marfona, Russet Burbank and Sylvana, there was a reduction in the incidence of sprouting in ethylene treatments at transfer, indicating that ethylene apparently increases the duration before dormancy break in these cultivars.

This study provides baseline data to guide the further exploitation of ethylene in the GB potato industry. These findings need to be analysed in conjunction with the biochemical data from Cranfield University to more fully understand the effects of ethylene on potatoes.

2. Introduction

The use of ethylene as a sprout suppressant is gaining ground in the UK. The main appeal to the potato industry is the absence of a deposited residue. This adds value to a crop and may become a requirement of consumers in the future. However, there is limited understanding of how ethylene works and its use is currently limited to low temperature pre-pack potato storage. Improved understanding may facilitate wider application, for example sprout control in warmer stored processing crops.

The aim of this three year study was to broaden the understanding of the application of ethylene as a sprout suppressant. A range of cultivars, and application timings were tested and periodically assessed for sugars and plant growth regulators at Cranfield University (CU) and physical sprouting at Sutton Bridge Crop Storage Research (SBCSR).

The initial storage trial studied ten cultivars (Desiree, Estima, Fianna, King Edward, Marfona, Maris Piper, Mayan Gold, Russet Burbank, Saturna and Sylvana). In the second year four cultivars (Estima, Marfona, Russet Burbank and Saturna) were used with an expanded treatment range including 1-methyl cyclopropene (1-MCP) applications. Technical limitations in the quantity of crop that could be treated necessitated a reduction in the scope of the Sutton Bridge component of the study, achieved by reducing replication from 4 to 3 trays and assessing only the same treatments as were carried out in the first year. For the third and final year CU essentially replicated the second year treatment regime with two cultivars, Estima and Marfona, SBCSR replicated the second year experiment with all four varieties.

This report covers the SBCSR storage and sprouting assessment components of the study and is intended as an aid for interpreting the extensive biochemical data generated by CU.

3. Material and methods

3.1 Methods

Treatments and experimental design

Crops were divided into two experimental stores, one with no supplied ethylene and the other with ethylene supplied at 10 ppm. There were four treatments. Two were full term storage in these stores. The other treatments were reciprocal transfers between the two stores, triggered by a 10% sprout eye movement in the untreated crop. The treatments were referred to as *Ethylene*, *Untreated*, *Ethylene→untreated* and *Untreated→ethylene*. The experimental design was an unreplicated comparison of treatments with variation measured by four in-store replicates.

Controlled environment store set up and control

Two 12-tonne Controlled Environment Rooms were set at a target temperature of 6.0 C (tolerance ± 0.5 °C) and 95% RH (tolerance ± 5%), see Appendices; Figures 5 and 6 (2008/09), Figs. 40 and 41(2009/10), Figs. 55 and 56 (2010/11) provide the trial period store control data. The rooms were identically configured to constantly recirculate air. Air was discharged by overhead throw from the conditioning duct and then drawn back into a return at the bottom of the store for refrigeration or heating as necessary.

Humidification method, however, differed between stores. The untreated store was fitted with a Humimax HM2 2000 *[Munters Ltd]* fan assisted humidification cell, whereas the treated store had a conventional compressed air atomiser. No chlorpropham (CIPC) sprout suppressant had ever been used in these stores.

The trayed crop was stacked onto trolley-racks. One shelf was allocated to each cultivar/treatment combination at random but this order was replicated in both stores. Trays were stacked randomly within shelves.

Ethylene was monitored and controlled by an EMU2 TS Ethylene Management Unit *[BioFresh Ltd]* which sampled and measured the concentration of ethylene gas in store air using a Polytron *[Dräger]* electro-chemical sensor calibrated specifically for ethylene. Sampled air was drawn through a narrow bore tube from the opening of the store's air return duct. This unit drove an external control mechanism with solenoid valves to control the introduction of ethylene, from a pressurised cylinder, with reference to a configurable set-point. An integral data logger recorded the ethylene concentration and was downloaded at weekly intervals see Appendices, Figure 4 for 2008/09, Fig 39 for 2009/10, and Fig 54 for 2010/11. Real-time ethylene readings were checked manually each day.

To minimise the risk of ethylene contamination from treated to untreated crops a second untreated store was employed on each transfer occasion. In this store, any ethylene associated with the *Ethylene→untreated* material was allowed to dissipate for a minimum of 24 hours before moving to the designated untreated store.

Eye movement and sprouting assessments

The trigger for reciprocal transfer between the stores was when 10% of the untreated tubers of a sample demonstrated white sprout tissue development. This sprout movement was monitored in whole trays at approximately weekly intervals and, where possible, a tray was assessed only once to minimise handling stress.

Within 24 hours of intake, four 25 tuber samples from each crop were taken for pre-treatment sprout assessment. Thereafter sprouting assessments were carried out on sub-samples of 25 tubers from the selected trays on each of four occasions: after 28 days of ethylene treatment, at the time of 10% eye movement transfer, transfer plus 28 days and full term storage (30 weeks). The length of the longest sprout on each tuber was measured and also the number of sprouting sites. When a large number of sprouting assessments were due, the allocated trays were moved to a 3.0 C cold store, which effectively halted sprout development until assessments were possible.

If the threshold for transfer had not been achieved by the 28 day sampling occasion, the treatments designated for transfer were not assessed as, by definition, there was no difference from the continuous treatments. For the same reason, any crop that achieved the transfer threshold before ethylene treatment began, was not assessed for any transfer treatment or related sampling occasion. Sampling occasions and dates are shown in Figure 10 for 2008/09, Fig 13 for 2009/10 and Fig 15 for 2010/11.

Relative dormancy assessment

Immediately after sprouting assessment the four 25 tuber intake samples for individual cultivars were pooled and stored in paper-sacks at 15 °C and 95% RH. At approximately weekly intervals, tubers were transferred to an alternate paper-sack and any tuber with a sprout of 3 mm or longer was counted and discarded. This process continued until all tubers had sprouted.

1-Methyl Cyclopropene and control treatment *2009-10* and *2010-2011*

Some CU treatments required treatment with 1-methyl cyclopropene (1-MCP) [Rohm & Haas]. The application of this chemical took place at 6.0 °C in 0.5 m^3 sealed chambers, with internal circulation, for 24 hours. As a control, all tubers were similarly sealed, either with or without 1-MCP, in chambers prior to other storage treatment regimes. Because of limited availability of sealed chambers at Sutton Bridge it was necessary for this component of the trial to begin a day later than the CU trial.

3.2 Year 1 materials and methods (2008/09)

Crop, loading and temperature pull-down

Ten cultivars were selected to represent a range of physiological dormancy characteristics (see Appendices, Table 7). The crops were loaded into the treatment stores in two batches of five depending on their availability. The first batch was delivered on the 24th August 2008 and comprised Desiree, Maris Piper, King Edward, Estima and Marfona [supplied by *Solanum*].

The second batch arrived later, and over several days. Mayan Gold 6th October 2008 and Sylvana 7th October 2008 *[Greenvale AP]*, Russet Burbank 8th October 2008 *[McCain Foods]*, Saturna 9th October 2008 *[G H Chennells]* and Fianna 10th October 2008 *[H Prins]*.

As soon as possible, potatoes were passed over a grading line to remove soil, rots, damage, green and undersize tubers (< 45 mm) and loaded into 10 kg (capacity) plastic trays. Once in trays, crops underwent a controlled pull-down regime of 0.5 °C per day, at ambient relative humidity (RH), to a holding temperature of 6.0 °C. This was to minimise temperature stress and allow time for skin healing after handling. The second batch of crops went into a holding store at 10 °C on arrival, to synchronise the start of their pull-down.

Treatment of the two batches started on 15th and 23rd October 2008 respectively.

3.3 Year 2 materials and methods (2009/10)

Treatments and experimental design

Crop, loading and temperature pull-down

Four commonly grown cultivars were selected to represent a range of ethylene responses and physiological dormancy characteristics (see Appendices, Table 7) agreed at the project meeting 18 August 2009. Estima was supplied on 16th October 2009 *[source: Elveden Farms]*, Saturna on 21st October 2009 *[R.S. Cockerill]* and Marfona on 22nd October 2009 *[C. Wright & Son]*. Russet Burbank *[Greenvale AP]* was delivered on 3rd November 2009.

As soon as possible, potatoes were hand graded to remove soil, rots, damage, green and undersize tubers (< 45 mm) and loaded into 10 kg (capacity) plastic trays. Once in trays, crops underwent a controlled pull-down regime of 0.5 C per day, at ambient relative humidity (RH), to a holding temperature of 6.0 C. This was to minimise temperature stress and allow time for skin healing after handling. However, due to the late arrival of Russet Burbank the temperature of this crop was pulled down at an accelerated rate of 1.0 C per day in order to meet the start of the experiment. Treatment started on 11th November 2009.

3.4 Year 3 materials and methods (2010/11)

Crop loading and temperature pull-down

For added replication, CU decided to repeat the previous experiments concentrating on Estima and Marfona only. Later a second batch, comprising Russet Burbank and Saturna, were also sourced for sprouting assessment only by SBSCR. The physiological dormancy characteristics of the four varieties are shown Appendices, Table 7. Intake of Estima and Marfona was on 12th October 2010 *[C. Wright & Son]*, Russet Burbank *[Greenvale AP]* arrived on 26th October 2010 and Saturna on 1st November 2010 *[R.S. Cockerill]*.

As soon as possible, potatoes were hand graded to remove soil, rots, damage, green and undersize tubers (< 45 mm) and loaded into 10 kg (capacity) plastic trays. Once in trays, crops underwent a controlled pull-down regime of 0.5 C per day, at ambient relative humidity (RH), to a holding temperature of 6.0 C.

This was to minimise temperature stress and allow time for skin healing. Treatment started on 30th October 2010 and then on 18th November 2010 for the second batch.

4. Results

4.1 Year 1 Results (2008/09)

Ethylene concentration and control in store

The recorded ethylene readings for both ethylene treated and untreated rooms are shown in Appendices Figure 4. Data were not automatically recorded for a sum total of 23 out of 210 experimental days (Appendices Table 8), but were manually recorded every day (results available but not shown). The control of ethylene in the ethylene treated store was relatively stable apart from an interruption to the gas supply over the weekend of the 8th and 9th November 2008. The ethylene reading was less stable in the untreated store; the maximum reading was 6 ppm on 31st December 2008. However, all independent verification gave very low ethylene levels, peaking at 0.2 ppm (Appendices, Table 9).

Dormancy

None of the cultivars were sprouting at intake. However, King Edward, a very short dormancy cultivar grown in the UK, had already passed the 10% sprout movement threshold as ethylene treatments began. Consequently, only the full-term *Ethylene* and *Untreated* treatments were continued as any swap at this stage would simply reproduce existing treatments.

The relative dormancy (50% 3mm sprout growth at 15°C) results are shown in Figure 1. They demonstrate a broad range of dormancies from short (e.g. Mayan Gold and King Edward) to long (e.g. Russet Burbank and Sylvana). When compared with the treatment transfer date (10% eye movement at 6°C), the rank of dormancies although broadly similar showed some notable disagreements (Table 1). Fianna in particular was more dormant at 6°C storage and Sylvana and Desiree less so. In this study, the transfer date is a more directly relevant measure of dormancy.

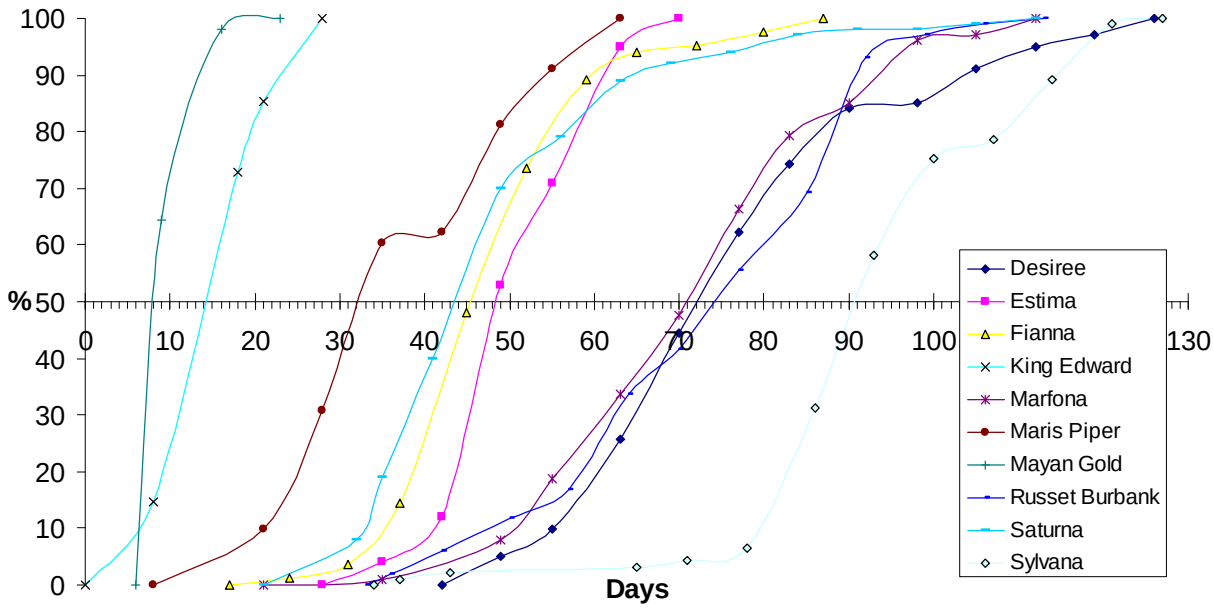

Figure 1. Dormancy break at 15 °C for the potato varieties used in the study (tubers sprouting 3 mm or more)

Sprouting

Ethylene reduced sprouting in all varieties. Table 2 shows the actual mean longest spout length after 30 weeks of storage both with and without ethylene. Exceptional sprout inhibition was achieved in Russet Burbank and Sylvana, both relatively long dormant varieties. The least inhibition was achieved in the very short dormancy variety Mayan Gold. Although sprout inhibition appeared generally better in long dormant cultivars there were major exceptions; most notably Marfona, which was long dormant and weakly suppressed.

Generally, there was little difference in longest sprout length between treatments before the final assessment at week 30 because the earlier assessments were made before, at and shortly after dormancy break. The sprout inhibition due to ethylene then became very apparent, but there was little difference between *Untreated* and *Ethylene→untreated*. Similarly there was little difference between *Ethylene* and *Untreated→ethylene.* Histograms of means of sprouting for all cultivars, treatments and assessment occasions are shown in Appendix 8.1.2, Figures 7 - 36.

The length of the longest sprout on a tuber is the most practical measure of sprouting but is relatively insensitive at low sprout incidences. Total sprout incidence is more sensitive. However, after dormancy break, 100% incidence is rapidly approached. The incidence data show that there was little sprouting at 28 days where this preceded dormancy break. At transfer, the longer dormant varieties, for example Marfona, Russet Burbank and Sylvana, had more than 20% lower incidence of sprouting in the two ethylene treatments.

Table 1. Rank comparison of relative dormancy period against transfer day

Dormancy Days at 15 °C for 50% of plants to show sprouts ≥ 3mm	**Variety rank** (NIAB dormancy rating in brackets)		**Variety rank**	**Eye Movement** Days at 6°C for 10% of plants to show eye movement = transfer day
8	Mayan Gold (4)		King Edward	Missed
14	King Edward (6)		Mayan Gold	6
35	Maris Piper (5)		Maris Piper	14
43	Saturna (-)		Saturna	15
45	Fianna (8)		Desiree	51
48	Estima (5)		Estima	64
71	Marfona (5)		Sylvana	84
72	Desiree (4)		Marfona	92
74	Russet Burbank (-)		Fianna	97
91	Sylvana (-)		Russet Burbank	97

Table 2. Effect of ethylene on mean longest sprout length, after 30 weeks of storage at 6ºC, and dormancy period

Cultivar	Mean longest sprout length (mm) after 30 weeks of storage		Dormancy (days until 10% incidence of eye movement)
	Ethylene	Untreated	
Sylvana	0.8	18.2	84
Russet Burbank	1.0	13.5	97
Estima	2.6	16.3	64
Fianna	3.3	14.4	97
Desiree	3.9	24.3	51
King Edward	6.3	14.0	Missed
Saturna	6.7	13.3	15
Maris Piper	7.1	25.4	14
Marfona	11.1	21.4	92
Mayan Gold	23.8	30.8	6

The number of sprouting sites increases markedly between dormancy break (transfer) and 28 days later except for the short dormancy varieties such as Saturna and Mayan Gold. The difference between treatments gave patterns broadly similar to the longest sprout data where at 'transfer + 28 days', *Untreated* and *Ethylene→untreated* showed similar but more sprout sites than *Ethylene* and *Untreated→ethylene.* However, by 30 weeks the differences between treatments had become negligible except for the long dormant varieties Fianna, Russet Burbank and Sylvana.

Sprout vigour

The sprout growth of some of the short dormant cultivars (e.g. Mayan Gold and King Edward) subjectively appeared more vigorous than the longer dormant varieties (e.g. Russet Burbank) and also more vigorous close to break of dormancy. Sprout "vigour" was approximately estimated in two ways by subtracting the sprout length at transfer from length at either 'transfer + 28 days' or '30 weeks' to give a rate of growth. The latter was plotted per 28 day month for comparison; see Appendix 8.1.3 for figures and description. As might be expected, the post-transfer untreated treatments were generally more vigorous than those in ethylene, where a difference had had time to develop. Appendix 8.1.3 Figure 37 showed that vigour in the first 28 days ranged up to approximately 3 mm of growth but that the rate of growth per 28 days up to 30 weeks ranged higher, up to 5 mm (Appendix 8.1.3, Figure 38).

4.2 Year 2 Results (2009/10)

Originally this study was to include Mayan Gold as a short dormant cultivar. However, the growing conditions this season were unusually hot and dry which promoted sprouting in the field. All available Mayan Gold was found to be sprouting in the field beyond the 10% eye movement threshold and was subsequently dropped from the study. Crops of Estima and Marfona sourced in September 2009 had to be replaced due to unacceptable levels of sprouting. All crops had some level of sprouting at harvest and it was especially difficult to find Estima with a low level of sprouting. Any tubers found with long sprouts, and often associated root growth, were discarded before the trial started. The lack of sprouting in this trial may have resulted from the season's unusual field conditions or the necessity to select the least sprouting crops or both.

All Russet Burbank is grown under contract to *McCain Foods,* whose policy this season was for it to be sprayed in field with maleic hydrazide (MH), a sprout inhibiting treatment used to prevent volunteers growing in the following crop. This would confound a sprout inhibition study. The only MH untreated Russet Burbank available were crops destined for seed. The top size fraction of a crop, too big for sale as seed, was used in this study. The crop was grown in Scotland and not subject to the conditions that caused field sprouting. However, at 15 C, the crop broke dormancy much more rapidly than expected and this might be due to the agronomy techniques used to ensure vigorous seed growth. Nevertheless, the early break of dormancy was less pronounced at 6 C, with 10% eye movement occurring at 75 days (97 last season).

Ethylene concentration and control in store

Ethylene levels were only recorded in the treated room and are shown in Appendix 8.2.1 Figure 39. Data were not automatically recorded for a total of 17 out of 198 experimental days (Appendix 8.2.1, Table 11), but were manually recorded every day (results not shown). The control of ethylene in the ethylene treated store was relatively stable apart from an interruption to the gas supply on 10th May 2010. Independent verification of the untreated room found no ethylene with one exception on 15th May 2010 at 0.647 ppm. The ethylene treated room usually had levels close to the target of 10 ppm except on 23rd November 2009 when the level was almost double (Appendix 8.2.1, Table 12).

Dormancy

None of the dormancy sub-samples was sprouting at intake. The relative dormancy on arrival at SBCSR (50% 3mm sprout growth at 15°C) is shown in Figure 2. It is noteworthy that the rate of break of dormancy of the varieties was similar for all varieties except Estima, which was distinctly more prolonged. Also, the normally long dormant Russet Burbank was unusually quick to break dormancy at 26 days compared with 74 days last season. The rank did not agree with that of transfer date (10% eye movement at 6°C), see Table 3.

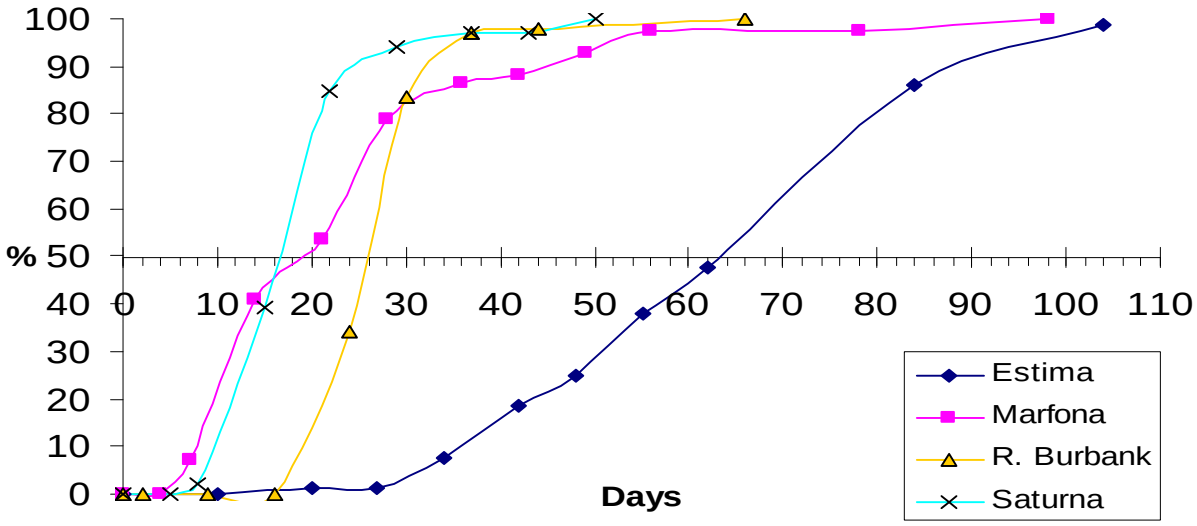

Figure 2. Dormancy break at 15 C (tubers sprouting 3 mm or more)

Sprouting

Unfortunately, the overall level of sprouting in this experiment was very low compared with the previous season. In fact, a direct comparison of sprout length after storage between continuous ethylene and the untreated crops revealed either very small or no differences and in the case of Marfona (known to be less responsive to ethylene) sprout length was greater in ethylene (Table 4). Histograms of means of sprouting for all cultivars, treatments and assessment occasions are shown in Appendix 8.2.2. Figures 42-53.

Table 3. Rank comparison of relative dormancy period against transfer day

Dormancy Days at 15 C for 50% of plants to show sprouts ≥ 3mm	**Variety rank** (NIAB dormancy rating in brackets)		**Variety rank**	**Eye movement** Days at 6 C for 10% of plants to show eye movement = transfer day
16	Saturna (-)		Saturna	18
19	Marfona (5)		Marfona	18
26	Russet Burbank (-)		Estima	36
63	Estima (5)		Russet Burbank	75

Table 4. Effect of ethylene on mean longest sprout length, after 30 weeks of storage at 6 ºC, and dormancy period

Cultivar	Mean longest sprout length (mm) after 30 weeks of storage		Dormancy (days until 10% incidence of eye movement)
	Ethylene	Untreated	
Russet Burbank	1.2	1.3	75
Estima	1.2	1.7	36
Saturna	3.5	4.0	18
Marfona	4.8	3.9	18

The length of the longest sprout on a tuber is the most practical measure of sprouting, but is relatively insensitive at low sprout incidences. Total sprout incidence is more sensitive. However, after dormancy break, 100% incidence is approached rapidly. The incidence data show that, at transfer, ethylene only inhibited sprouting in Estima (students t test $P<0.05$) and Russet Burbank ($P<0.05$).

The number of sprouting sites did not significantly differ due to ethylene treatment.

4.3 Year 3 Results (2010/11)

Ethylene concentration and control in store

Ethylene levels were automatically recorded in the treated room only (Appendix 8.3.1 Figure 54) and also manually recorded every day (results not shown). Data were not available for a total of 5 out of 234 experimental days (Appendix 8.3.1 Table 14). The control of ethylene in the ethylene treated store was stable apart from a slight upward sensor drift in November which requiring sensor replacement, and several incidences of freezing hardware in abnormally cold weather. Store atmosphere samples collected by CU on 7th January 2011 were analysed by gas chromatography to independently verify ethylene concentrations in the treatment stores. No ethylene was found in the untreated store and 9.433 ppm in the treated.

Dormancy

No tubers were sprouting at intake. The relative dormancy, estimated as days for 50% of tubers to achieve 3mm sprout growth at 15°C, is shown in Figure 3. Saturna was least dormant with 50% of tubers sprouting at 19 days. The other cultivars were all similar to each other, long dormant, with Russet Burbank demonstrating the longest dormant. The rank broadly agreed with that of transfer date (10% eye movement at 6°C), see Table 5.

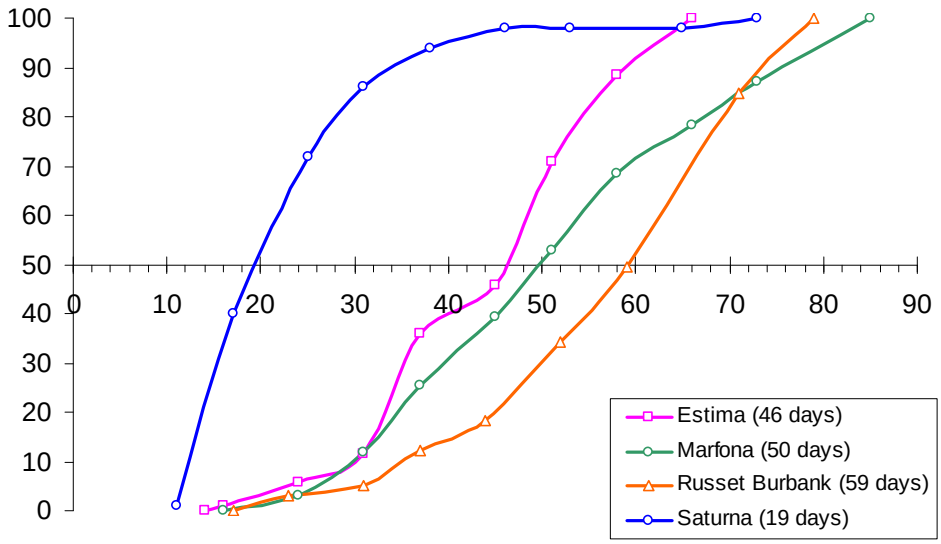

Figure 3. Dormancy break at 15 C (tubers sprouting 3 mm or more)

Sprouting

The trends in the sprouting data were very consistent between cultivars. For the mean length of longest sprout there was no significant difference due to ethylene treatment at time of transfer. At full term the *Untreated* and *Ethylene→untreated* crops were not significantly different from each other in sprouting incidence or sprout length and similarly both *Untreated→ethylene* and *Ethylene* were not significantly different from each other. However, the latter treatments always demonstrated significantly reduced sprout length ($P>0.05$) compared with the former. In Table 6 cultivars are ranked in order of greatest suppression in sprout length due to ethylene after full term storage.

It is notable that although Estima demonstrated the greatest difference between treatments, it nevertheless had the longest mean sprout length in ethylene of all the cultivars. Histograms of means of sprouting for all cultivars, treatments and assessment occasions are shown in Appendix 8.3.2., Figures 57-68.

Table 5. Rank comparison of relative dormancy period against transfer day

Dormancy	**Variety rank**		**Variety rank**	**Eye movement**
Days at 15 C for 50% of plants to show sprouts ≥ 3mm	(NIAB dormancy rating in brackets)			Days at 6 C for 10% of plants to show eye movement = transfer day
19	Saturna (-)	● —— ●	Saturna	60
46	Estima (5)	● —— ●	Estima	72
50	Marfona (5)	● —— ●	Marfona	83
59	Russet Burbank (-)	● —— ●	Russet Burbank	83

Table 6. Effect of ethylene on mean longest sprout length, after 30 weeks of storage at 6 ºC, and dormancy period

Cultivar	Mean longest sprout length (mm) after 30 weeks of storage		Dormancy (days until 10% incidence of eye movement)
	Ethylene	Untreated	
Russet Burbank	1.4	29.0	83
Saturna	5. 0	25.2	60
Estima	1.7	14.3	72
Marfona	2.6	12.0	83

The length of the longest sprout on a tuber is the most practical measure of sprouting, but is relatively insensitive at low sprout incidences. Total sprout incidence is more sensitive but, after dormancy break, 100% incidence is approached rapidly. The data show that, at transfer, ethylene inhibited sprouting incidence and there were significant differences in sprout length of Estima, Marfona and Saturna ($P<0.05$). The number of sprouting sites did not significantly differ due to ethylene treatment.

5. General discussion

Ethylene control in store

Prange *et al*. (2005) suggested that continuous exposure to ethylene over 23-33 weeks at 4 μL L^{-1} (4 ppm) was an effective method of sprout control in potatoes. Subsequently a rate of 10 ppm ethylene has become established as the industry standard, with refinements such as gradual introduction (ramping) of gas to avoid potential problems related to the increase in respiration induced by ethylene. In these trials, the target ethylene concentration in store was 10 ppm (unramped) and this concentration was achieved for essentially all of the storage period (See Appendices Figures 4, 39 and 54; daily manual recording data, not shown). Ethylene was occasionally detected in the untreated store with potential sources being exhaust products from propane-powered forklift use, potato production (<0.1 μL kg^{-1} h^{-1} at 20ºC; Knee *et al*., 1985) or positive feedback after transfer to the untreated store, despite a period of 'degassing' (Saltveit, 1999).

Overall, the control of 10 ppm ethylene within the store was acceptable and the ethylene concentration in the untreated store was always either nil or significantly less than that required to exert an effect according to Prange *et al*. (2005).

Effects of ethylene

There is enough evidence in this study to make some broad generalisations. At transfer there was usually a greater incidence of sprouting in the *Untreated* than *Ethylene*. Furthermore, where there is enough sprouting to demonstrate a difference at full term storage, *untreated* and *ethylene→untreated* potatoes tended to show no significant difference and had longer sprouts than the *untreated→ethylene* and *ethylene* regimes. The latter treatments also tended to show no significant difference. This pattern was seen in Desiree, Estima, Fianna, Marfona, Maris Piper, Russet Burbank, Saturna and Sylvana. No other trends were evident except that the number of sprouting sites was little affected by any treatment.

Dormancy

A comparison of relative dormancies is shown by cultivar for the four varieties common to all seasons in the study Appendix 8.4 Figures 69-72. Season to season, there was a wide variation in the time taken for 50% of tubers to show 3mm sprouts. Generally, the 2008/09 season had the longest dormancy periods and 2009/10 the shortest, but one crop that appeared different was Estima in 2009/10.

Its dormancy period was much longer than expected and the rate of dormancy break slower than in other seasons. The reason for this difference is unknown. Conversely, Russet Burbank broke dormancy in 2009/10 at a faster rate than in the other seasons of the trial, although a possible reason is that it was grown as a seed crop in Scotland. This dormancy information should be considered in conjunction with the biochemical data generated by CU.

Dormancy break

Rylski *et al* (1974) suggested that ethylene reduces the true dormant period compared with control tubers stored in air so ethylene breaks dormancy, but suppresses sprout elongation, a conclusion supported by others, for example Pruski *et al*. (2006). There was little or no evidence to support this conclusion in this study. Dormancy break is measured in terms of sprouting and it might be expected that an increase in eye activity would be observed in the presence of ethylene. However, there was only one observed incidence of increased sprouting by ethylene treatment at the time of transfer, all other cases ethylene appeared to reduce the sprouting incidence. This is possibly because the break of dormancy happens at or near to the onset of treatment and continuous ethylene may rapidly suppress sprout elongation.

In 2008/09 Maris Piper at transfer had a greater incidence of sprouting under ethylene, but this coincided with a particularly short time to achieve 10% sprouting (14 days). Thus a dormancy breaking effect may have overcome a sprout suppressing affect. However, there does not appear to be any lasting effect in the longer term as *Ethylene→untreated* did not sprout more than *Untreated.*

Timing of ethylene application

The two commercial suppliers of ethylene treatment in UK potato stores recommend different ethylene initiation timings with *BioFresh* recommending that ethylene is enabled early in storage (before dormancy break) and *Restrain* recommending that it should be enabled at dormancy break. Even though differences in sprouting can be detected before transfer, the insignificant difference in sprout length between *Ethylene* and *Untreated→ethylene*, at full term storage, would suggest that beginning ethylene treatment at dormancy break (as measured by 10% eye movement) is no less effective than treating with ethylene throughout the storage period. In the case of Russet Burbank this has amounted to more than three months expensive treatment for no beneficial effect.

6. Summary conclusions

- Ethylene is an effective agent for sprout control, having an effect on all varieties tested in this trial.
- It is particularly effective for some varieties but these results confirm that there is significant variation in response of different potato varieties to ethylene.
- The results support the previous finding that application of ethylene suppresses sprout elongation.
- The results do not provide evidence to support the previous finding that exogenous ethylene encourages dormancy break.

- The application of ethylene is as effective at the break of dormancy as application at the start of storage, but crops must be monitored closely to identify dormancy break.

Future work for consideration:

- Investigate timing of ethylene application.
- Test ethylene effect on dormancy break for this selection of potato varieties.
- Establish how the removal of all ethylene affects tubers, e.g. use of an ethylene scrubber to influence dormancy break.
- Determine whether varietal responses to ethylene can be broadly associated with shared characteristics (e.g. dormancy, determinacy, vigour etc.)
- Does ethylene break dormancy in all varieties?

7. References

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8. Appendices

8.1. Year 1 Data 2008/2009

Table 7. Dormancy ratings for the potato varieties used in the trial

Cultivar	Dormancy- The European Cultivated Potato Database
Desiree	Medium [**1**] Medium to long [**2**, **3**, **5**]
Estima	Medium to long [**1**] Long [**2**, **5**]
Fianna	-
King Edward	Medium [**2**] Medium to long [**1**]
Marfona	Medium to long [**1**] Long [**2**, **5**]
Maris Piper	Medium [**1**] Medium to long [**2**]
Mayan Gold	-
Russet Burbank	Long to very long [**4**]
Saturna	Medium [**1**] Long to very long [**2**, **5**]
Sylvana	-
Source	**1**. Leibniz Institute of Plant Genetics and Crop Plant Research (IPK), Germany **2**. SASA, UK **3**. Pannon University , Hungary **4.** HZPC B.V., Nederlands **5**. Nederlands Potato Consultative Foundation, Netherlands

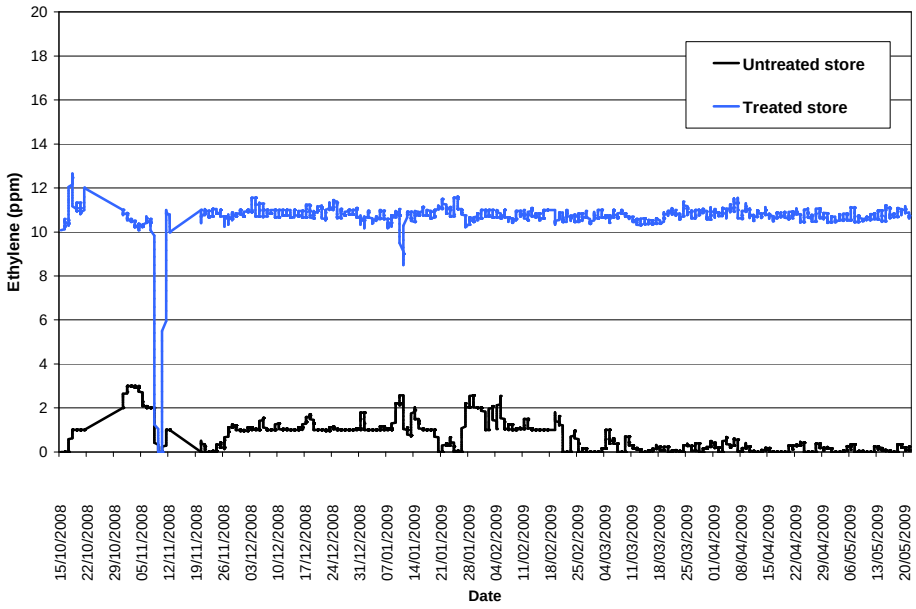

Figure 4. Rolling 24 hour average of hourly ethylene reading

Table 8. Time periods for when automatically recorded data was unavailable

Ethylene logger data missing		Number of days data not recorded
from	to	
20/10/2008	31/10/2008	11
11/11/2008	20/11/2008	9
16/02/2009	19/02/2009	3

Table 9. Independent measurement of ethylene in treatment stores

Sampling date	Untreated store, Ethylene (ppm)	Ethylene treated store, Ethylene (ppm)
9th October 2008	0*	-
21st October 2008	0*	10*
28th October 2008	0.11	13
7th November 2008	0	13
12th November 2008	0	10.6
18th December 2008	0.2	-
2nd January 2009	0.13	-
15th January 2009	0.12	10.8
28th January 2009	0.14	8.9
10th February 2009	0.097	11.13
24th February 2009	0	8.77

All measurements provided by Cranfield University using gas chromatography except * where a GasTec 172L ethylene detector tube was used (detection limit 0.05 ppm).

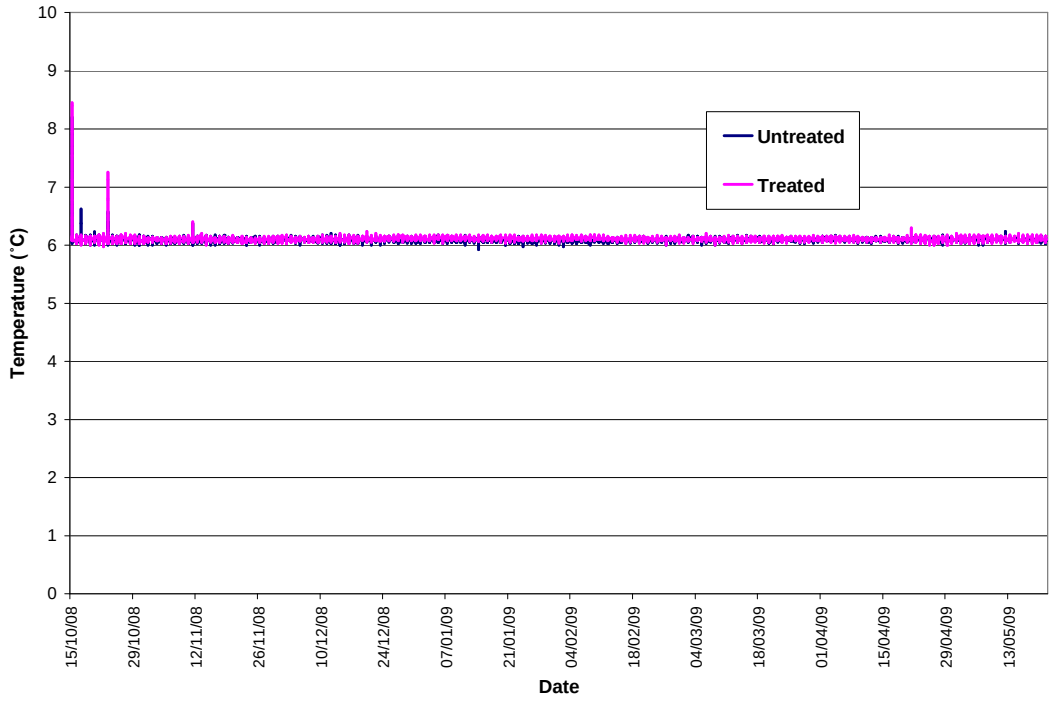

Figure 5. Store temperature for the trial period

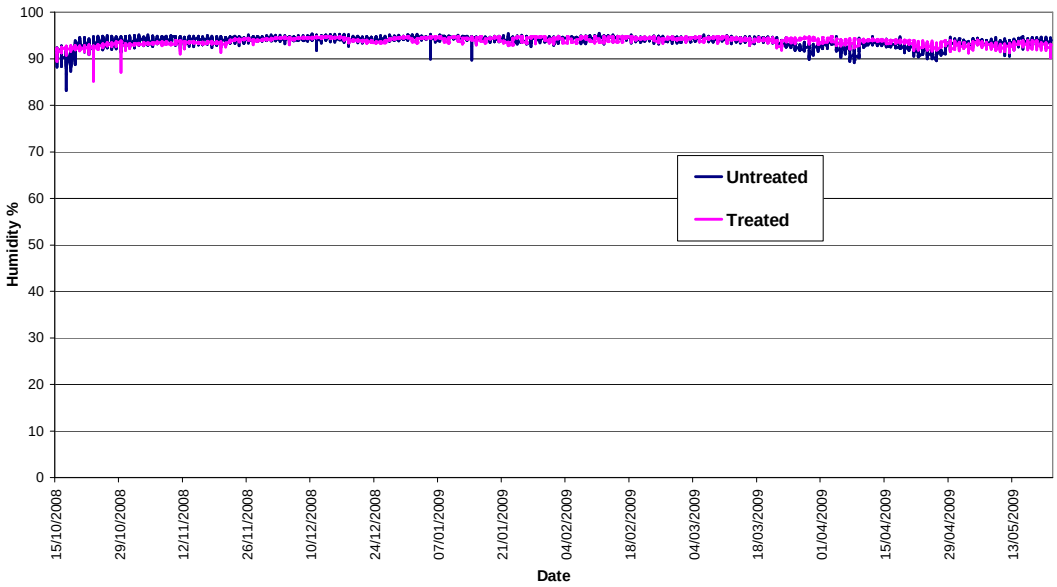

Figure 6. Store relative humidity for the trial period

Table 10. Sampling dates and occasions for sprouting assessments

Variety	28 days in ethylene	Transfer	28 days after Transfer	30 weeks
Desiree	12/11/2008	05/12/2008	02/01/2009	13/05/2009
Estima	12/11/2008	18/12/2008	15/01/2009	13/05/2009
Fianna	20/11/2008	28/01/2009	25/02/2009	21/05/2009
King Edward	12/11/2008	Missed	Missed	13/05/2009
Marfona	12/11/2008	15/01/2009	12/02/2009	13/05/2009
Maris Piper	12/11/2008	29/10/2008	26/11/2008	13/05/2009
Mayan Gold	20/11/2008	29/10/2008	26/11/2008	21/05/2009
Russet Burbank	20/11/2008	28/01/2009	25/02/2009	21/05/2009
Saturna	20/11/2008	07/11/2008	05/12/2008	21/05/2009
Sylvana	20/11/2008	15/01/2009	12/02/2009	21/05/2009

Sprouting 2008/09 by cultivar

Error bars showing +/- 1 sd

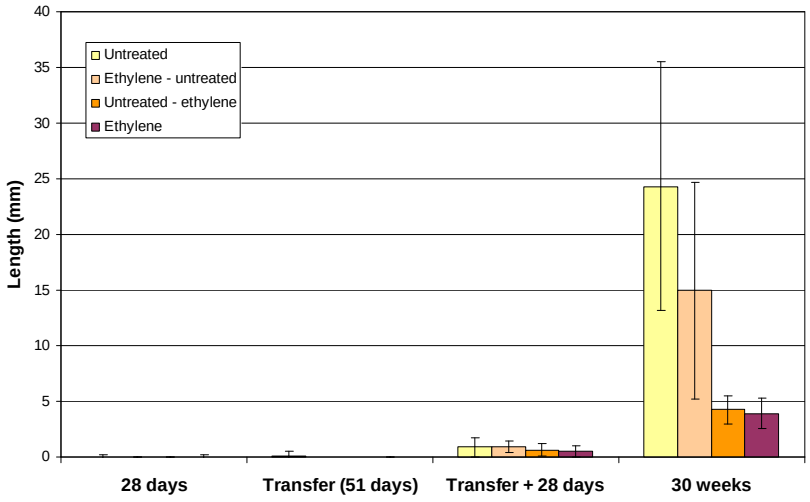

Figure 7. Desiree mean longest sprout

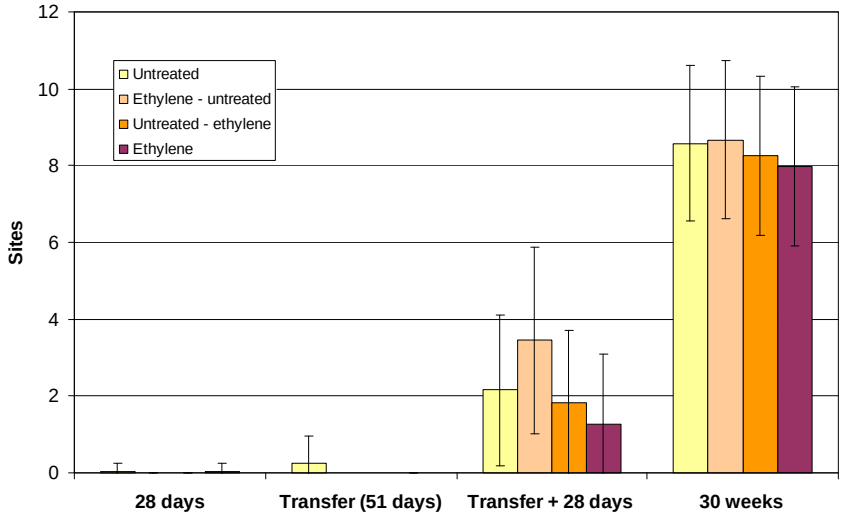

Figure 8. Desiree incidence of sprouting

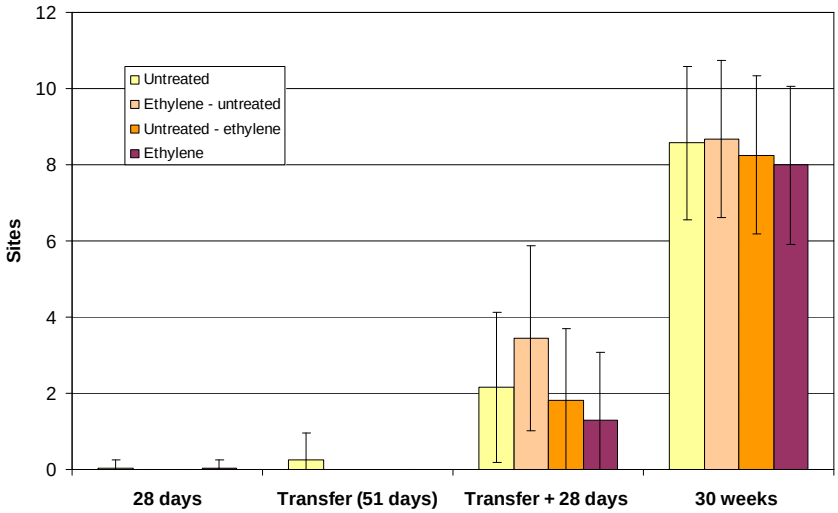

Figure 9. Desiree mean sprouting sites

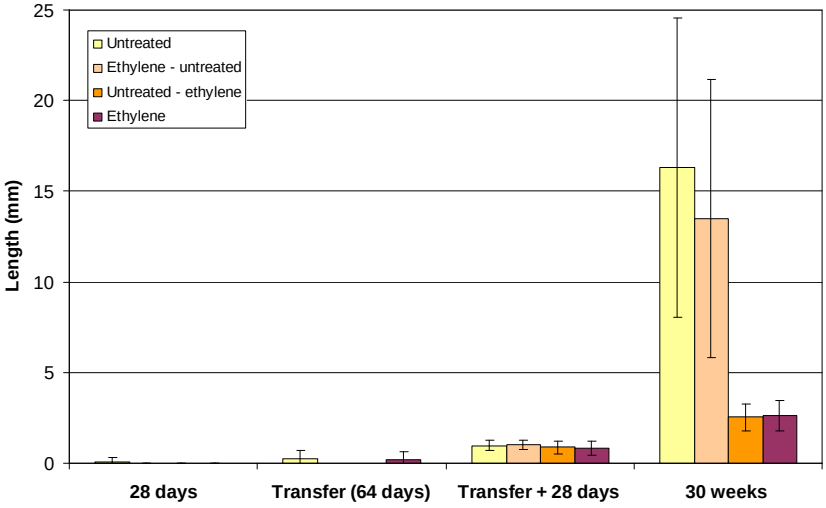

Figure 10. Estima mean longest sprout

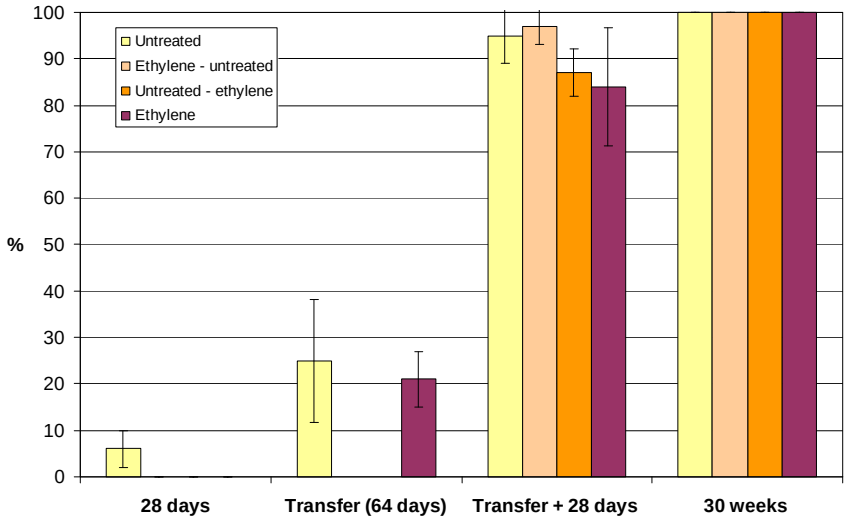

Figure 11. Estima incidence of sprouting

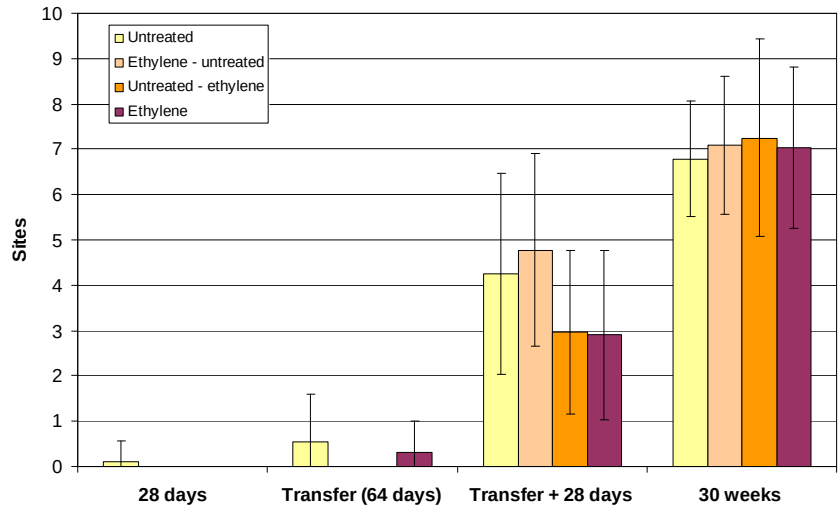

Figure 12. Estima mean sprouting sites

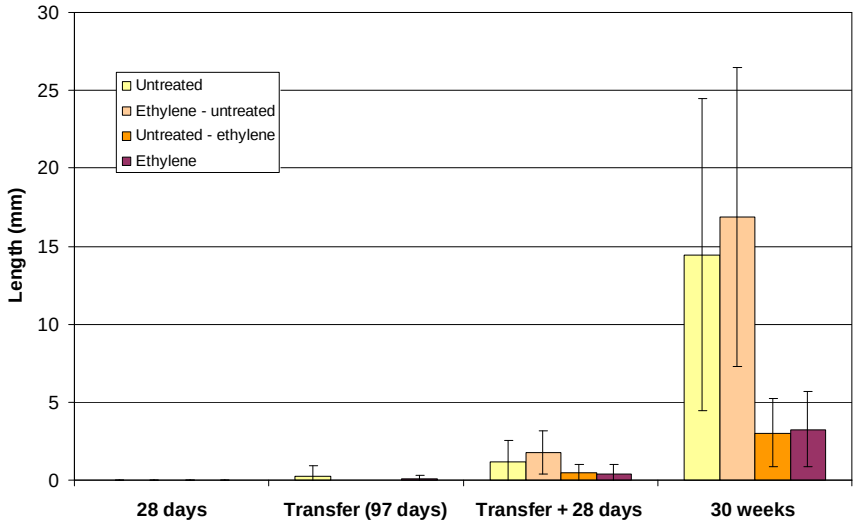

Figure 13. Fianna mean longest sprout

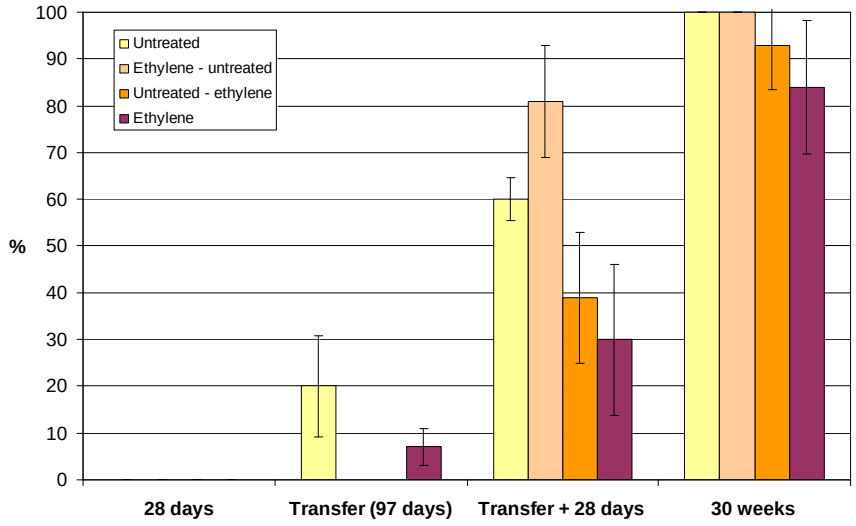

Figure 14. Fianna incidence of sprouting

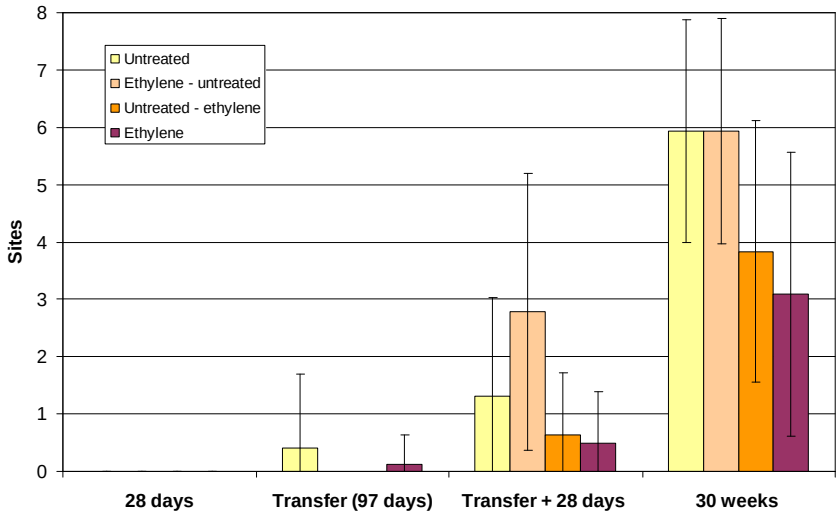

Figure 15. Fianna mean sprouting sites

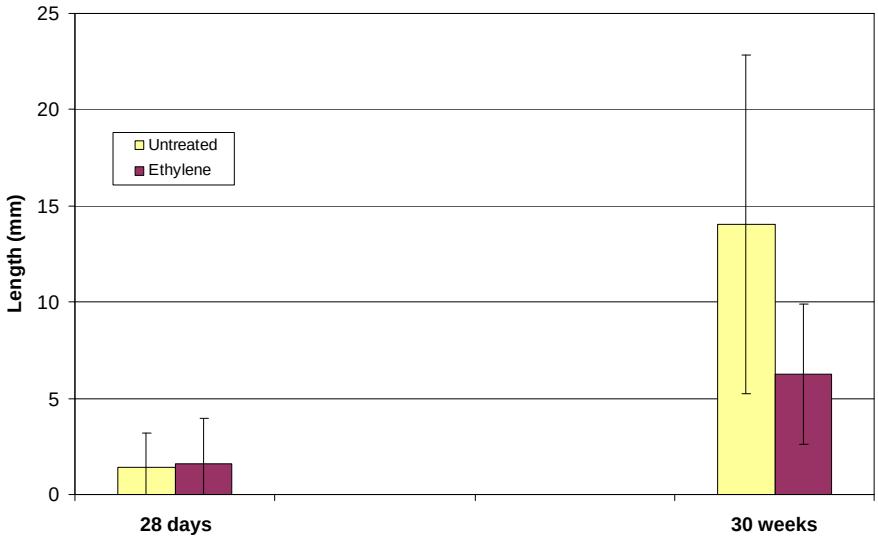

Figure 16. King Edward mean longest sprout

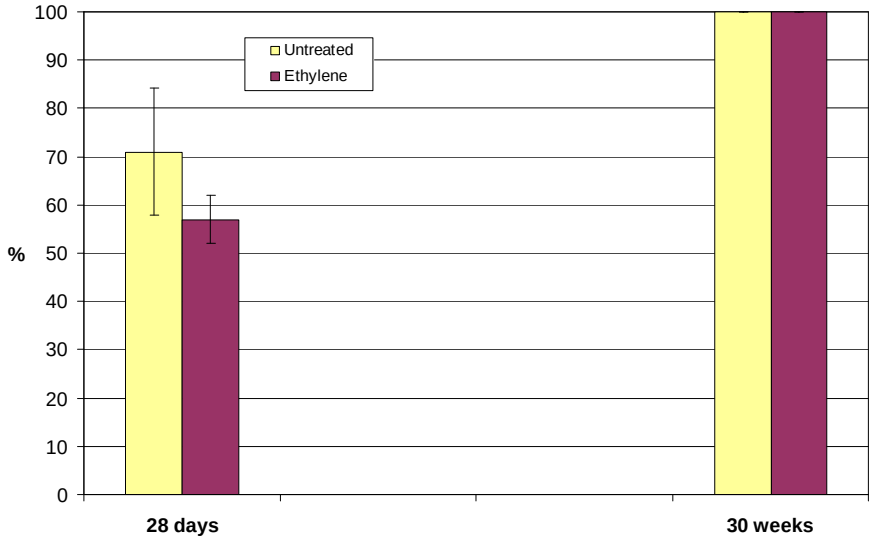

Figure 17. King Edward incidence of sprouting

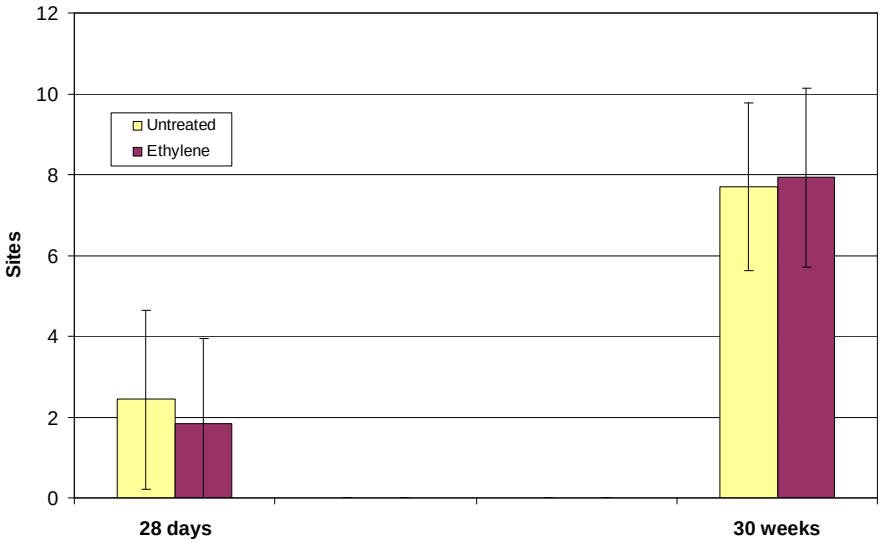

Figure 18. King Edward mean sprouting sites

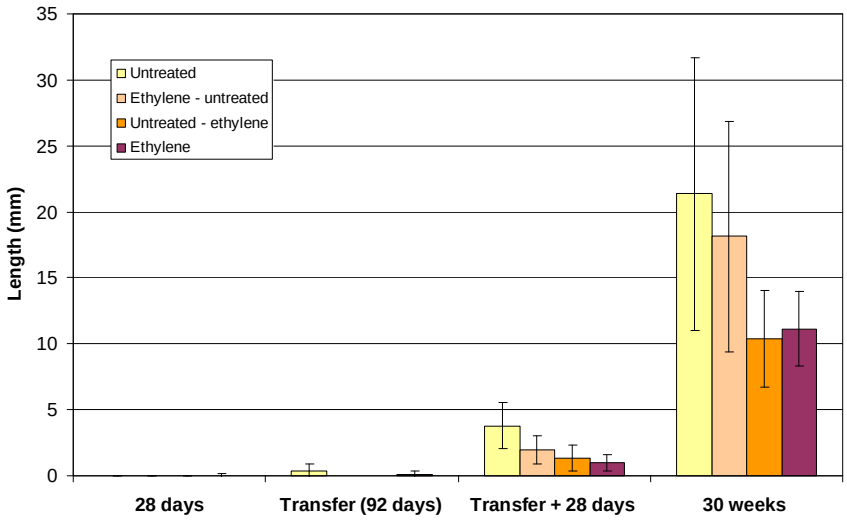

Figure 19. Marfona mean longest sprout

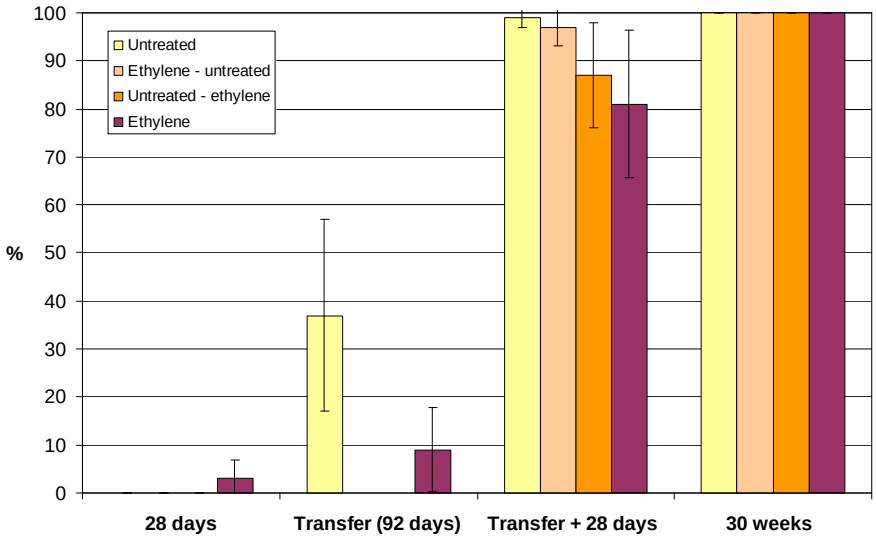

Figure 20. Marfona incidence of sprouting

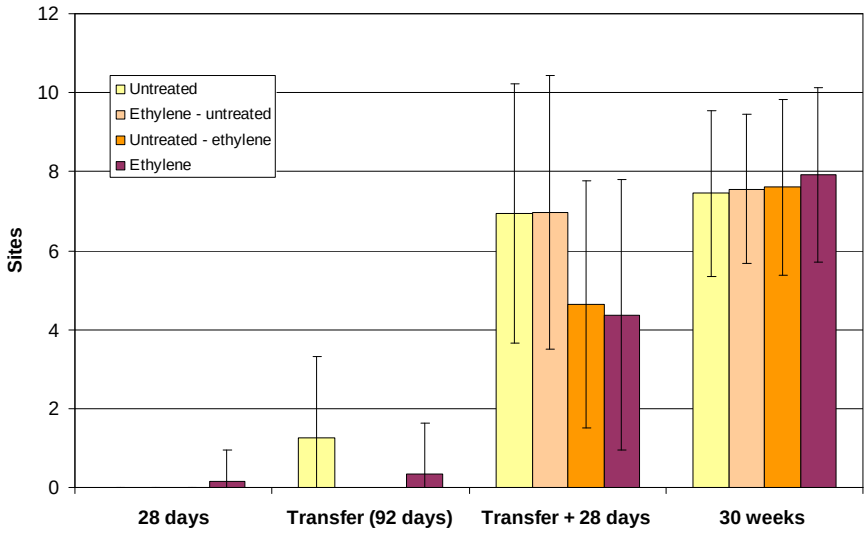

Figure 21. Marfona mean sprouting sites

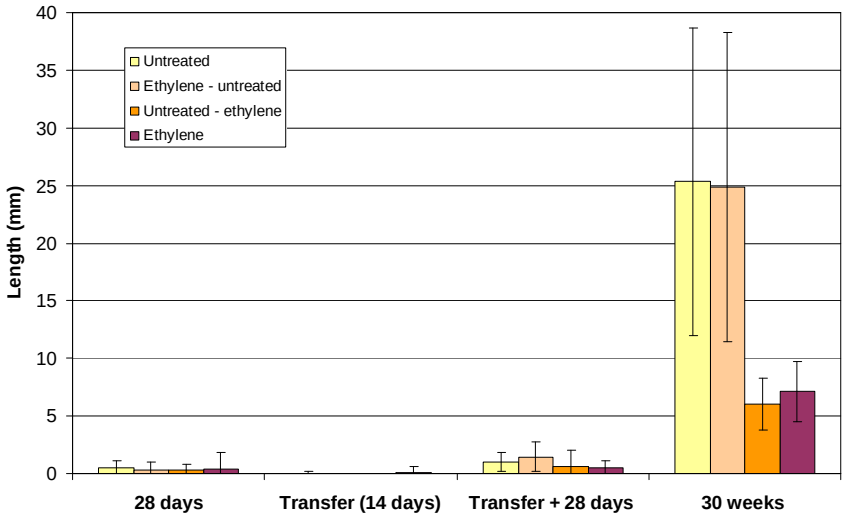

Figure 22. Maris Piper mean longest sprout

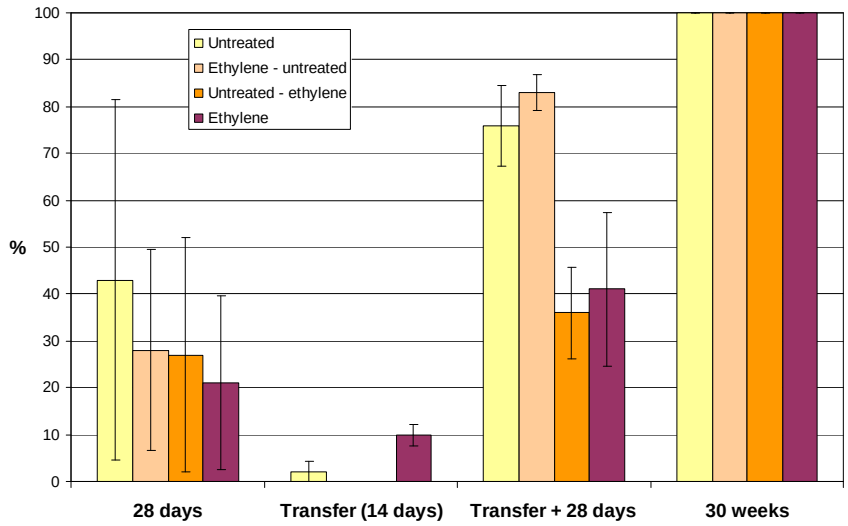

Figure 23. Maris Piper incidence of sprouting

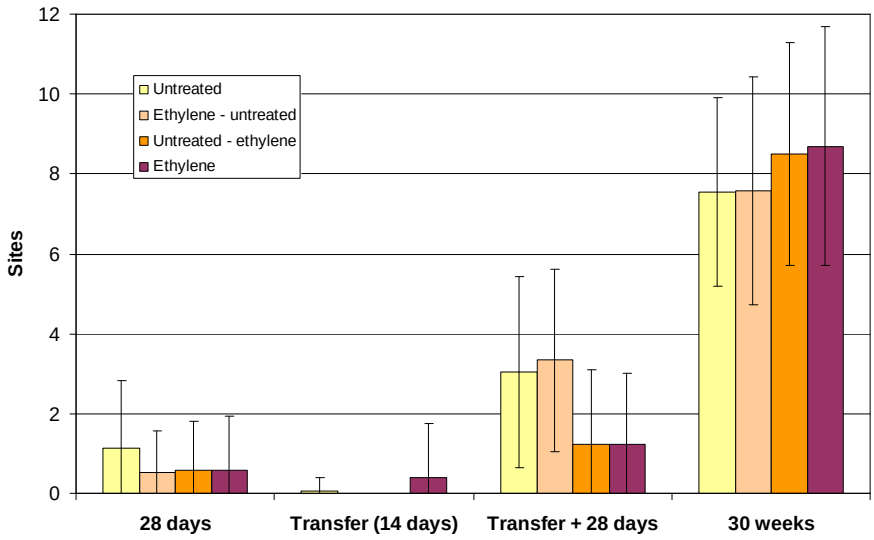

Figure 24. Maris Piper mean sprouting sites

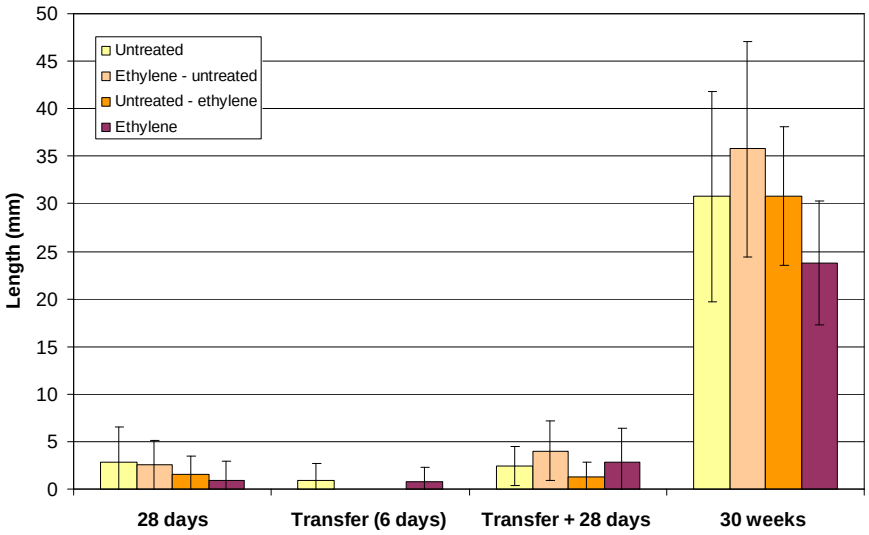

Figure 25. Mayan Gold mean longest sprout

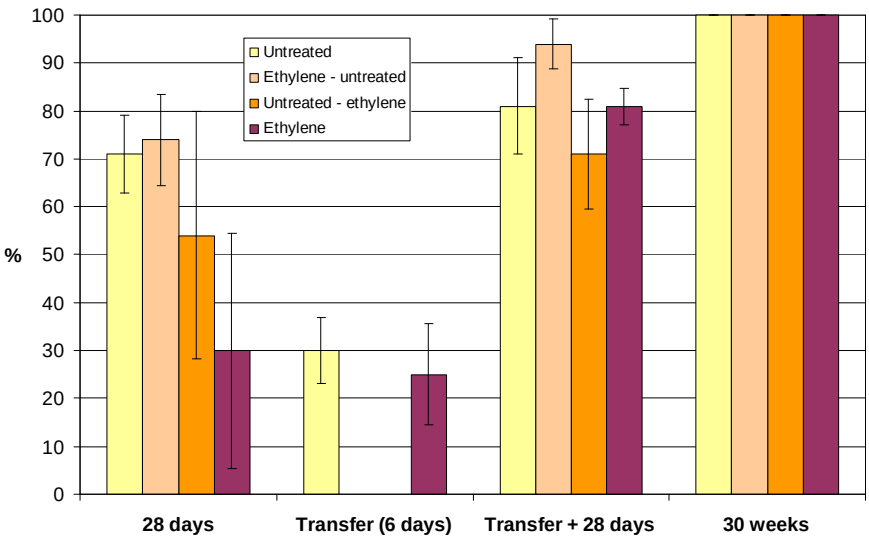

Figure 26. Mayan Gold incidence of sprouting

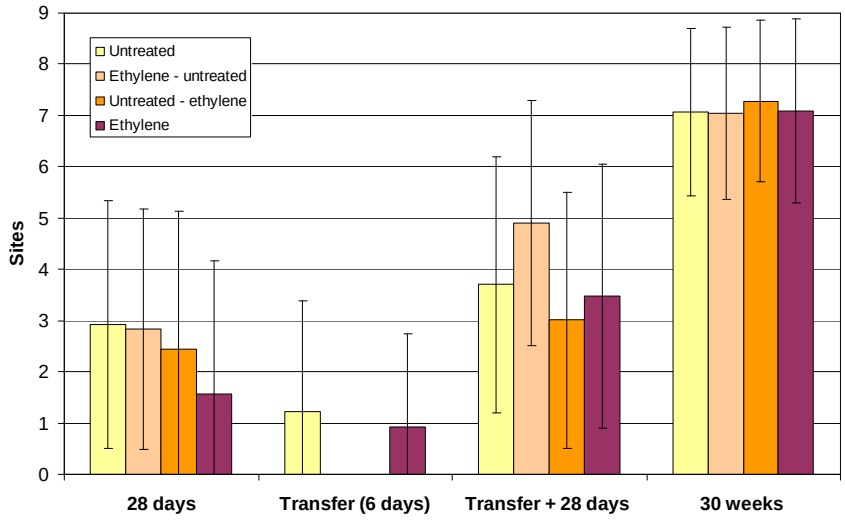

Figure 27. Mayan Gold mean sprouting sites

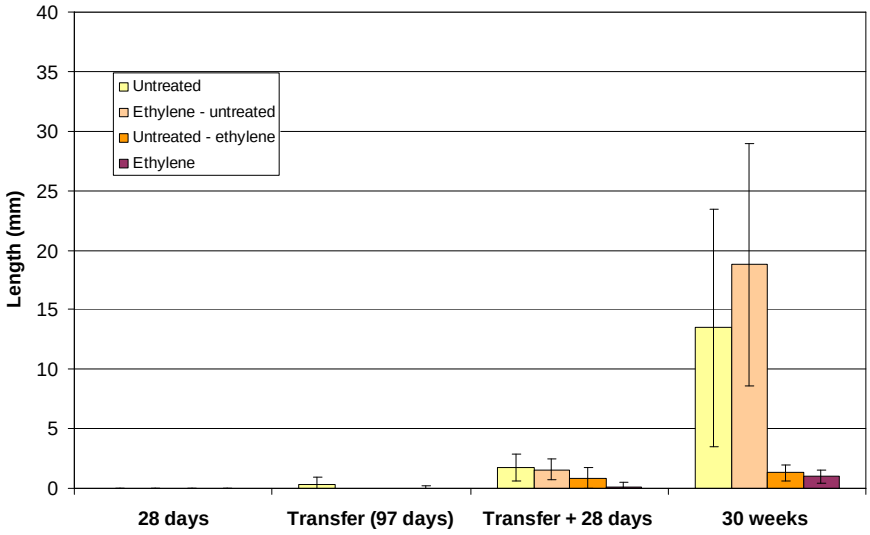

Figure 28. Russet Burbank mean longest sprout

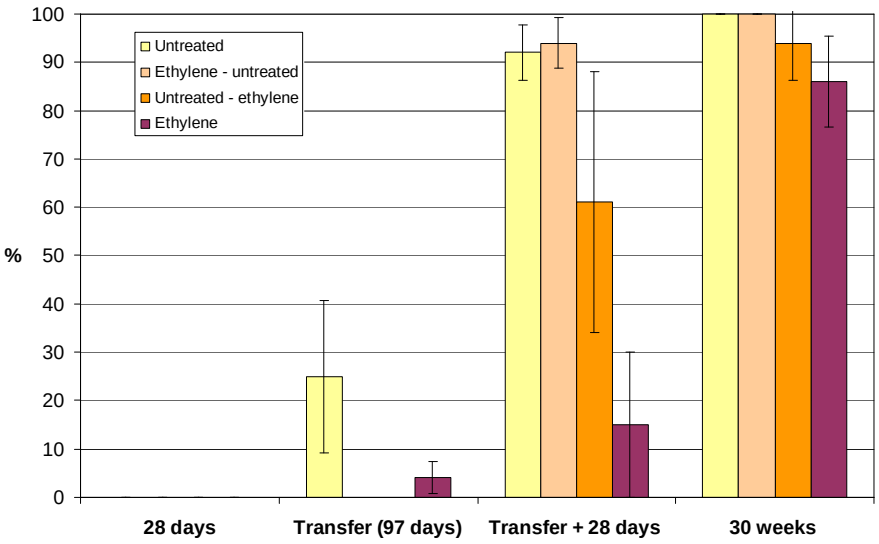

Figure 29. Russet Burbank incidence of sprouting

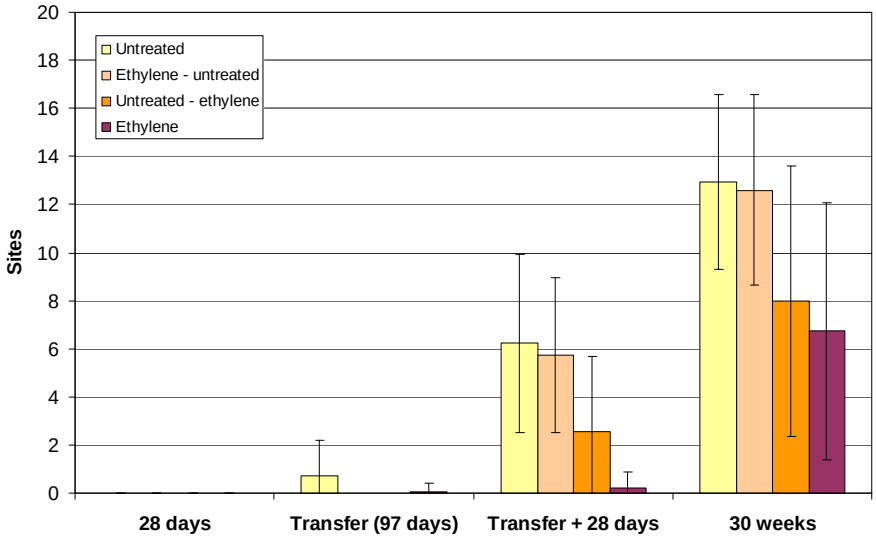

Figure 30. Russet Burbank mean sprouting sites

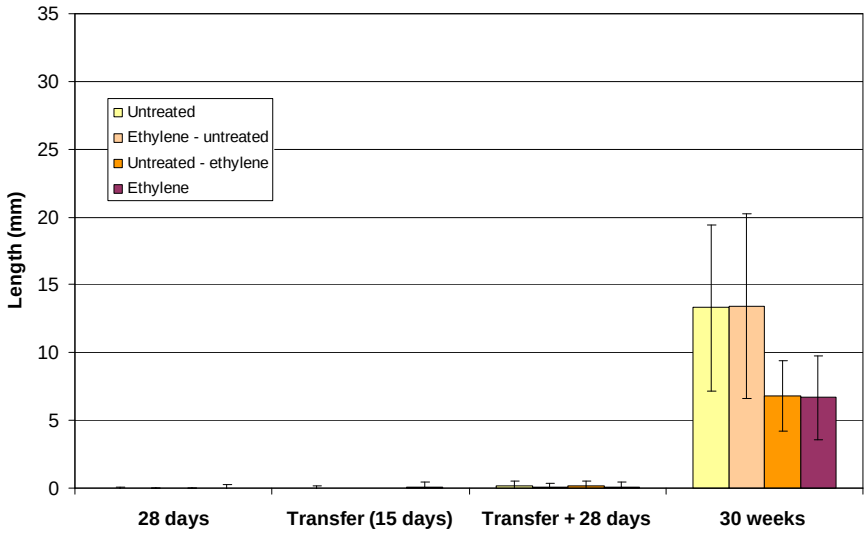

Figure 31. Saturna mean longest sprout

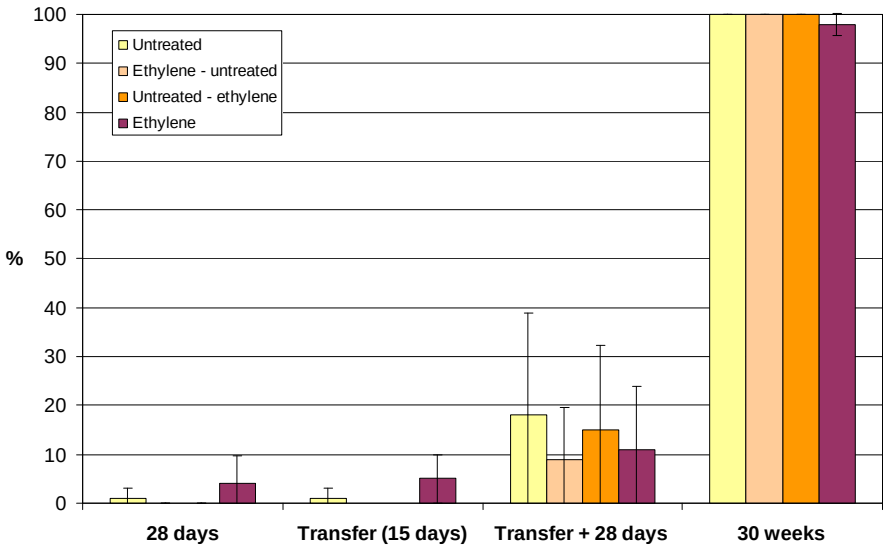

Figure 32. Saturna incidence of sprouting

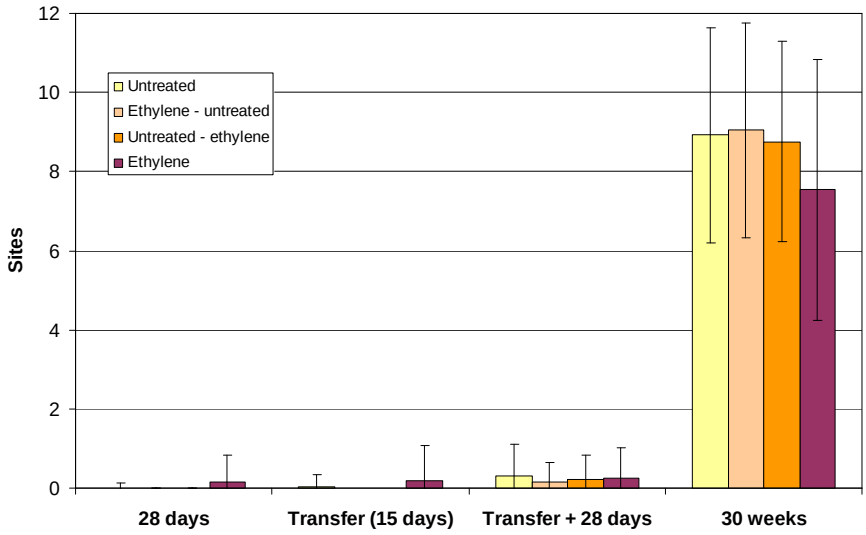

Figure 33. Saturna mean sprouting sites

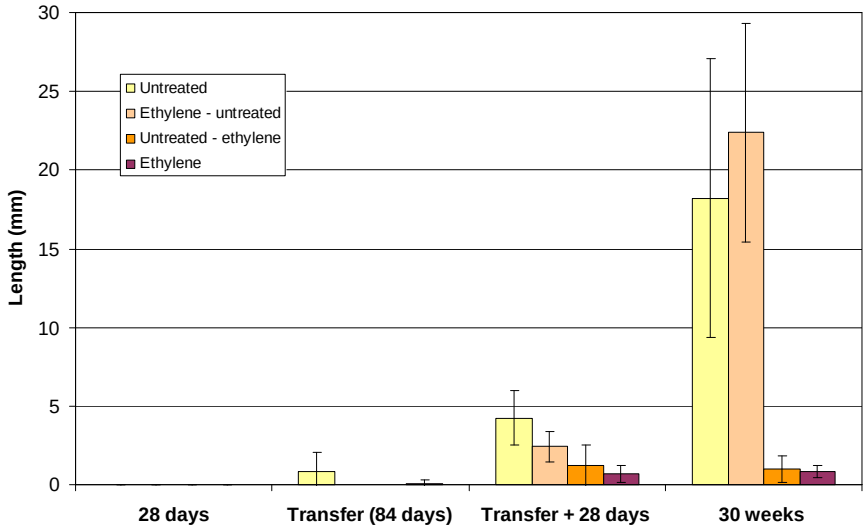

Figure 34. Sylvana mean longest sprout

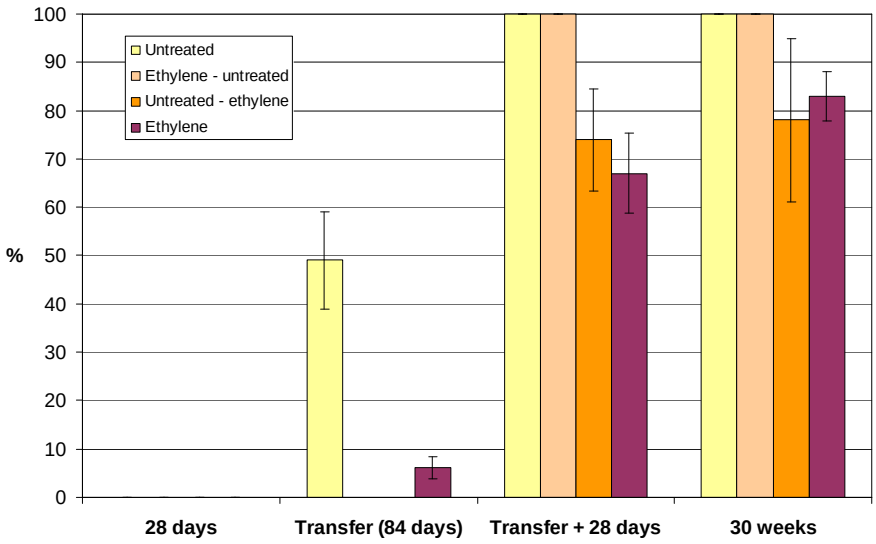

Figure 35. Sylvana incidence of sprouting

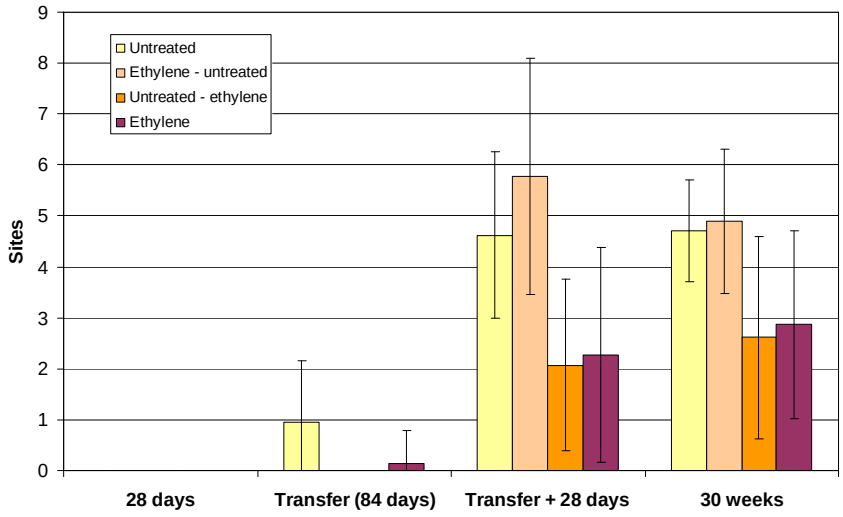

Figure 36. Sylvana mean sprouting sites

Vigour 2008/09

Figure 37 shows mean longest sprout growth over 28 days for all cultivars and treatments. During this period Desiree, Estima and Saturna had low vigour whereas most other cultivars showed greater vigour in the treatments without ethylene. *Untreated* Marfona and Sylvana appeared to have relatively high vigour at 3mm growth. *Ethylene→untreated* Fianna and Mayan Gold had more vigour than *Untreated*.

Figure 38 gives mean longest sprout growth in the period between 'transfer' and '30 weeks' per month (28 day month for comparison). Samples treated without ethylene were more vigorous than samples treated with ethylene, except for Mayan Gold in which all treatments were vigorous. On the whole there was little difference between the no ethylene treatments except for Desiree in which *Untreated* was more vigorous and for Russet Burbank and Sylvana which were more vigorous in *Ethylene→untreated* than in *Untreated*.

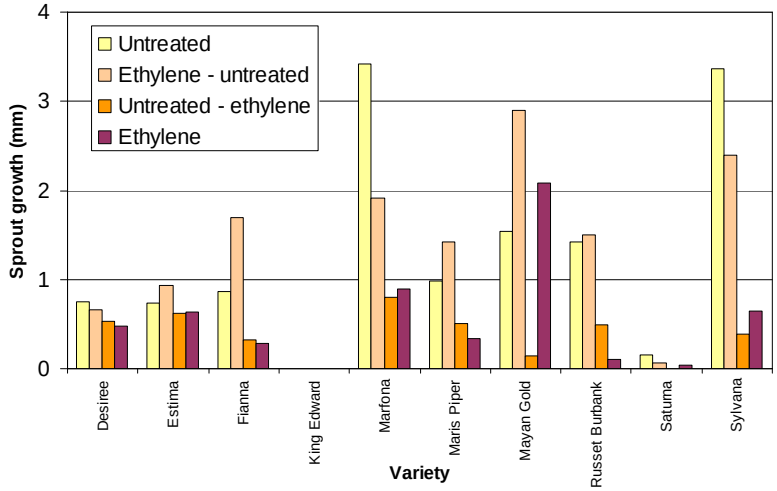

Figure 37. Sprout length difference from transfer to 28 days later

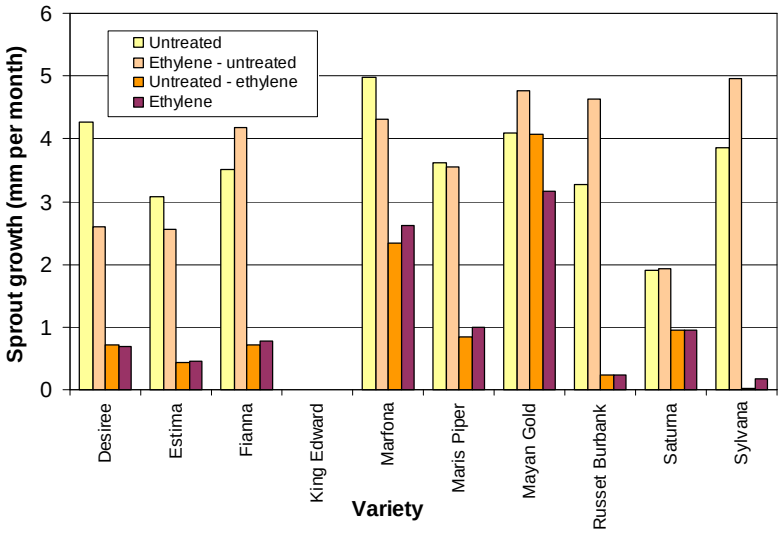

Figure 38. Sprout length difference from transfer to completion

8.2.1 Year 2 Data 2009/10

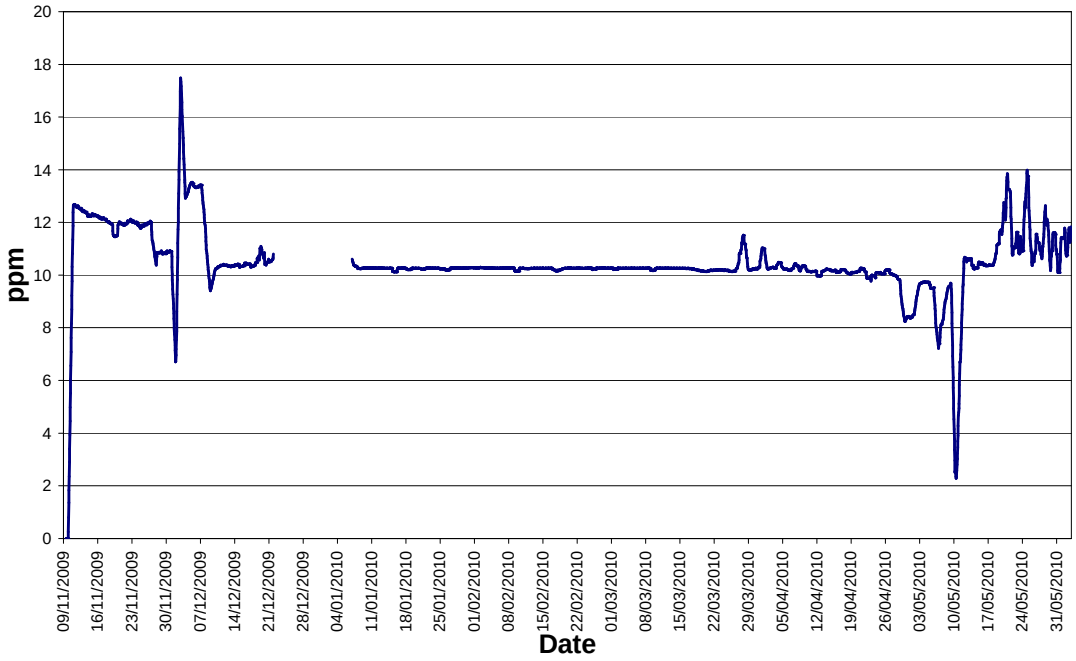

Figure 39. Rolling 24 hour average of hourly ethylene reading

Table 11. Time periods for when automatically recorded data was unavailable

Ethylene logger data missing		Time data not recorded	Reason
from	to		
21st December 2009	7th January 2010	17 days	Logger failure
25th February 2009	25th February 2009	4 hours	Power cut

Table 12. Independent measurement of Ethylene concentrations in treatment stores

Sampling date	Untreated store, Ethylene (ppm)	Ethylene treated store, Ethylene (ppm)
23rd November 2009	0	19.854
15th December 2009	0	10.821
25th January 2010	0	8.935
17th May 2008	0.647	9.437

All measurements provided by Cranfield University using gas chromatography

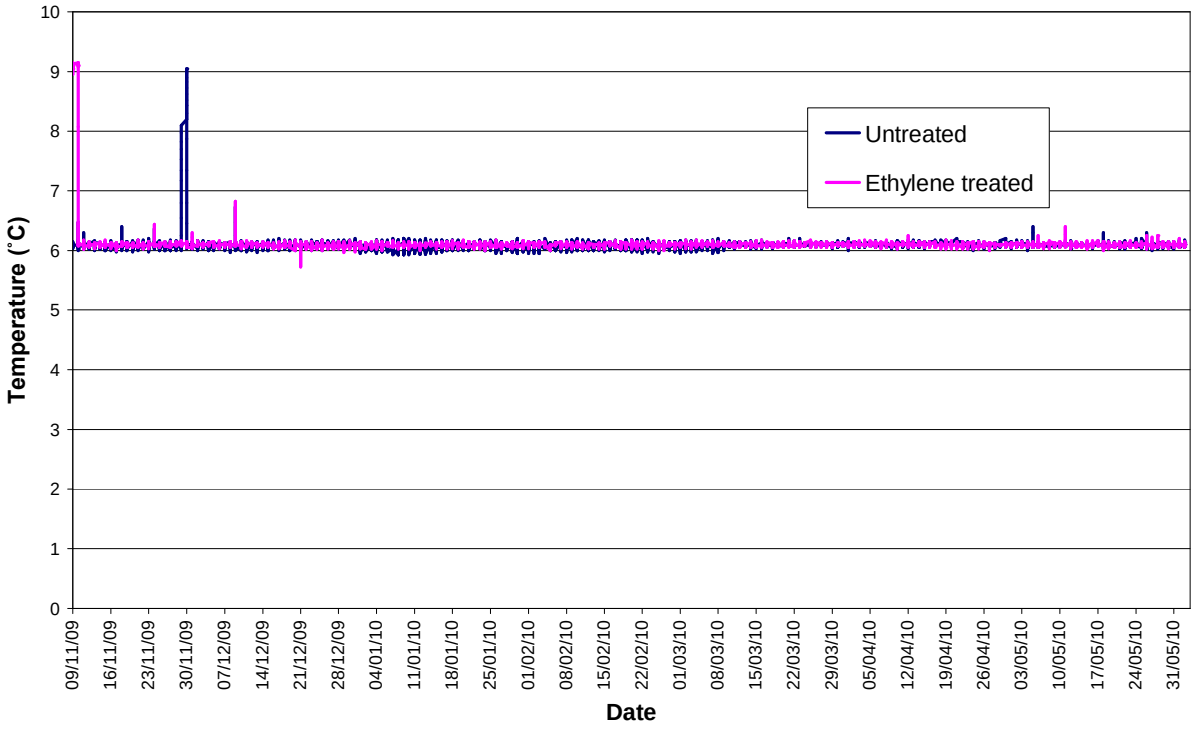

Figure 40. Store temperature for the trial period

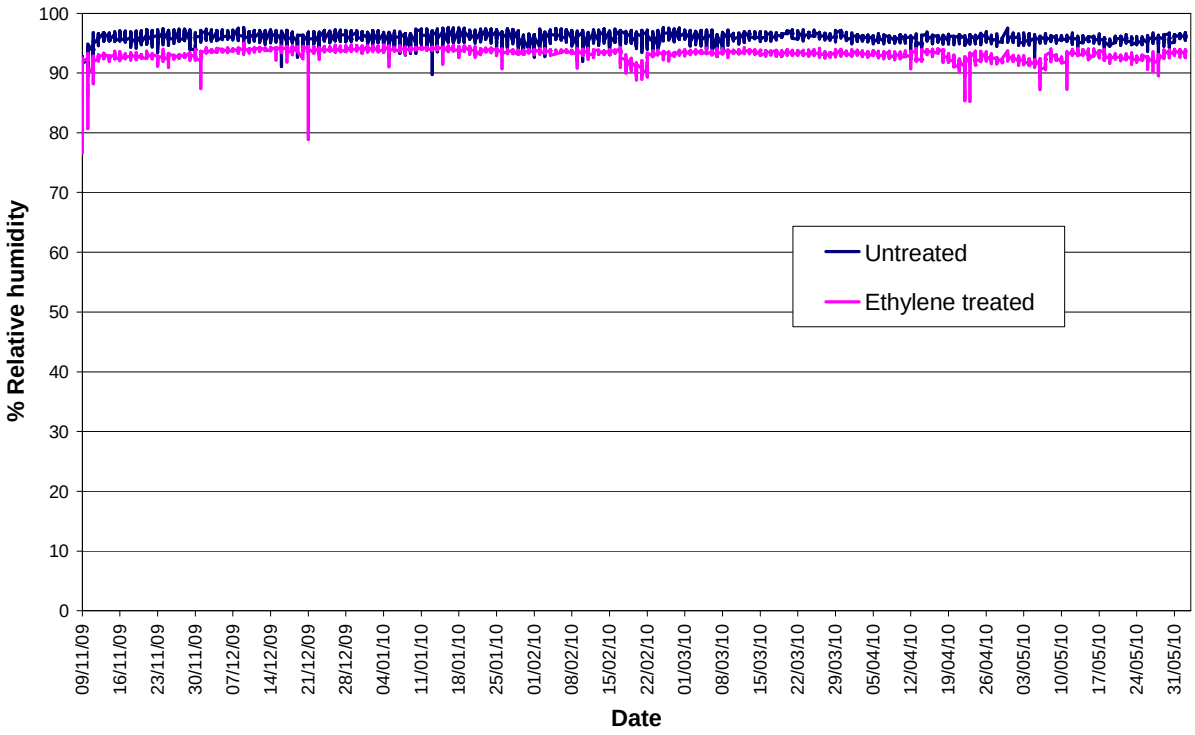

Figure 41. Store humidity for the trial period

Table 13. Sampling dates and occasions for start of sprouting assessments

Variety	Transfer	28 weeks
Estima	17/12/2009	27/05/2010
Marfona	29/11/2009	27/05/2010
Russet Burbank	25/01/2010	27/05/2010
Saturna	29/11/2009	27/05/2010

Treatments began on 11th November 2009

Sprouting 2009/10

Error bars show +/- 1 SD

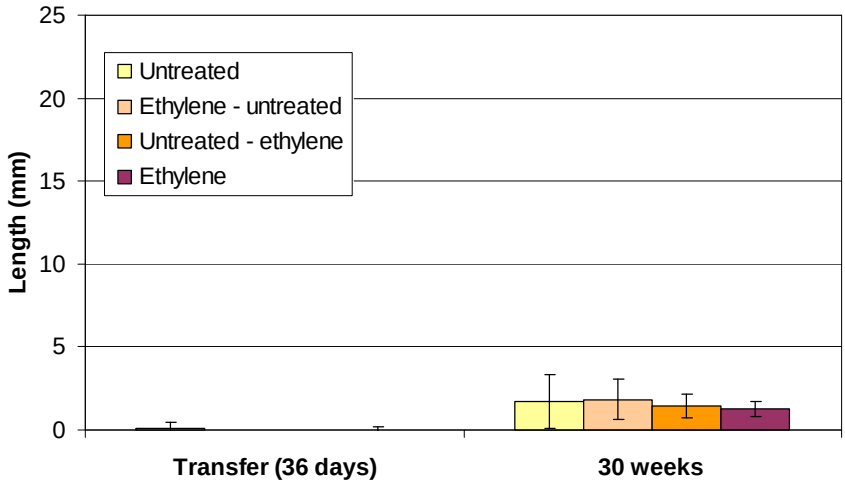

Figure 42. Estima mean longest sprout

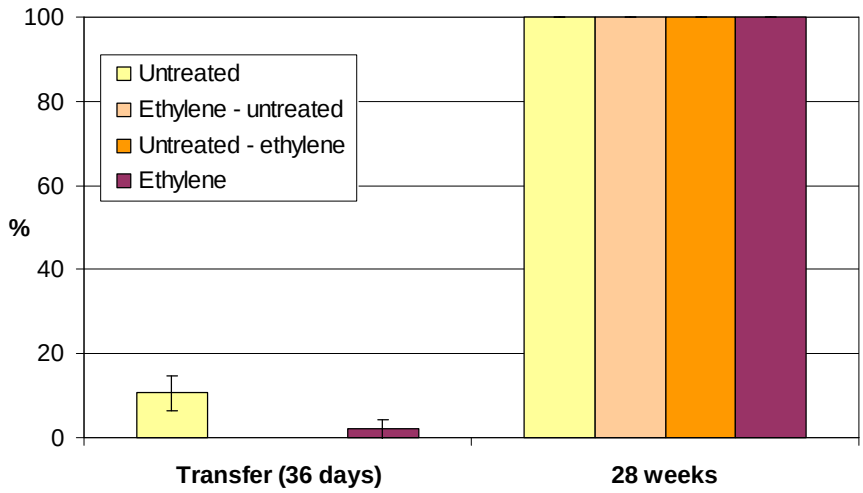

Figure 43. Estima incidence of sprouting

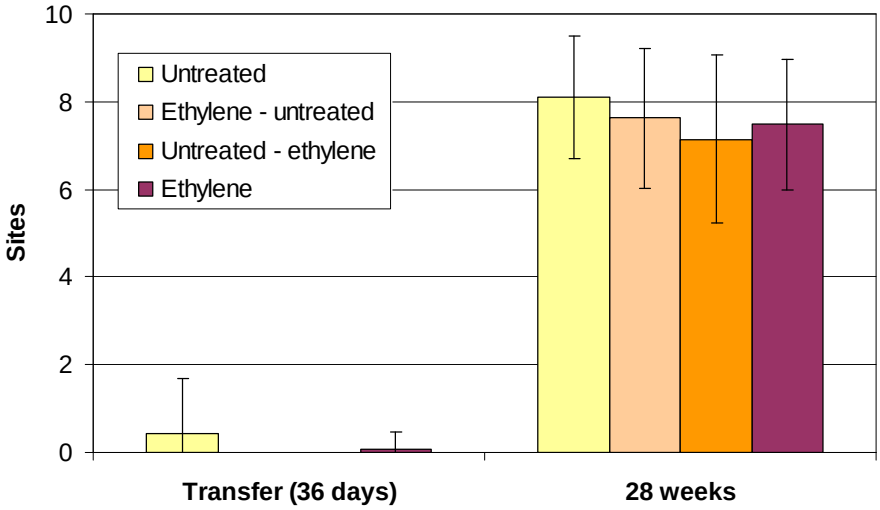

Figure 44. Estima mean sprouting sites

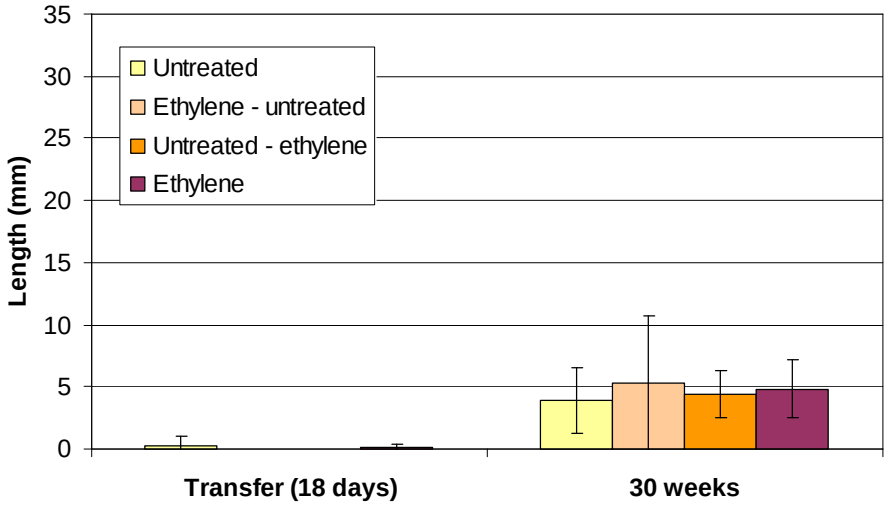

Figure 45. Marfona mean longest sprout

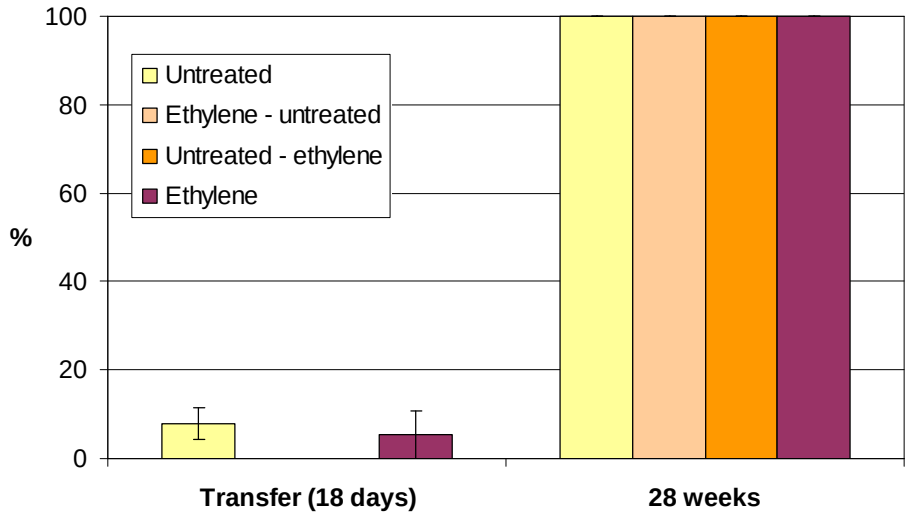

Figure 46. Marfona incidence of sprouting

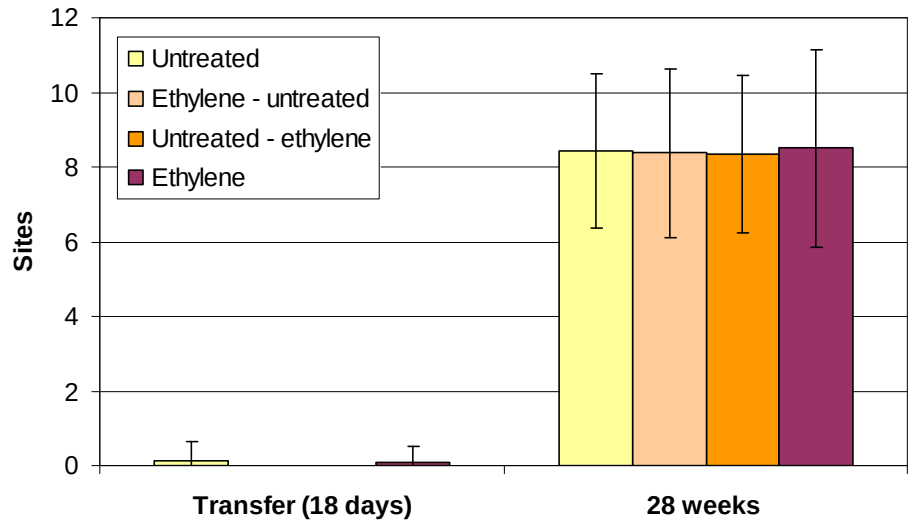

Figure 47. Marfona mean sprouting sites

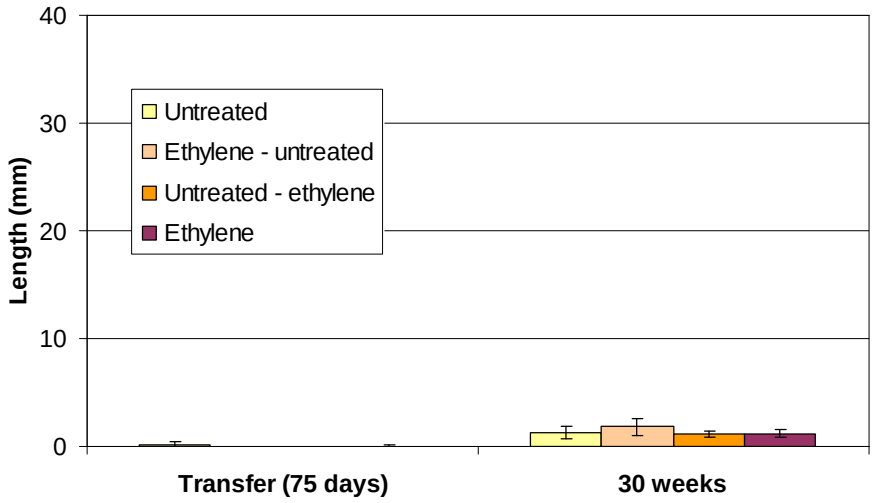

Figure 48. Russet Burbank mean longest sprout

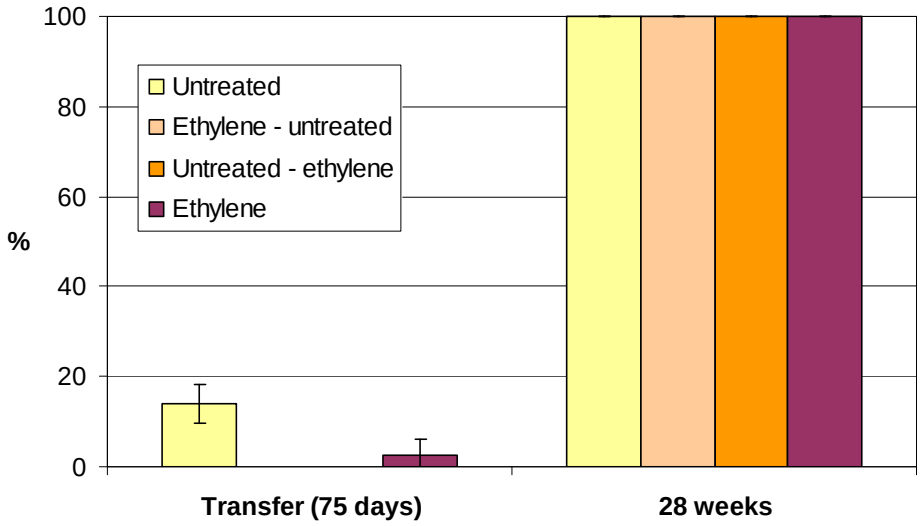

Figure 49. Russet Burbank incidence of sprouting

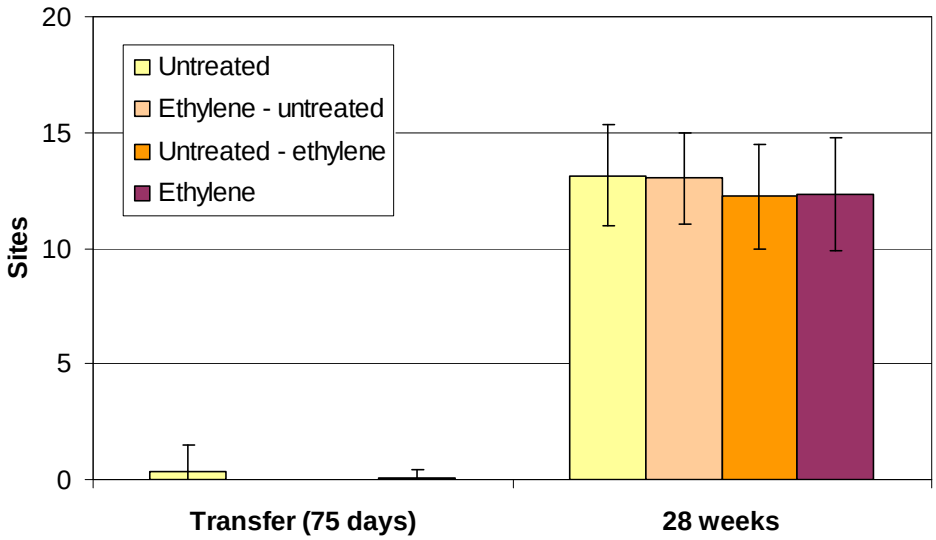

Figure 50. Russet Burbank mean sprouting sites

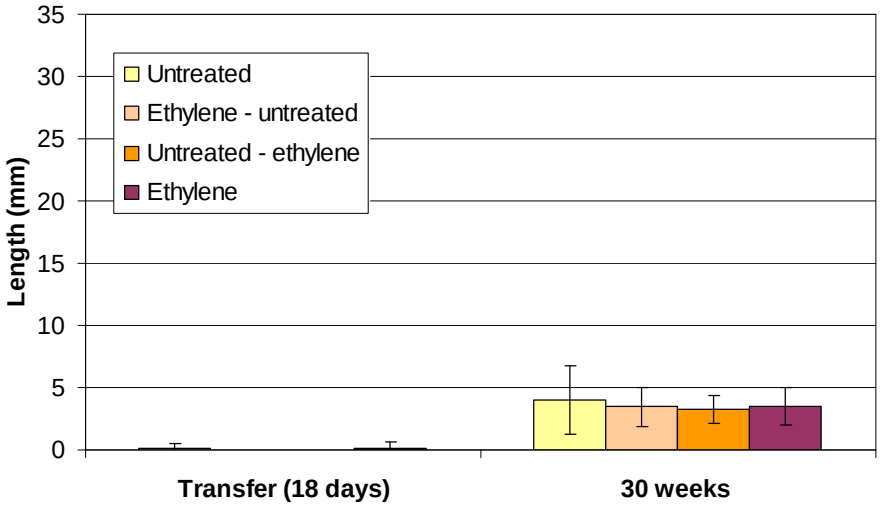

Figure 51. Saturna mean longest sprout

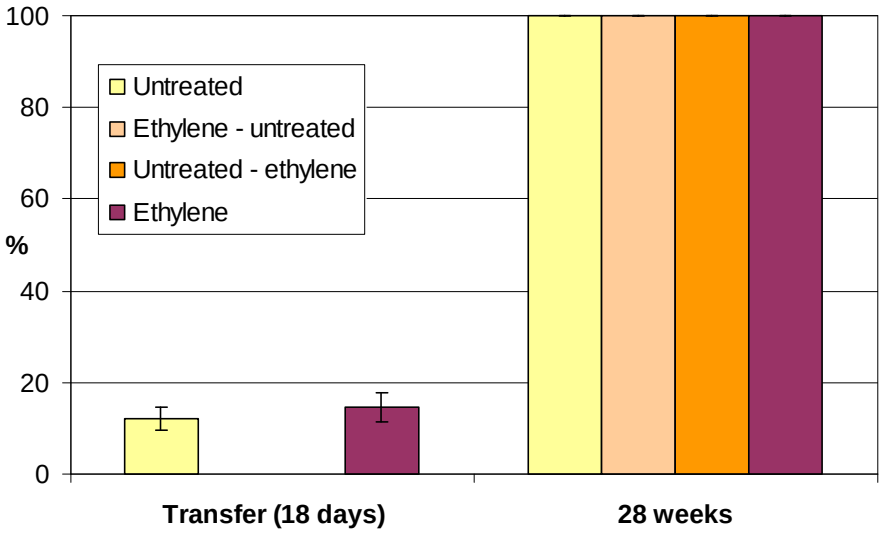

Figure 52. Saturna incidence of sprouting

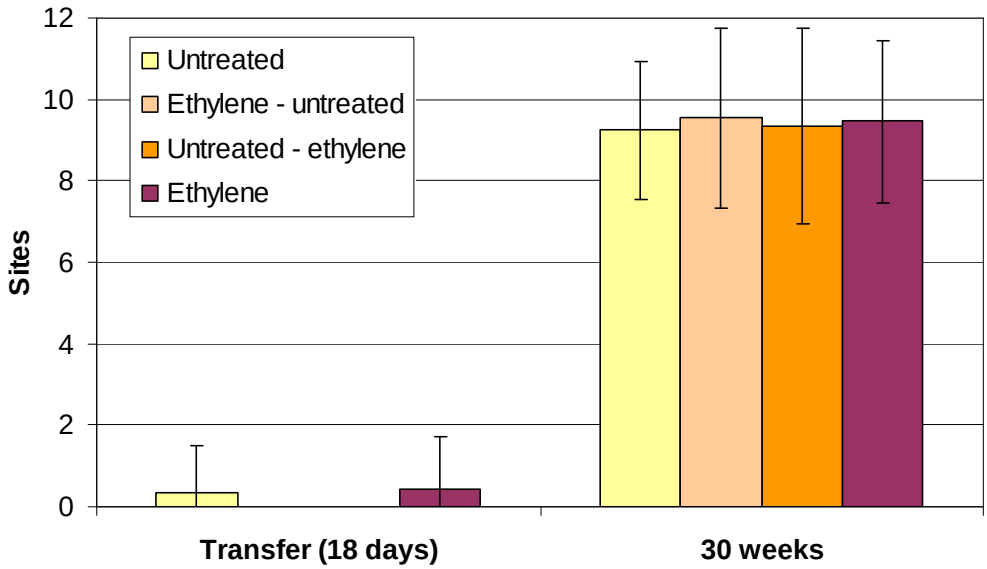

Figure 53. Saturna mean sprouting sites

8.3.1 Year 3 Data 2010/11

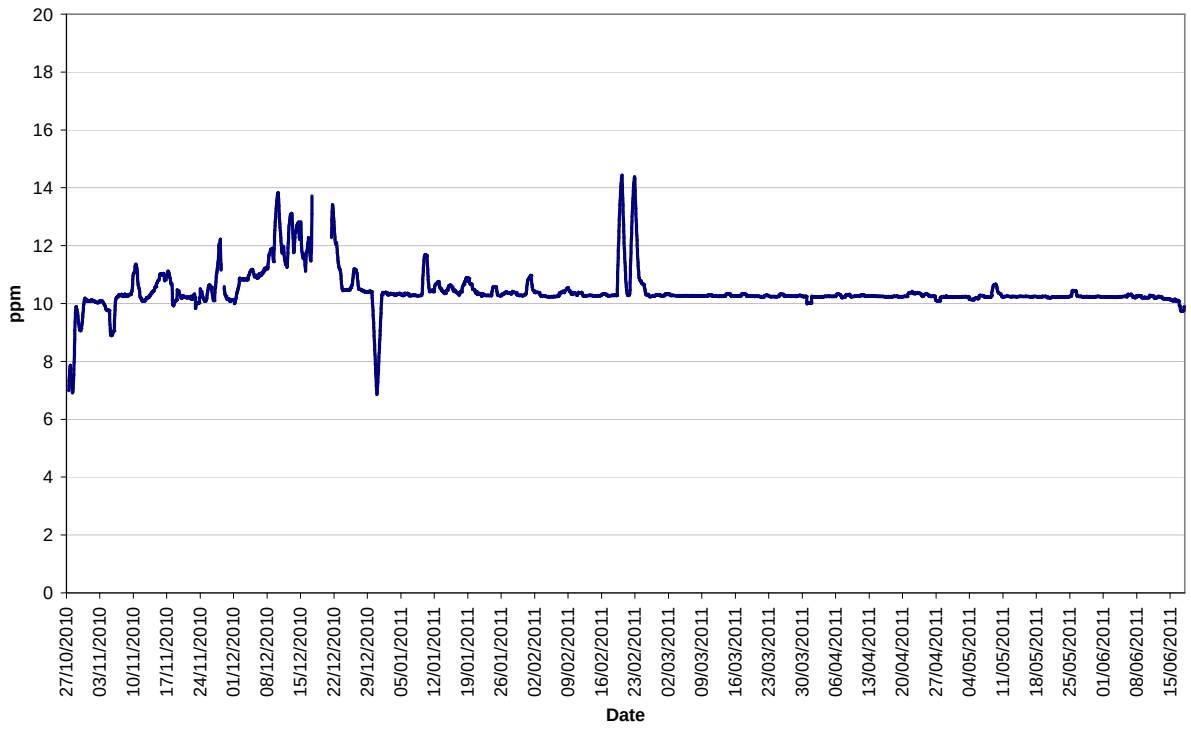

Figure 54. Rolling 24 hour average of hourly ethylene reading

Table 14. Time periods for when accurate automatically recorded data was unavailable

Ethylene logger data missing		Time data not recorded	Reason
from	to		
28th November 2010	29th November 2010	1 day	Frozen vent filter
17th November 2010	21st November 2010	4 days	Sensor replacement

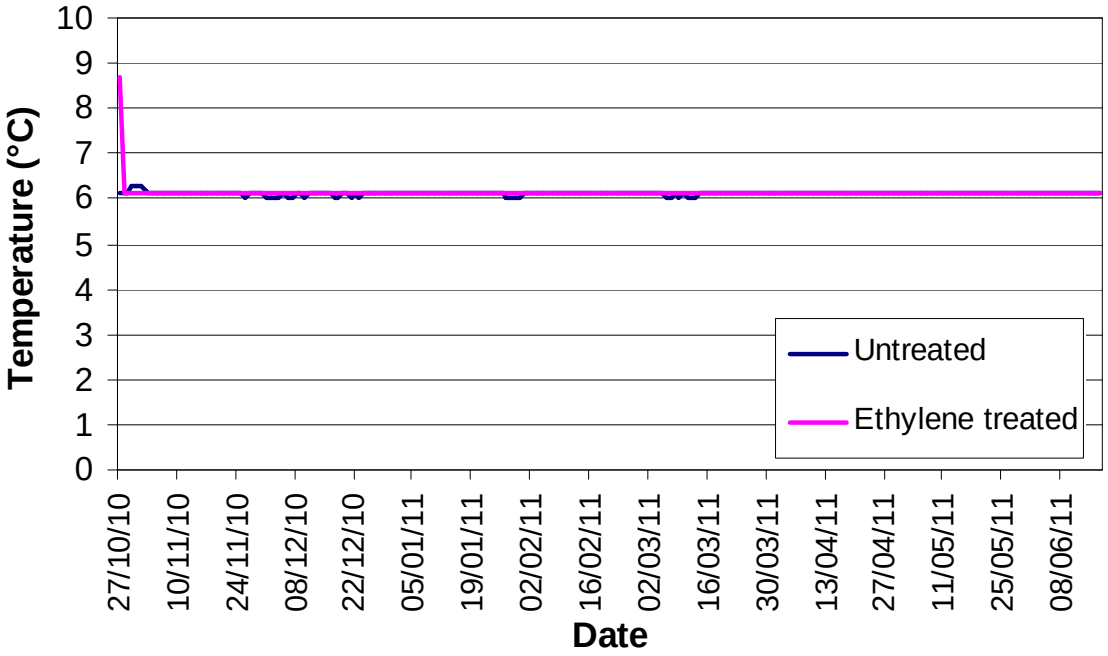

Figure 55. Store temperature for the trial period

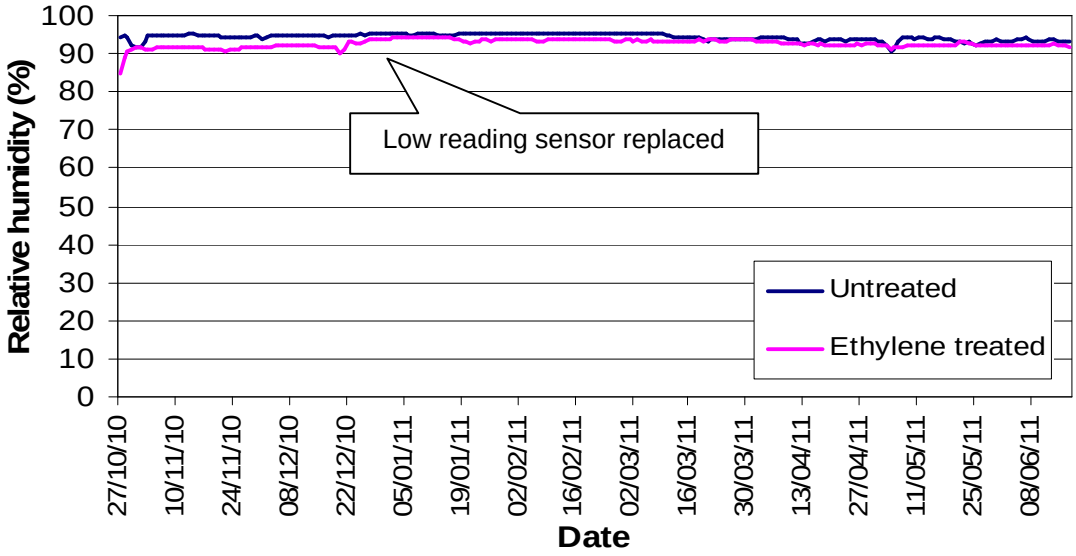

Figure 56. Store humidity for the trial period

Table 15. Sampling dates and occasions for start of sprouting assessments

Variety	Transfer	28 weeks
Estima	17/12/2009	27/05/2010
Marfona	29/11/2009	27/05/2010
Russet Burbank	25/01/2010	27/05/2010
Saturna	29/11/2009	27/05/2010

Treatments began on 11th November 2009

Sprouting 2010/11

Error bars show +/- 1 SD

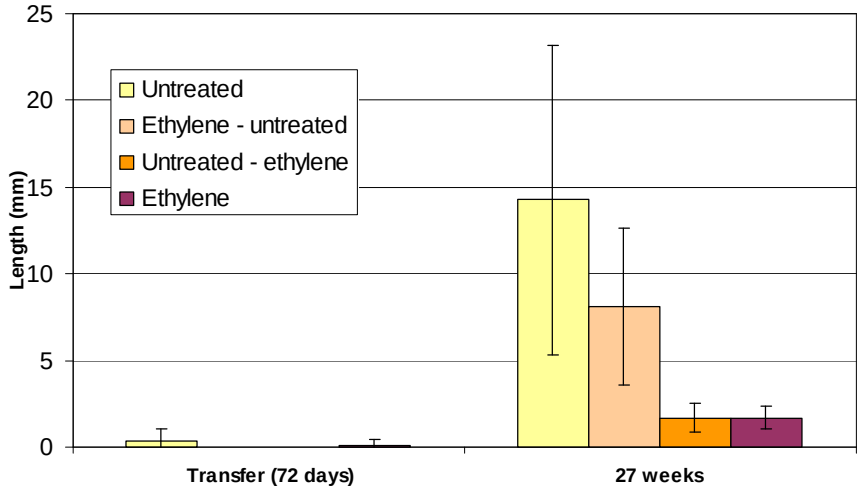

Figure 57. Estima mean longest sprout

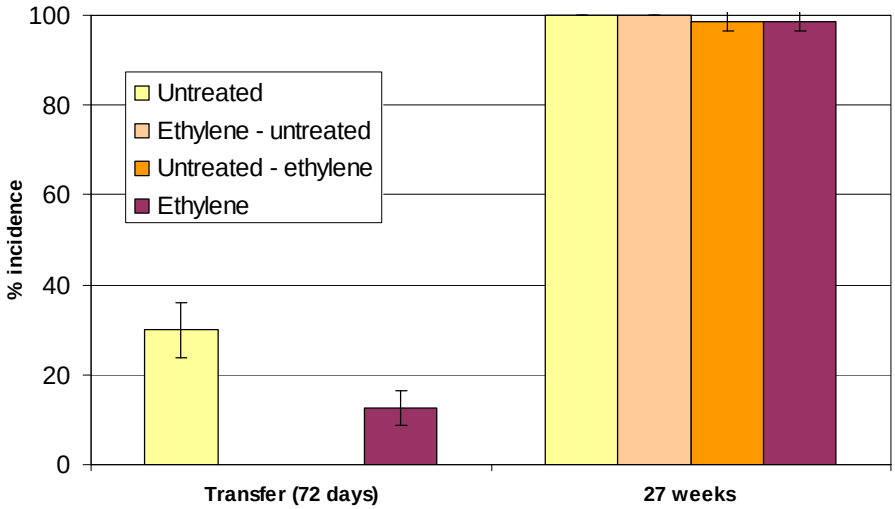

Figure 58. Estima incidence of sprouting

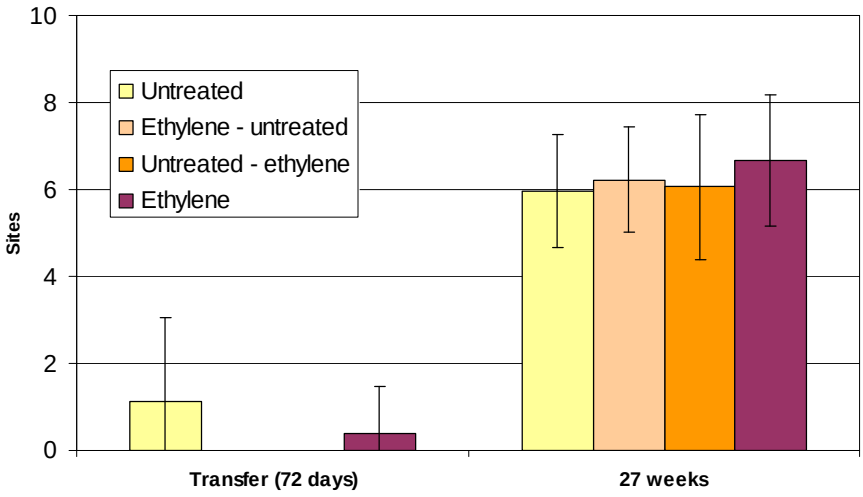

Figure 59. Estima mean sprouting sites

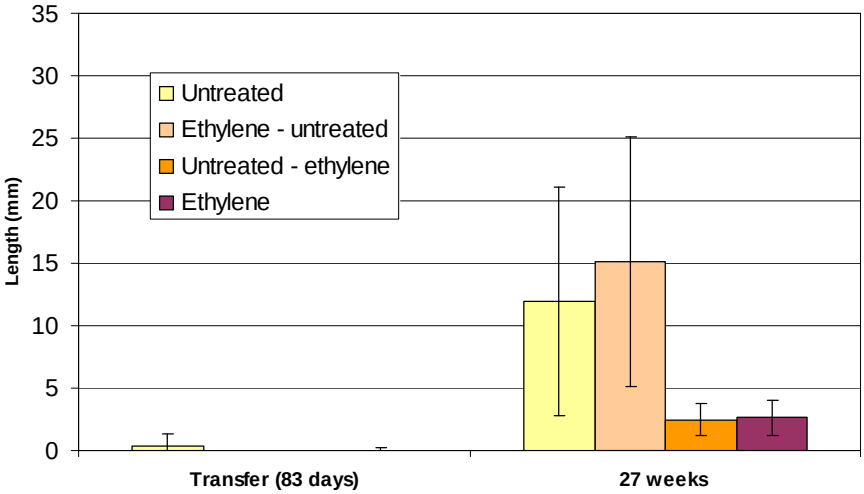

Figure 60. Marfona mean longest sprout

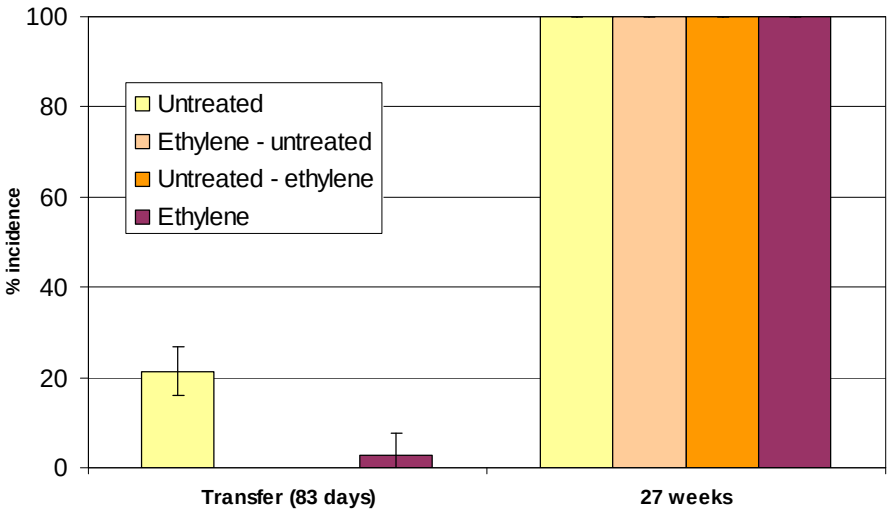

Figure 61. Marfona incidence of sprouting

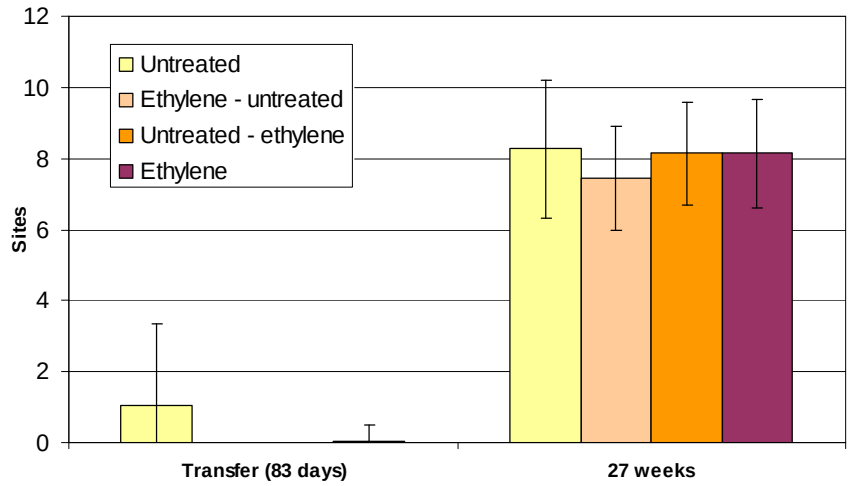

Figure 62. Marfona mean sprouting sites

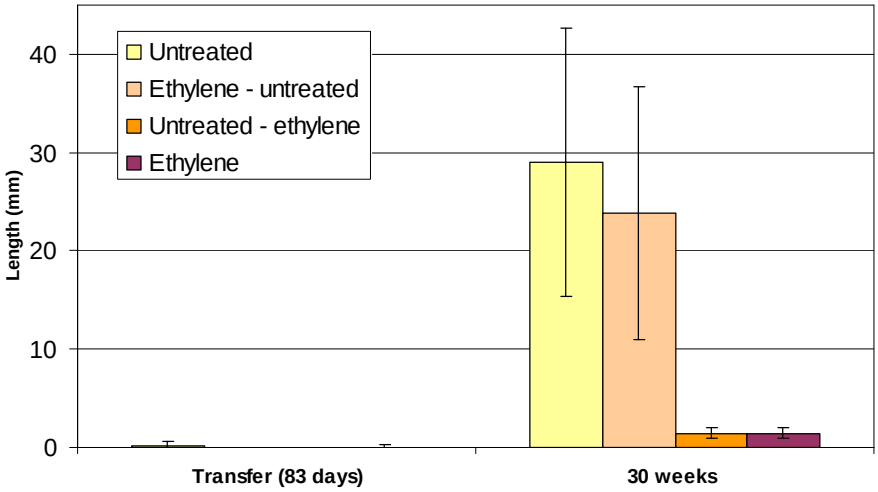

Figure 63. Russet Burbank mean longest sprout

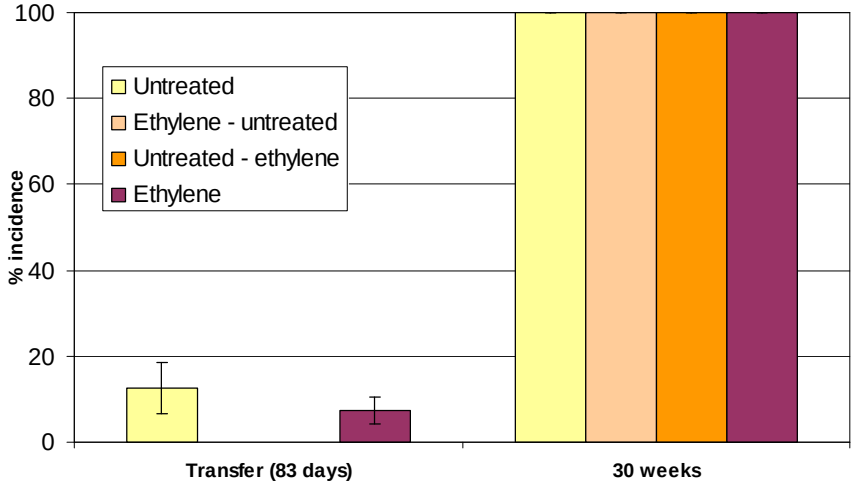

Figure 64. Russet Burbank incidence of sprouting

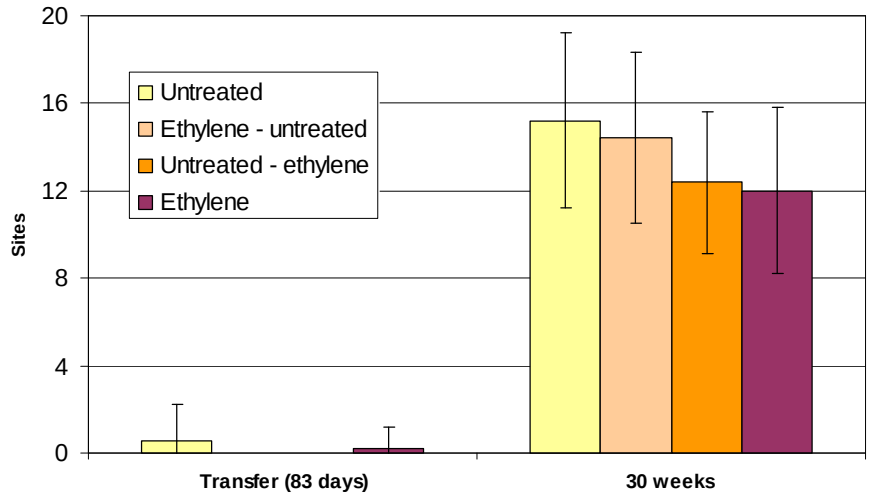

Figure 65. Russet Burbank mean sprouting sites

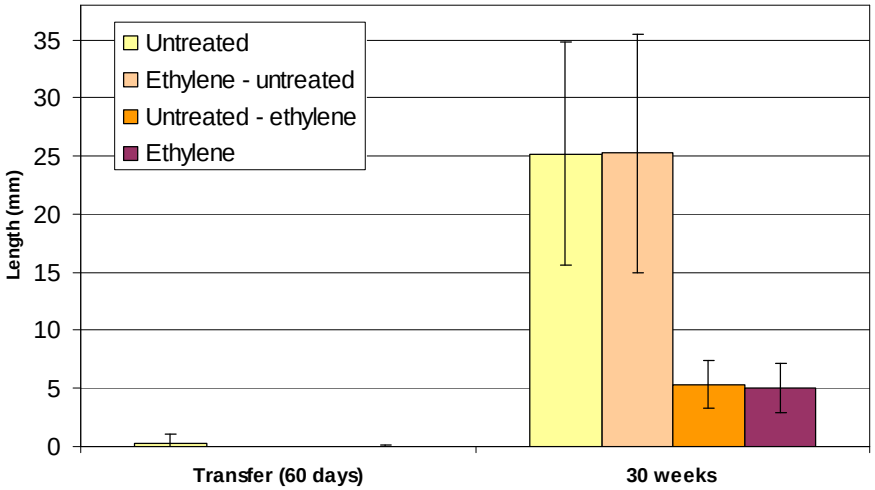

Figure 66. Saturna mean longest sprout

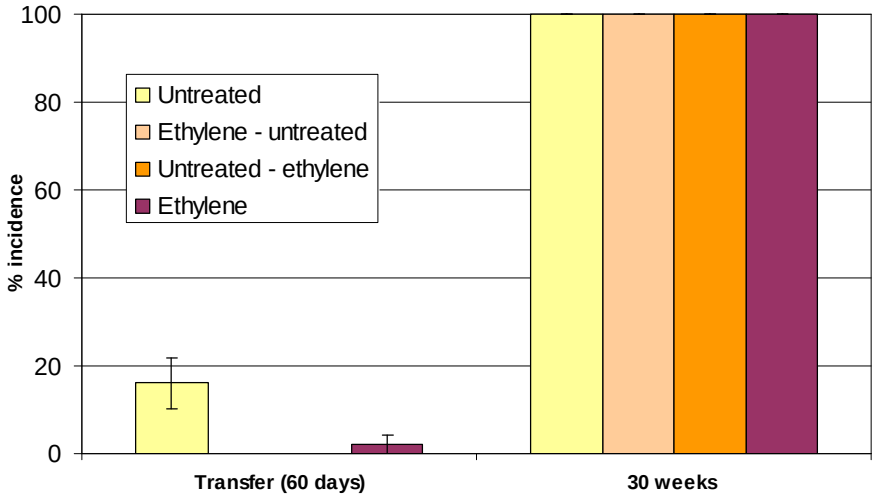

Figure 67. Saturna incidence of sprouting

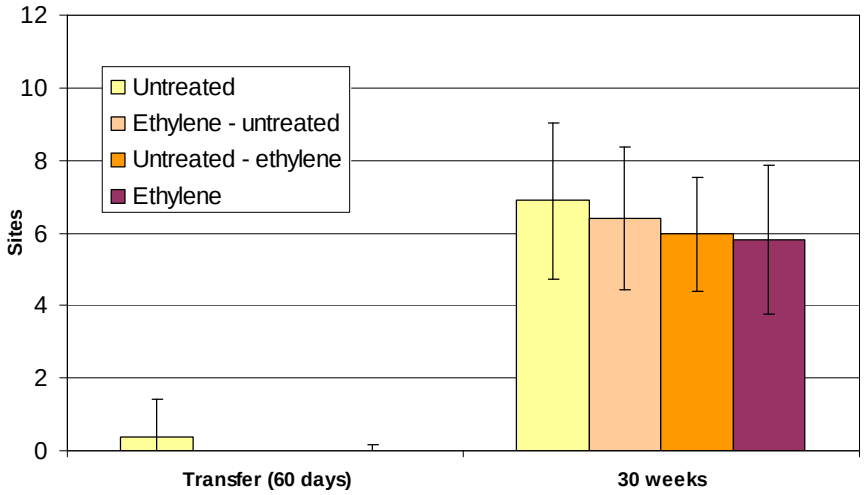

Figure 68. Saturna mean sprouting sites

8.4 Comparison of relative dormancy in three seasons by cultivar

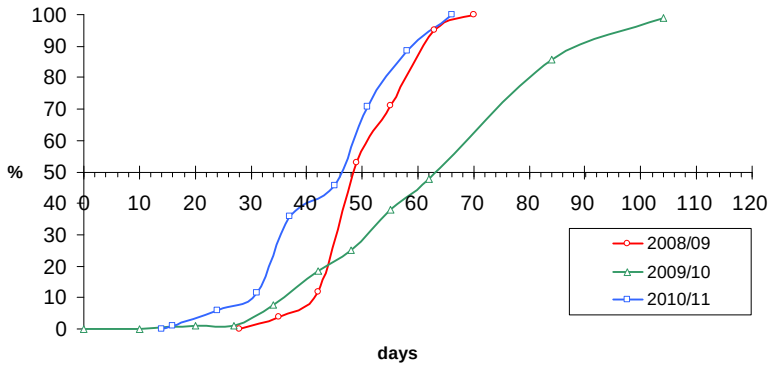

Figure 69. Estima dormancy break at 15 C (for three seasons)

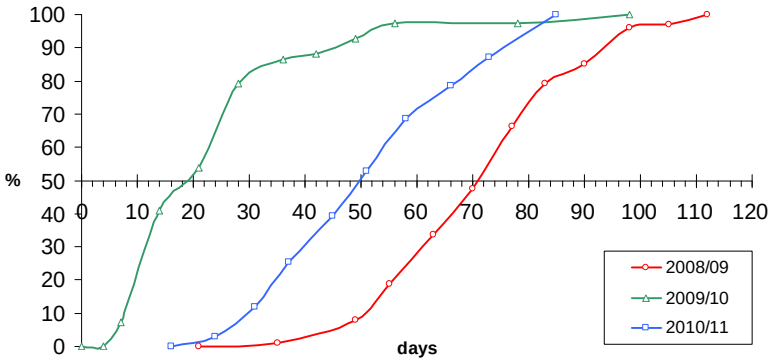

Figure 70. Marfona dormancy break at 15 C (for three seasons)

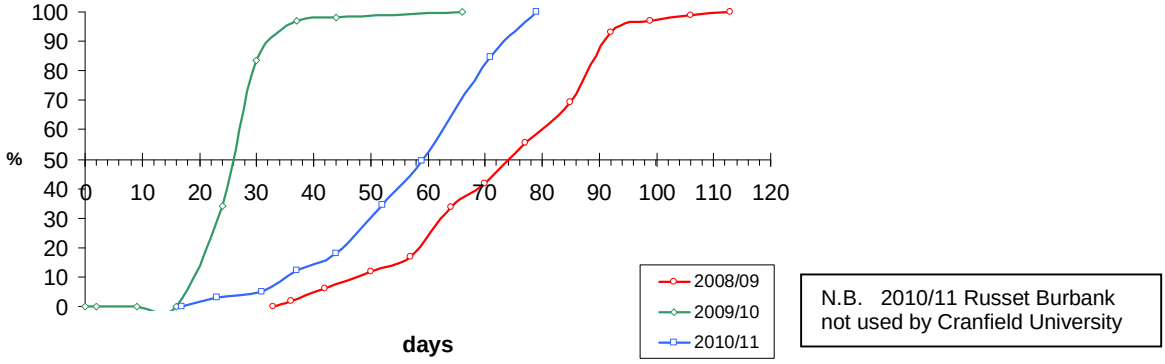

Figure 71. Russet Burbank dormancy break at 15 C (for three seasons)

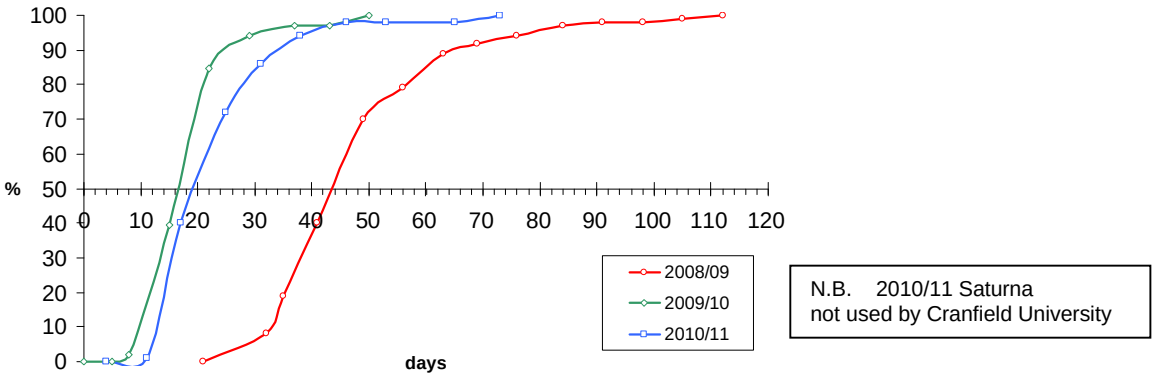

Figure 72. Saturna dormancy break at 15 C (for three seasons)

APPENDIX F

Project R298 (SBCSR)

Effect of ethylene and CO_2 concentrations on potato tuber biochemistry during short and long term storage

Student: Sofia Foukaraki

Supervisors: Professor Leon A. Terry, Dr. Gemma A. Chope

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3.5.2 Elasticity

4. Discussion

5. References

1. Experimental design

1.1 Plant material

Three potato cultivars were used in this experiment *viz.* Maris Piper, Marfona, Estima (n=180 tubers in total for 2 outturns). Tubers were stored at 6°C under two ethylene (0 and 10 μL ethylene L^{-1}) and three CO_2 (ambient, 1.5%, 4.5%) concentrations. Assessments were made after short- (16th January 2009) and long- (16th June 2009) term storage.

2. Methods

2.1 Sample preparation

Potatoes were collected on 16th January 2009 (Outturn 1) and 16th June 2009 (Outturn 2) from SBCSR and transported to Cranfield University within 2h. On arrival, potatoes were carefully washed with tap water and left to dry in air. They were then subsequently processed for texture and biochemical analysis. Two equatorial slices (thickness 10 mm each) were cut with a sharp knife from the central portion of each tuber (Fig. 1a, b). One slice was used for biochemical analysis and divided into flesh (20 g fresh weight) and peel (5 g fresh weight) before being immediately snap-frozen in liquid nitrogen. This slice was divided into two halves (Fig. 1c). One half was stored at -80°C (stock sample) and the other samples (remaining flesh slice and whole of peel, Fig. 1c, d) were stored at -40°C. Fresh weight (FW) was recorded. Samples stored at -40°C were subsequently freeze-dried in the dark using a digital freeze-drier (Scanvac,

Lynge, Denmark) at -50°C for 7 days. After lyophilisation, dry weight (DW) of the samples was recorded and then stored at -40°C until required. The adjacent slice was used for textural analysis. Total number of samples was n = 540 samples (peel and flesh x 2).

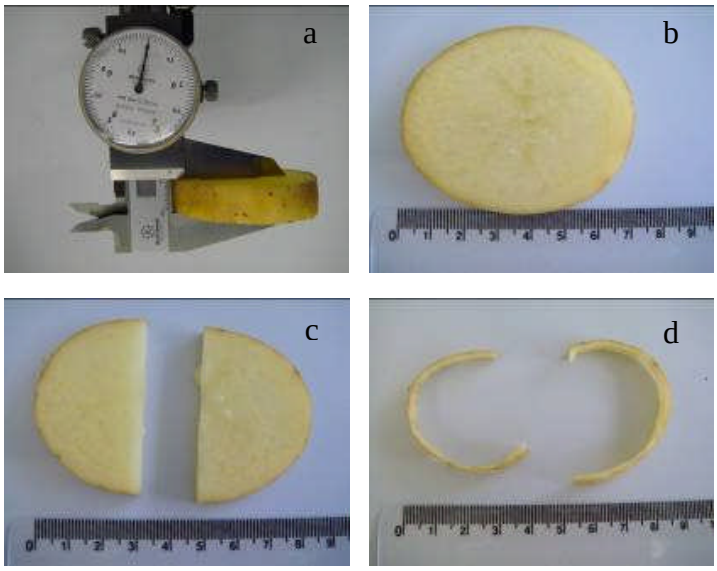

Figure 1. Flesh and peel sampling before snap-freezing procedure.

2.2 Texture analysis

Texture analysis was performed using an Instron (model 5542, MA) uniaxial testing machine (Fig. 2a) according to Landahl *et al.* (2009) with slight modifications. The machine was programmed (Bluehill 2, version 2.11, Instron) such that an 8 mm diameter cylindrical probe indented the sample to a depth of 2 mm at a cross head speed of 10 mm min $^{-1}$ (Fig. 2b). Three penetrations were performed on each slice (n=3) in the form of triangle inside the vascular band and the mean value calculated (Fig. 2c). Force (N), deformation (mm) and thickness of the slice (mm) were recorded using the Bluehill software (Fig. 3). Texture measurements were performed on short- (Outturn 1:16th January 2009) and long-term (Outturn 2: 16th June 2009) stored tubers (n=180).

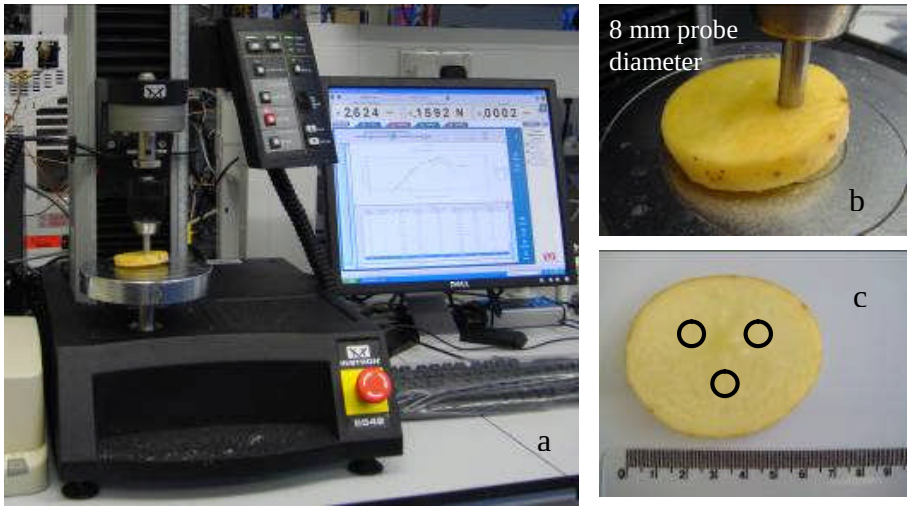

Figure 2. Texture analysis performed using Instron on fresh potato slices.

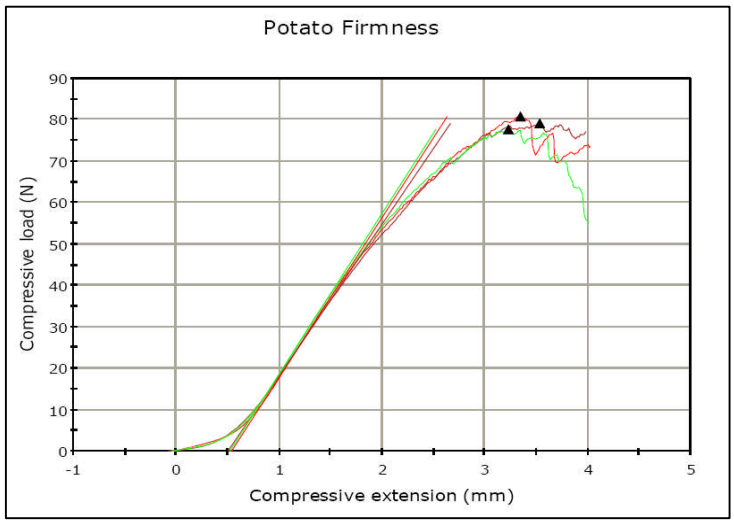

Figure 3. Firmness of potato slice measured at a cross head speed of 10 mm min^{-1} to a depth of 2 mm with a cylindrical probe of 8 mm diameter (each colour represents one penetration).

2.3 Extraction and quantification of non-structural carbohydrates

Freeze-dried powder of potato flesh or peel (150 mg) was combined with 3 ml of 62.5:37.5 HPLC grade methanol:water[1] (v/v) and mixed well. Vials (7 ml polystyrene bijou vials; Sterilin, Staffs., UK) of the slurry were placed in a shaking water bath (Fisons, Leics., UK) at 55°C for 15 min. They were removed briefly and vortexed (Vortex Genie 2, Scientific Industries, NY) for 20 s every 5 min to prevent layering and then left to cool. The cooled samples were filtered through a 0.2 μm Millex-GV syringe driven filter unit (Millipore Corporation, MA, USA) and stored at -40°C until required (Davis *et al.*, 2007)

Non-structural carbohydrates were quantified using an Agilent 1200 series HPLC binary pump (Agilent, Berks., UK) equipped with an Agilent refractive index detector (RID) G1362A (Giné Bordonaba and Terry, 2009). Extracts were diluted (1:5) immediately before analysis. The diluted extract (20 μL) was injected into a Rezex RCM monosaccharide Ca^{2+} size exclusion column of 300 mm x 7.8 mm diameter, 8 μm particle size (Phenomenex, CA; Part no. 00H-0130-K0) with a Carbo-Ca^{+} security guard column of 4 mm x 3 mm diameter (Phenomenex; Part no. AJ0-4493). The mobile phase used was HPLC grade water (filtered through a 0.4 μm filter and degassed using He) at a flow rate of 0.6 mL min^{-1} (Terry *et al.*, 2007; Giné Bordonaba and Terry, 2008). Temperature of the optical unit in the detector was set at 30ºC. The presence and abundance of fructose, glucose and sucrose were automatically calculated by comparing sample peak area to standards (0.025-2.5 mg mL^{-1}) using ChemStation Rev. B.02.01.

[1] This extraction solvent mix was shown to be the most efficacious for recovery or sugars from potato (data not shown) in contrast to some previous reports (*cf.* discussion by Davis *et al.*, 2007) and further backs up previous work conducted in the Plant Science Laboratory at Cranfield.

3. Results

Results for biochemical composition are presented separately for flesh and peel.

3.1 Biochemical composition of flesh of potato cvs. Estima, Marfona and Maris Piper tubers

Sucrose concentration was significantly higher in potato cvs. Estima (19 mg g^{-1} DW) and Marfona (29.81 mg g^{-1} DW) tubers that were treated with 10 μL ethylene L^{-1} and 4.5% CO_2, compared to those treated with 4.5% CO_2 in the absence of ethylene (15.82 and 19.58 mg g^{-1} DW, respectively), after short term storage. In contrast, higher sucrose concentration was recorded in potato cv. Maris Piper tubers that were treated with 4.5% CO_2 concentration in the absence of ethylene (23.2 mg g^{-1} DW), than in those tubers treated with 10 μL ethylene L^{-1} + 4.5% CO_2 (18.18 mg g^{-1} DW), after short term storage. However, after long term storage, the highest sucrose concentration was recorded in potato cvs. Marfona and Maris Piper tubers treated with 10 μL ethylene L^{-1} + ambient CO_2 concentration and in potato cv. Estima tubers that were treated with 4.5% CO_2 in the absence of ethylene. Sucrose concentration in potato cvs. Estima, Marfona and Maris Piper tubers was significantly increased with time, after treatment with 10 μL ethylene L^{-1} and ambient CO_2 concentration. In contrast, when tubers of all cvs. were treated with 10 μL ethylene L^{-1} and 1.5% CO_2, sucrose concentration did not change with time (Fig. 4).

Glucose and sucrose concentrations in potato cvs. Estima and Marfona tubers followed a similar pattern under both storage periods (Fig. 4). Glucose and fructose concentration in potato cvs. Estima and Marfona tubers were significantly higher after long term storage, compared to short term storage, when treated with 10 μL ethylene L^{-1}

and ambient CO_2 concentration. In contrast, significantly lower values for glucose and fructose were recorded after long term storage in both cvs. when treated with 10 μL ethylene L^{-1} and 1.5% or 4.5% CO_2. Higher glucose and fructose concentrations were also recorded for potato cv. Maris Piper after long term storage under 10 μL ethylene L^{-1} and ambient CO_2 concentration than after short term storage (Fig. 4). Glucose and fructose concentration in potato cvs. Estima, Marfona and Maris Piper tubers significantly increased with time, after treatment with 10 μL ethylene L^{-1} and ambient CO_2 concentration. In contrast, when tubers were treated with 10 μL ethylene L^{-1} and 1.5% or 4.5% CO_2, glucose and fructose concentration significantly decreased with time in potato cvs. Estima and Marfona, but not in cv. Maris Piper tubers (Fig. 4).

3.2 Dry weight of flesh of potato cvs. Estima, Marfona and Maris Piper tubers

No significant differences in dry weight were recorded between treatments in short and long term storage for potato cvs. Estima, Marfona and Maris Piper (Fig. 4).

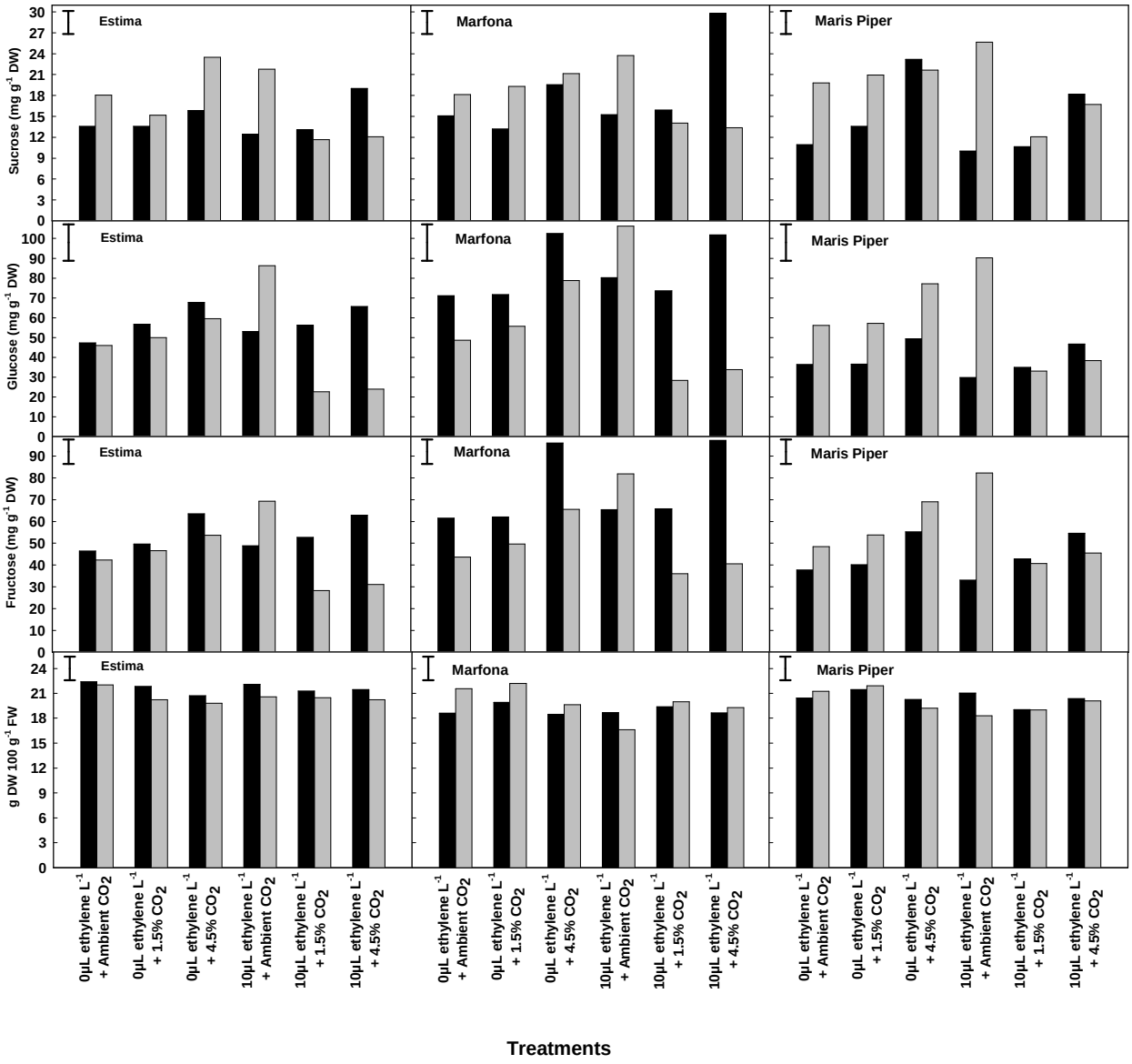

Figure 4. Sucrose, glucose and fructose concentrations (mg g^{-1} DW) and dry weight (g 100 g^{-1} fresh weight) in flesh of potato cvs. Estima, Marfona and Maris Piper measured after short ■ and long ■ term storage, under six different storage atmospheres *viz*. 0 µL ethylene L^{-1} + ambient CO_2; 0 µL ethylene L^{-1} + 1.5% CO_2; 0 µL ethylene L^{-1} + 4.5% CO_2; 10 µL ethylene L^{-1} + ambient CO_2; 10 µL ethylene L^{-1} + 1.5% CO_2 and 10 µL ethylene L^{-1} + 4.5% CO_2. Individual treatment data are means; n=5. $LSD_{0.05}$ value (sucrose: 3.32; glucose: 18.39; fructose: 11.17; dry weight: 2.84) is for comparison of individual treatment means.

3.3 Biochemical composition of peel of potato cvs. Estima, Marfona and Maris Piper tubers

The same pattern of change in sucrose concentration was followed in peel as in flesh. The highest sucrose concentration was recorded in peel of potato cvs. Estima (26.91 mg g^{-1} DW) and Marfona (33.56 mg g^{-1} DW) tubers treated with 10 μL ethylene L^{-1} + 4.5% CO_2 and in potato cv. Maris Piper (24.22 mg g^{-1} DW) tubers that were treated with 4.5% CO_2 in the absence of ethylene, after short term storage (Fig. 5). Sucrose concentration was significantly higher in peel of potato cvs. Estima (26.91 mg g^{-1} DW) and Marfona (33.56 mg g^{-1} DW) tubers that were treated with 10 μL ethylene L^{-1} and 4.5% CO_2, compared to those treated with 4.5% CO_2 in the absence of ethylene (8.58 and 11.30 mg g^{-1} DW, respectively), after short term storage. In contrast, higher sucrose concentration was recorded in potato cv. Maris Piper tubers that were treated with 4.5% CO_2 concentration in the absence of ethylene (24.22 mg g^{-1} DW), than in those tubers treated with 10 μL ethylene L^{-1} + 4.5% CO_2 (23.17 mg g^{-1} DW), after short term storage, but this was not significant. However, after long term storage, the highest sucrose concentration was recorded in potato cvs. Estima and Marfona tubers treated with 1.5 % CO_2 concentration in the absence of ethylene and in potato cv. Maris Piper tubers that were treated with 10 μL ethylene L^{-1} + 4.5% CO_2 concentration.

Glucose and fructose concentrations in peel during short and long term storage followed a similar pattern under both storage periods in potato cvs. Estima and Marfona tubers. Glucose and fructose concentration in peel of potato cvs. Estima and Marfona tubers were significantly lower after long term storage, compared to short term storage, when treated with 10 μL ethylene L^{-1} and 1.5% or 4.5% CO_2 concentration, as well in the presence of 4.5% CO_2 and absence of ethylene. Significantly higher peel glucose and fructose concentrations were recorded for potato cv. Maris Piper after long term storage under 10 μL ethylene L^{-1} and ambient CO_2 concentration than in short term

storage. In contrast, significantly lower values of glucose and fructose concentration were recorded in the peel of tubers that were treated with 10 μL ethylene L^{-1} and 1.5% or 4.5% CO_2 concentration (Fig. 5).

Sucrose, glucose and fructose concentration in peel of potato cv. Maris Piper tubers significantly increased with time, after treatment with 10 μL ethylene L^{-1} and ambient CO_2 concentration, but there was no significant difference in potato cvs. Estima and Marfona tubers. In contrast, when tubers of all cvs. were treated with 10 μL ethylene L^{-1} and 1.5% or 4.5% CO_2, sugar concentration in peel significantly decreased with time (Fig. 5). No significant differences were recorded in sugar concentration in peel of potato cv. Marfona tubers that were treated with ambient or 1.5% CO_2 concentration in the absence of ethylene during short- and long-term storage, but significantly lower values were recorded after long-term storage when treated with 4.5% CO_2 concentration (Fig. 5).

3.4 Dry weight of peel of potato cvs. Estima, Marfona and Maris Piper tubers

Significantly higher dry weight was recorded in peel of potato cv. Marfona tubers treated with ambient CO_2 concentration in the absence of ethylene during short tern storage (Fig. 5). Significantly higher dry weight content was recorded in peel of potato cv. Estima when treated with 4.5% CO_2 in the absence of ethylene, during long term storage. No significant differences were recorded between all other treatments in short and long term storage for peel of potato cvs. Estima, Marfona and Maris Piper (Fig. 5).

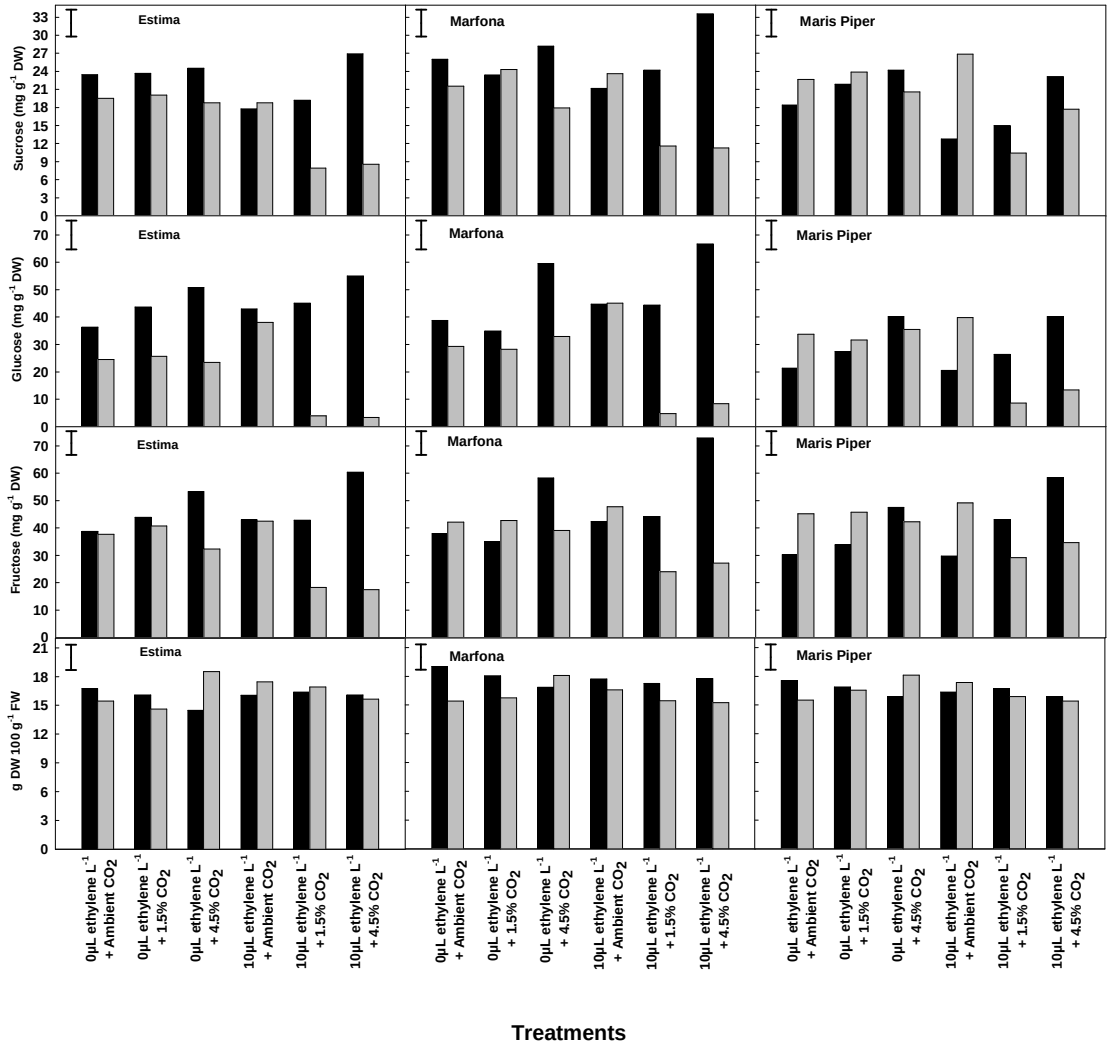

Figure 5. Sucrose, glucose and fructose concentrations (mg g^{-1} DW) and dry weight (g 100 g^{-1} fresh weight) in peel of potato cvs. Estima, Marfona and Maris Piper measured after short ■ and long ■ term storage, under six different storage atmospheres *viz*. 0 µL ethylene L^{-1} + ambient CO_2; 0 µL ethylene L^{-1} + 1.5% CO_2; 0 µL ethylene L^{-1} + 4.5% CO_2; 10 µL ethylene L^{-1} + ambient CO_2; 10 µL ethylene L^{-1} + 1.5% CO_2 and 10 µL ethylene L^{-1} + 4.5% CO_2. Individual treatment data are means; n=5. $LSD_{0.05}$ value (sucrose: 4.45; glucose: 10.43; fructose: 8.76; dry weight: 2.65) is for comparison of individual treatment means.

3.5 Texture measurements of potato cvs. Estima, Marfona and Maris Piper tubers

Texture measurements are expressed in terms of firmness and elasticity of tubers.

3.5.1 Firmness

Significantly higher firmness was shown for potato cvs. Estima, Marfona and Maris Piper tubers that were treated with 10 μL ethylene L^{-1} and ambient CO_2 concentration compared to all other treatments after short term storage (Fig. 6). Between cultivars, potato cv. Estima tubers were the most firm (124.4 N) compared to Maris Piper (118.8 N) and Marfona (109.9 N) tubers, but this was not significant. No significant differences existed between all other treatments after short term storage (Fig. 6). There were also no significant differences between treatments after long term storage of potato cvs. Estima, Marfona and Maris Piper tubers. Firmness of potato cvs. Estima, Marfona and Maris Piper tubers treated with 10μL ethylene L^{-1} and ambient CO_2 significantly decreased over time (short-term: Estima: 124.4 N; Marfona: 118.8 N; Maris Piper: 109.9 N; long-term: Estima: 74.1 N; Marfona: 75.5 N; Maris Piper: 71.5N) (Fig. 6).

3.5.2 Elasticity

No significant differences in elasticity were recorded between treatments in potato cvs. Marfona and Maris Piper tubers after short term storage (Fig. 6). In contrast, treating potato cv. Estima tubers with 10 μL ethylene L^{-1} plus ambient CO_2 concentration resulted in significantly more elastic tubers (13.63 N mm^{-2}), than when treated with ambient CO_2 concentration in the absence of 10 μL ethylene L^{-1} after short term storage (6.49 N mm^{-2}). All cultivars were significantly more elastic in the presence of 10 μL ethylene L^{-1} and 1.5% CO_2 concentration after long term storage. In addition, potato cv. Maris Piper tubers were also more elastic under 10 μL ethylene L^{-1}

and 4.5% CO_2 (7.74 N mm^{-2}), than when treated with 4.5% CO_2 concentration only (4.21 N mm^{-2}), after long term storage. Potato cv. Estima tubers were significantly more elastic under 10 μL ethylene L^{-1} + ambient CO_2 concentration (13.63 N mm^{-2}) and under 0 μL ethylene L^{-1} + 1.5% CO_2 (9.2 N mm^{-2}) after short term storage, than after long term storage (8.15 and 4.88 N mm^{-2} respectively). Similarly and comparing both storage terms, potato cv. Maris Piper tubers stored for a short term, were significantly more elastic under 0 μL ethylene L^{-1} + ambient CO_2 (10.16 N mm^{-2}) , 10 μL ethylene L^{-1} + ambient CO_2 (11.14 N mm^{-2}) and 0 μL ethylene L^{-1} + 4.5% CO_2 (9.18 N mm^{-2}), than for a longer term (4.86, 7.84 and 4.21 N mm^{-2}, respectively). No significant differences were recorded between both storage terms for potato cv. Marfona tubers.

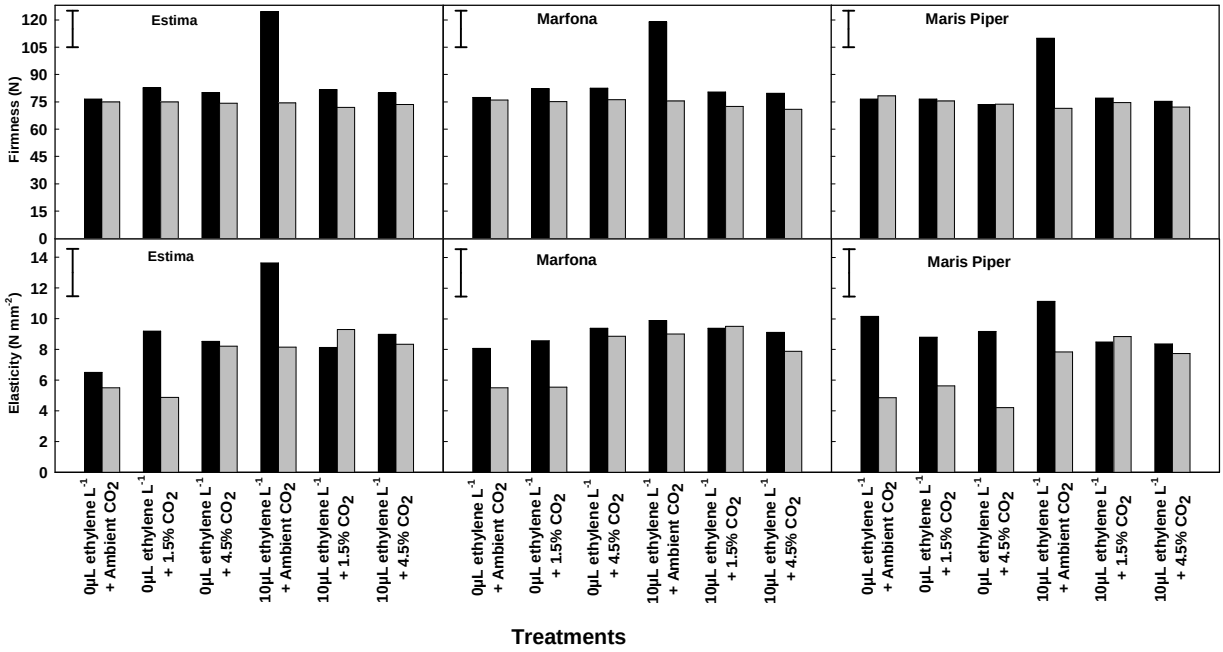

Figure 6. Firmness (N) and elasticity (N mm^{-2}) of potato cvs. Estima, Marfona and Maris Piper measured after short ■ and long ■ term storage, under six different atmospheres *viz.* 0 μL ethylene L^{-1} + ambient CO_2; 0 μL ethylene L^{-1} + 1.5% CO_2; 0 μL ethylene L^{-1} + 4.5% CO_2; 10 μL ethylene L^{-1} + ambient CO_2; 10 μL ethylene L^{-1} + 1.5% CO_2 and 10 μL ethylene L^{-1} + 4.5% CO_2. Individual treatment data are means; n=12. $LSD_{0.05}$ value (firmness: 20.03; elasticity: 3.08) is for comparison of individual treatment means.

4. Discussion

Low temperatures can effectively reduce sprouting of potatoes during storage (Prange *et al.*, 1998), but also promote the conversion of starch to sugars (Ross and Davies, 1992), leading to increased sweetness of the marketable potatoes and therefore lower quality when processed (dark colour during frying) (Blenkinsop *et al.*, 2002). Most ethylene research on potato has been undertaken using cv. Russett Burbank, particularly in the USA and Canada. There is not enough work concerning the different potato cultivars grown in UK and how sugar concentration is affected by ethylene and storage conditions.

Storing potatoes at 6°C and under 10 μL ethylene L^{-1} and different CO_2 concentrations resulted in an increase in the amount of sugars in both flesh and peel of the selected varieties that was cultivar-dependent. Sucrose, glucose and fructose concentrations in flesh of potato cvs. Estima, Marfona and Maris Piper that were treated with 10 μL ethylene L^{-1} and ambient CO_2 concentration were significantly higher compared to all other treatments after long term storage. In contrast to the above, glucose and fructose concentrations in flesh of the same cultivars significantly decreased during storage when treated with 10 μL ethylene L^{-1} and 1.5% or 4.5% CO_2 concentration. According to the results, there seems to be an effect of storage time and ethylene application and CO_2 concentration on sugar concentration of cultivars. Potato cultivars responded differently under different treatments. However, potato cvs. Estima and Marfona seemed to have a similar response regarding sugar concentration under same treatments, in contrast to potato cv. Maris Piper. Day *et al.* (1978) and Prange *et al.* (1998) have demonstrated an increase in sugar concentration in ethylene-treated potato cv. Russett Burbank tubers. Exposure of cv. Russett Burbank tubers to 4 μL L^{-1} ethylene for 23-33 weeks at 9°C inhibited sprouting, but higher ethylene concentrations

(40-400 μL L^{-1}) gave better sprout inhibition as well reduced darkening during frying (Daniels-Lake *et al.*, 2005). This suggests that there are different metabolic pathways controlling ethylene-induced sweetening and sprout inhibition (Daniels-Lake *et al.*, 2007).

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APPENDIX G

CONFERENCES

7th International Postharvest Symposium
Kuala Lumpur, Malaysia, 25-29 June 2012
(oral presentation)

Differential Effect of Ethylene Treatments on Non-Structural Carbohydrate Composition in Flesh and Peel of Six UK-grown Potato Cultivars

Sofia G. Foukaraki, Gemma A. Chope and Leon A. Terry
Plant Science Laboratory, Cranfield University, Bedfordshire, MK43 0AL, UK

Keywords: fructose, glucose, sucrose, flesh, peel

Abstract

Long term storage of potato tubers allows year round availability of the crop. Storing potatoes under low temperatures causes high sugar accumulation in tubers, leading to undesirable darkening during processing caused by the Maillard reaction. As an alternative, continuous exposure to ethylene during storage has been shown to prolong storage life of potato by suppressing sprouting, yet there is still a dearth of information on the biochemical effects of ethylene in cultivars other than 'Russet Burbank', and indeed on whether continuous ethylene treatment is indeed required. In this study, 'King Edward', 'Maris Piper', 'Mayan Gold', 'Desiree', 'Sylvana' and 'Fianna' potatoes were stored at 6°C under four ethylene treatments (*viz.* continuous ethylene (10 μL L^{-1}), continuous air, transfer from air to ethylene after first indication of sprouting and vice versa) for thirty weeks. Samples were taken after harvest and at four occasions during storage. Non-structural carbohydrates (fructose, glucose, sucrose and starch) were determined in both potato flesh and peel from all cultivars as ethylene has been reported to have some negative effects on sugar metabolism. Storage time and ethylene application resulted in greater sugar concentration in both flesh and peel in a treatment and cultivar-dependent manner. Chemometric analysis revealed clustering of samples according to all four ethylene treatments. Differences in sugar profiles were shown between flesh and peel tissues in all cultivars. Sufficient sprout control was achieved in cvs. 'Desiree' and 'Fianna' tubers which received ethylene after the trigger point of dormancy break was reached, whilst sugar accumulation was minimised.

7thI international Postharvest Symposium
Kuala Lumpur, Malaysia, 25-29 June 2012
(oral presentation)

A new liquid chromatography ultra high definition accurate mass spectrometry method for the simultaneous quantitation of nine plant hormones in fruits and vegetables

José Juan Ordaz Ortiz, Sofia G. Foukaraki, Leon A. Terry
Plant Science Laboratory, Cranfield University, Bedfordshire, MK43 0AL, UK

Keywords: UHPLC, Q-TOF MS, phytohormones

Abstract

Plant hormones are important molecules which at low concentration can regulate various postharvest physiological processes. Mass spectrometry has become a powerful technique for the quantitation of multiple classes of plant hormones because of its high sensitivity and selectivity. We have developed a new ultra high pressure liquid chromatography-full scan high definition accurate mass spectrometry method (UHPLC-Q-TOF MS) for simultaneous determination of nine key plant hormones (abscisic acid (ABA) and four ABA metabolites, cytokinins (zeatin, zeatin riboside) and gibberellins (GA1, GA4). The compounds were extracted with methanol-water-formic acid, purified by Sep-Pack plus C18 and Oasis MCX cartridges, and separated and quantified by UPLC Q-TOF MS using an electrospray ionization source in both negative and positive modes. The method was validated by determining the linearity ($R^2 \geq 0.999$) over the concentration range of 5 – 150 ng/mL for most compounds. The limits of detection (LODs) of the technique, for example, ranged between 0.25 and 1.41 ng mL^{-1} for abscisic acid (ABA) and 7'hydroxy abscisic acid (7'OH-ABA) respectively, with limits of quantitation (LOQs) between 0.87 and 4.70 ng/mL, respectively. Precision of the method was obtained with intra- and inter-day relative standards deviations ($\leq$ 4.2 %) and accuracies for compounds typically ranging between 92- 112. Recoveries were evaluated on spiked potato samples using SPE C18 and Oasis MCX cartridges. In addition, we evaluated the mass accuracy for most compounds (< 2 ppm) achieving similar results for those obtained with FT-ICR and Orbitrap instruments.

4th Postharvest Unlimited 2011
Leavenworth, WA, USA, 23-26 May 2011
(oral presentation)

1-MCP and ethylene exposure effects on the postharvest quality of the UK-grown 'Marfona' potato cultivar

Sofia G. Foukaraki, Gemma A. Chope and Leon A. Terry*

Plant Science Laboratory, Cranfield University, Bedfordshire, MK43 0AL, UK.
Corresponding author. Tel.: +44-7500-766-490
E-mail address: l.a.terry@cranfield.ac.uk (L.A. Terry)

It has previously been shown that ethylene application can successfully inhibit sprouting incidence and therefore promote the longer storage of potatoes. The Chemicals Regulation Directorate in UK has approved the use of ethylene for potato storage (50 μL L^{-1}), while a concentration of 10 μL L-1 has been shown to be effective for controlling sprouting in potatoes during long term storage. In contrast to the positive effects of ethylene on potato storage, the blocking of ethylene perception by 1-methylcyclopropene (1-MCP) may be expected to have a deleterious effect on potato storage. In this study, the effect of 1-MCP and ethylene on biochemical composition, ethylene and carbon dioxide production and sprouting in the UK-grown potato cultivar *viz.* Marfona was investigated. Potato tubers were harvested and then slowly cooled from 15°C to 6°C over a two week period. Tubers were then exposed to +/-1-MCP for 24h. After the 1-MCP treatment the tubers were placed in trays and stored in the presence or absence of continuous ethylene (10 μL L^{-1}) at 6°C at Sutton Bridge Crop Storage Research Unit (Lincs., UK). At dormancy break (10% eye movement of tubers assessed in air at 6°C) a sub-sample from each treatment was transferred to either ethylene or no ethylene, resulting in four treatments: continuous ethylene, continuous air, transfer from ethylene to air and *vice versa*. All tubers were stored for six months. Ethylene-treated tubers that did not receive the 24h 1-MCP treatment contained higher sucrose, glucose and fructose concentrations than the air-treated ones during storage. In contrast, there were no significant differences between treatments in the non-1-MCP-treated tubers. Respiration and ethylene production rates were only affected in the MCP-treated tubers. Higher number of sprouts was detected in the non-MCP-treated tubers than the MCP-treated ones of the transition treatments.
The results suggest that the 24h 1-MCP exposure before storage of tubers under continuous ethylene significantly suppressed the action of ethylene in terms of sugar concentration of tubers, respiration and ethylene production and sprouting.

28th International Horticultural Congress
Lisbon, Portugal, 22-27 August 2010
(oral presentation)

Ethylene exposure after dormancy break is as effective in controlling sprout growth as continuous ethylene for some UK-grown potato cultivars

Sofia G. Foukaraki, Gemma A. Chope and Leon A. Terry*

Plant Science Laboratory, Cranfield University, Bedfordshire, MK43 0AL, UK.
Corresponding author. Tel.: +44-7500-766-490
E-mail address: l.a.terry@cranfield.ac.uk (L.A. Terry)

Ethylene application can effectively extend potato storage life by suppressing sprouting incidence. An ethylene concentration of 50 μL L^{-1} (57.5 mg m^{-3}) has been approved by the Chemicals Regulation Directorate (CRD) in the UK for use in potato storage, but a continuous treatment of 10 μL L^{-1} is more commonly used by industry. Although ethylene can extend storage life, it has previously been shown to negatively affect the textural and taste characteristics of some potato cultivars. On the other hand, sprout growth also reduces the marketability of potatoes. In this study, the effect of ethylene on biochemical composition, texture and sprouting in two UK-grown potato cultivars *viz.* Marfona and Sylvana was investigated. Potato tubers were harvested and then slowly cooled from 15°C to 6°C over a two week period. Tubers were then placed in trays and stored in the presence or absence of continuous ethylene (10 μL L^{-1}) at 6°C at Sutton Bridge Experimental Unit (Lincs., UK). At dormancy break (10% eye movement of tubers assessed in air at 6°C) a sub-sample from each treatment was transferred to either ethylene or no ethylene, resulting in four treatments: continuous ethylene, continuous air, transfer from ethylene to air and *vice versa*. All tubers were stored for six months.

Ethylene-treated tubers contained higher sucrose, glucose and fructose concentrations than untreated ones. Firmness decreased with time with all treatments in tubers cv. Marfona, but not cv. Sylvana. Sprouting incidence was affected by treatment in tubers cv. Sylvana, but not in cv. tubers Marfona. Moreover, ethylene application after dormancy break was as effective as continuous ethylene treatment for cv. Sylvana tubers only. The results suggest that ethylene applied after dormancy break can prolong storage for some UK-grown varieties.

8th International Symposium on the Plant Hormone Ethylene

Cornell University, Ithaca, New York, USA, 21-25 June 2009
(oral presentation)

Effect of transition between ethylene and air storage on two potato varieties

Sofia G. Foukaraki, Gemma A. Chope and Leon A. Terry

Plant Science Laboratory, Cranfield University, Bedfordshire, MK43 0AL, UK.
Presenter's e-mail address: s.foukaraki.s05@cranfield.ac.uk

Exposure to ethylene (10 μL L^{-1}) extends potato storage life, but also affects taste and texture. Most research has been conducted on potato cv. Russett Burbank tubers, and there is a paucity of work concerning UK-grown potato cultivars. In addition, the transition between ethylene and air during storage has not been investigated.

In this study, the effect of the transition between ethylene (10 μL L^{-1}) and air (and vice versa) on potato cv. Maris Piper and potato variety Mayan Gold, in terms of sugars composition, was assessed. After harvest, potatoes were transported to Sutton Bridge Experimental Unit (Lincs., UK) and initially stored at 15°C, then slowly cooled to 6°C over two weeks. Tubers were then stored in the presence or absence of continuous ethylene (10 μL L^{-1}) at 6°C. When tubers showed first indication of sprouting (eye movement), they were transferred to/from ethylene.

Significant differences were shown between cultivars regarding their sugar content. Sucrose, glucose and fructose concentration in tubers of both cultivars increased during storage. Higher sucrose, glucose and fructose concentrations were recorded in ethylene-treated vs. untreated tubers at the time of tuber transition for cv. Maris Piper, but not for Mayan Gold. However, under continuous ethylene treatment (10 μL L^{-1}) sugar content increased between time of eye movement and four weeks later in Mayan Gold but not in Maris Piper tubers. The results herein suggest that both cultivars responded differently to ethylene. The combination of ethylene and air treatments at different storage timings could prolong storage life while suppressing the increase in sugars during storage.

6th International Postharvest Symposium
Antalya, Turkey 8-12 April, 2009
(poster presentation)

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Differential effect of ethylene on sugars in UK-grown potato cultivars during storage

Sofia G. Foukaraki, Gemma A. Chope and Leon A. Terry
Plant Science Laboratory, Cranfield University, Bedfordshire, MK43 0AL, UK
* Corresponding author. Tel.: +44 7500 766490; Fax: +44 1234 758380; l.a.terry@cranfield.ac.uk

Background

Long-term storage of potatoes allows year-round availability of the crop. Storage at low temperatures (2-4ºC) and the application of sprout suppressants are effective methods of extending potato storage life. However, low temperature storage can elevate the rate of conversion of starch to sugars, with a subsequent increase in potato tuber sweetness leading to a darker colour during frying. Continuous exposure to ethylene (10 µL L^{-1}) is effective in extending potato storage life and has recently been approved by the UK Pesticides Safety Directorate for use in commercial potato storage facilities. There is a paucity of research concerning the effect of ethylene on tuber sugar concentration of different UK-grown potato cultivars. Most ethylene research on potato has been based on cv. Russett Burbank, particularly in the USA and Canada. Here, we present the effect of ethylene on sugar concentration in five UK-grown potato cultivars *viz.* Sylvana, Marfona, Estima, Desiree and Fianna.

Materials and Methods

Potato tubers were harvested and transported to the storage facilities at Sutton Bridge Experimental Unit (Lincs., UK) as soon after harvest as possible. The tubers were initially stored at 15ºC and then slowly cooled to 6ºC over a period of two weeks. Tubers were then placed in trays and stored in the presence or absence of ethylene (10 µL L^{-1}) at 6ºC for *ca.* 6 weeks. After this period, potatoes were transported to Cranfield University. On arrival, they were washed with water and left to dry. Flesh samples were processed for biochemical analysis as follows. A slice (10 mm) was cut from the central portion of each tuber and snap-frozen in liquid nitrogen. Samples were then freeze-dried, ground into a fine powder and stored at -40ºC until required. Non-structural carbohydrates (NSCs) (*viz.* sucrose, glucose and fructose) were quantified using HPLC (**Fig. 1**)[1]. Sweetness index was calculated as (1.0 x glucose + 2.30 x fructose + 1.35 x sucrose)[2]

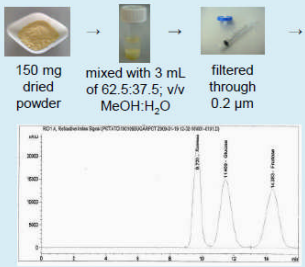

Figure 1. Analysis of NSCs in freeze-dried potato powder using HPLC-RID.

Results

- Significantly higher sweetness indices were calculated for ethylene-treated tubers of all cultivars compared to non-ethylene treated tubers (Fig. 2).
- Significant differences in dry matter content were shown between cvs. ($P \leq 0.001$), but not between treatments ($P = 0.937$). Potato cv. Fianna tubers contained the greatest proportion of dry matter (**Fig. 3**), but the lowest sweetness index (**Fig. 2**). In contrast, cv. Sylvana tubers contained the least dry matter, but were ranked amongst the highest by sweetness index.
- Significant differences existed for sucrose, glucose and fructose between treatments ($P \leq 0.001$) and cvs. ($P < 0.05$) (**Fig. 4**). Ethylene-treated tubers contained higher concentrations of sugars than controls. Tubers cv. Sylvana had the highest total sugar content and Fianna the lowest (**Fig. 4**).
- There was a significant interaction between cvs. and treatments for glucose ($P = 0.003$) and fructose ($P = 0.026$) concentrations. Estima and Desiree were among the cultivars least affected by ethylene treatment, while ethylene-treated Fianna tubers showed the greatest increase (> 3-fold) in sugars (**Fig. 4**).

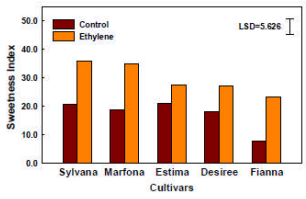

Figure 2. Sweetness index of potato cvs. Sylvana, Marfona, Estima, Desiree and Fianna tubers stored for *ca.* 6 weeks in +/- 10 µL ethylene L^{-1} at 6ºC. Individual treatment data are means (n = 4).

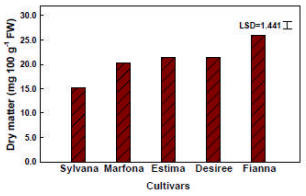

Figure 3. Dry matter content (g 100 g^{-1} FW) in potato cvs. Sylvana, Marfona, Estima, Desiree and Fianna tubers. Data values are means for both treated and untreated tubers (n = 8).

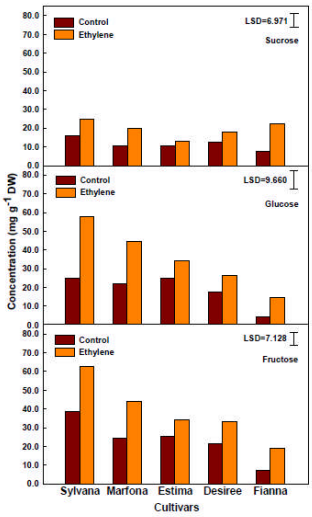

Figure 4. Concentration of sucrose, glucose and fructose (mg g^{-1} DW) in potato cvs. Sylvana, Marfona, Estima, Desiree and Fianna tubers stored for *ca.* 6 weeks in +/- 10 µL ethylene L^{-1} at 6ºC. Individual treatment data are means (n = 4).

Conclusion

Low temperature storage of potatoes results in the conversion of starch to sugars, leading to increased sweetness and reduced quality upon processing (darker fry colour). Storing potatoes at 6ºC in the presence of 10 µL ethylene L^{-1} resulted in an increase in the tuber sugar concentration of the cultivars analyzed. Different cultivars responded differently to ethylene treatments. It is demonstrated that ethylene treatments may allow extension of storage life without significantly affecting the quality upon processing for certain cvs. (*viz.* Estima and Desiree).

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