Effects of Preharvest Factors and Postharvest Treatments on Fruit Quality of *Prunus domestica* L.

Dissertation

zur Erlangung des akademischen Grades Doktor an der Landwirtschaft

(Dr. rer. hort.)

eingereicht an der
Lebenswissenschaftlichen Fakultät der
Humboldt-Universität zu Berlin

von:

Herrn Dipl.-Ing. Yousef Rezaei Kalaj

Präsident der Humboldt-Universität zu Berlin:
Prof. Dr. Jan-Hendrik Olbertz

Dekan der der Lebenswissenschaftlichen Fakultät
Prof. Dr. Richard Lucius

Gutachter/in:

1. Prof. Dr. Uwe Schmidt
2. Prof. Dr. Dominikus Kittemann
3. Dr. Martin Geyer

Tag der mündlichen Prüfung: 04.03.2016

Contents

List of figures

List of tables

Abbreviations

Ca	Calcium
CL	crop load
cm	centimetre
CV	cultivar
DAFB	day after full bloom
DMC	dry matter content
e.g.	for example
ECa	soil apparent electrical conductivity
et al.	et alia (and others)
FWHM	full width at half maximum
g	gram
GL	Gaussian–Lorentzian function
HCL	high crop load
HECa	high soil ECa
HMDS	high maximum daily shrinkage
IP	inflection point
K	Potassium
kPa/MPa	Kilopascal/ Megapascal
LCL	low crop load
LECa	low soil ECa
LLBI	Laser light backscattering imaging
LMDS	low maximum daily shrinkage
LSD	least significant difference
LVDT	linear variable displacement transducer
MDS	maximum daily trunk shrinkage
mg	milligram
ml	millilitre
MNTD	minimum daily trunk diameter
mW	mill watt
MXTD	maximum daily trunk diameter
N	Nitrogen
NAI	Normalized anthocyanin index
NDVI	Normalized difference vegetation index
nm	nanometre
ºC	degree Celsius
PA	pigment analyser
PWP	permanent wilting point
r	Pearson's correlation
r^2	coefficient of determination

RDI	regulated deficit irrigation
RH	relative humidity
RWC	relative water content
s	second
SAS	statistical analysis software
SSC	soluble solids content
SSC:TA	sugar-to-acid ratio
T	time of measurement
TA	titratable acidity
TCSA	trunk cross-sectional area
TDV	trunk diameter variation
VPD	vapour pressure deficit
VS	Versasheen plus Sorbitol
µm	micrometre

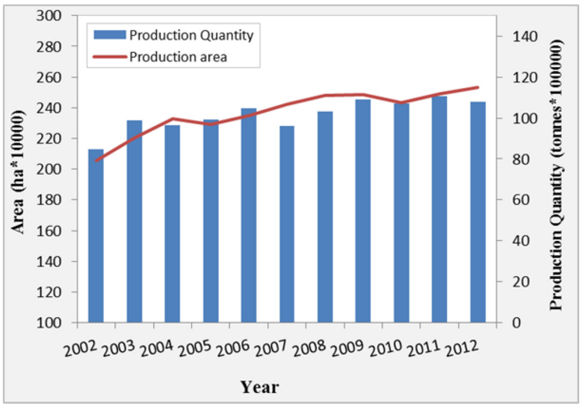
1. Introduction

1.1. Plum production worldwide

The plum (*Prunus domestica L.*) belongs to the Rosaceae family in the genus *Prunus*, which covers all of the stone fruits, such as apricot (*P. armeniaca*), peach and nectarine (*P. persica*), sweet cherry (*P. avium*) and almond (*P. dolcis*). The genus *Prunus* includes 40 species, which are highly diverse from a taxonomical perspective. The most important commercial species of plum are classified into European (e.g. *P. domestica*) and Asian (e.g. *P. salicina*) groups around the world Topp et al. (2012).

In recent years, the production of stone fruit such as plums has increased due to successes in implementing long distance transport to receiving markets (Crisosto et al., 1995). Plum marketing has improved by creating new cultivars and advancements in postharvest technology (Crisosto et al., 1995). According to the FAO, world production of plums in 2012 was about 11 million tons, and produced from an area of 2.5 million hectares (Tab.1; FAOSTAT, 2014). As shown in Tab. 1, China is the world's largest producer of plums with about 55% (6 Mt) of total production. In Germany, the most important tree fruits are apple, pear, cherry and plum. Germany is a producer as well as an importer of plums and ranks 28th worldwide in plum production (0.036 Mt; Tab. 1; FAOSTAT, 2014). 'Hanka', 'Presenta', 'Jojo' and 'Haganta' are some of common cultivars cultivated in Germany.

Tab. 1. (A) World plum production and orchard area during 2002 to 2012; (B) list of plum production in top countries around the world in 2012 (FAOSTAT 2014).



(A)

No.	Country	Production (Thousand tons)	Area (Thousand ha)
1	China	6000	1750
2	Romania	424	67
3	Serbia	391	158
4	Chile	300	22
5	Turkey	297	21
6	Iran	295	12
7	USA	229	34
8	India	215	27
9	France	209	18
10	Spain	205	16
28	Germany	36	4
	Total	11000	2500

(B)

World production and the production area of plums have increased by 17 to 30% over the last 11 years (during 2002 to 2012; Fig. 1). In recent years, the benefits of plums for human health, due to their abundance of compounds such as anthocyanins, pectins and carotenoids, have also been reported (Ionica et al., 2012; Ionica et al., 2013). Despite this, plum consumption has not increased in USA and some European countries, which can be attributed to a lack of fruit ripening before consumption (Crisosto et al., 2004; Crisosto et al., 2007).

1.2. Plum quality

Postharvest quality is ultimately defined in terms of consumer satisfaction. Production of a uniform high quality plum can provide consumer satisfaction, while non-uniform fruit quality is detrimental to effective marketing and export (Crisosto et al., 2004). Many decisions will profoundly influence the post-storage quality of plums. Nowadays, researchers have established that the maximum postharvest quality can be reached by understanding the role of preharvest factors such as climate, water availability, soil properties, mineral nutrition, thinning (crop load), fruit canopy position and cultivar selection (Crisosto et al., 1995; Crisosto et al., 1997).

Soil properties should be considered to be some of the main preharvest factors that strongly affect fruit quality (Rato et al., 2008). Apparent electrical conductivity (ECa) is influenced by soil chemical and physical properties (Corwin and Lesch, 2005), especially by soil texture and moisture in non-saline soils (Lund et al., 2000). Therefore, ECa can be used to map the spatial variation in soils in order to apply different management strategies (Terron et al., 2011). This also means that each ECa zone may have a specific influence on tree and fruit quality. The effect of soil ECa, which may also indicate soil water availability (Schumann and Zaman, 2003), on fruit quality may be influenced and modified by crop load. Crop load as a preharvest factor has been shown to strongly affect postharvest quality and performance (Wünsche et al., 2005).

1.3. Consumer expectations

Demand for and consumption of plums will certainly increase if consumers are satisfied. In general, consumers prefer fully-ripe, tasty, fruit with a rich flavour, and free of any internal defects, i.e. chilling injury (Crisosto et al., 2004). Attributes such as fruit size, skin colour, soluble solids content (SSC) and titratable acidity (TA) determine fruit maturity and, therefore, consumer acceptance (Crisosto and Crisosto, 2005; Usenik et al., 2008). Fruit flesh firmness is an important factor when considering an optimum harvest date, as well as prolonged shelf life (Dodd, 1984; Taylor et al., 1993a; Abdi et al., 1997). Hence, harvest maturity strongly affects fruit quality. Late-harvested fruit can achieve customer satisfaction but cannot be stored for a long time. On the other hand, early harvest as a method to extend storage life can result in low-quality fruit (Crisosto et al., 1995). Scientists have conducted many experiments to find the optimum harvest date for plums; however, it is not easy to determine the optimal picking time for plums due to a lack of obvious maturity indices (Usenik et al., 2008). To properly meet consumers' expectations, it is urgently necessary to define specific maturity parameters for each cultivar (Casquero and Guerra, 2009).

1.4. Postharvest quality and storability of plums

Stone fruits such as plums have a relatively short shelf life (Crisosto et al., 1995). They can quickly pass from ideal ripeness to overmaturity and will readily lose water and shrivel (Kader and Mitchell, 1989). Therefore, optimum storage conditions should effectively delay ripening and maintain plum quality. Low temperature (0°C) is recommended to conserve fruit quality. However, even at low temperatures, plums are only stored for 2-5 weeks (Crisosto et al., 1999). Moreover, postharvest treatments such as heat treatment and application of 1-MCP have recently been studied to improve fruit quality maintenance (Serrano et al., 2004; Candan et al., 2008). In addition, the application of edible coatings has been suggested to enhance the shelf life of plums. Eum et al. (2009) reported a positive effect of carbohydrate-based edible coatings (Versasheen) with sorbitol as a plasticizer to control plum quality during short-term storage at room temperature.

2. State of the art

Many factors can affect the quality of fruit, both at harvest and during the post-harvest period. During the last decade, several authors have published results on the effects of various preharvest factors on fruit quality parameters. Among others, these factors include soil properties and climate during cultivation (Crisosto et al., 1995). Moreover, a number of production practices and other preharvest parameters, such as mineral nutrition, canopy position, pruning, irrigation and crop load, also influence postharvest quality and the shelf life of plums (Crisosto et al., 1995; Kader, 2002).

2.1. Preharvest factors

2.1.1. Genotypic variation

Tree genotype (cultivar and/or rootstock) plays an important role in determining fruit quality and postharvest storage potential (Crisosto and Costa, 2008). The cultivar of the fruit species is one of the most important factors in determining the variation in, e.g., the fruit's soluble solids content and acidity (Crisosto et al., 1995; Crisosto et al., 1997). Nowadays, horticultural breeding and biotechnology could play a significant role in improving and maintaining postharvest quality and the safety of fresh produce. Moreover, the growers have the choice of selecting preferred cultivars prior to planting crops (Kader, 2002).

'**Jojo**' is a hybrid of 'Ortenauer' x 'Stanley' (Fig. 1. A). It is self-fertile and one of the few truly Sharka (plum pox virus) resistant plums. The fruit is oval-shaped and medium to large sized with dark blue skin. The optimum harvest date is in August and September, within a long harvesting period. Ripe fruit are firm and juicy with a mixed, sweet and sour taste.

'**Tophit plus**' is a hybrid of 'Cacanska Najbolja' x 'President'. It is sharka (plum pox virus) tolerant (Fig. 1. B). It has very large, egg-shaped fruit with dark blue skin. It is late ripening and self-fertile to a limited extent (additional pollinators are recommended). The optimum harvest date is in September. Ripe fruit are firm and juicy with a mixed taste of sweet and sour. They have a good culinary quality and storability.

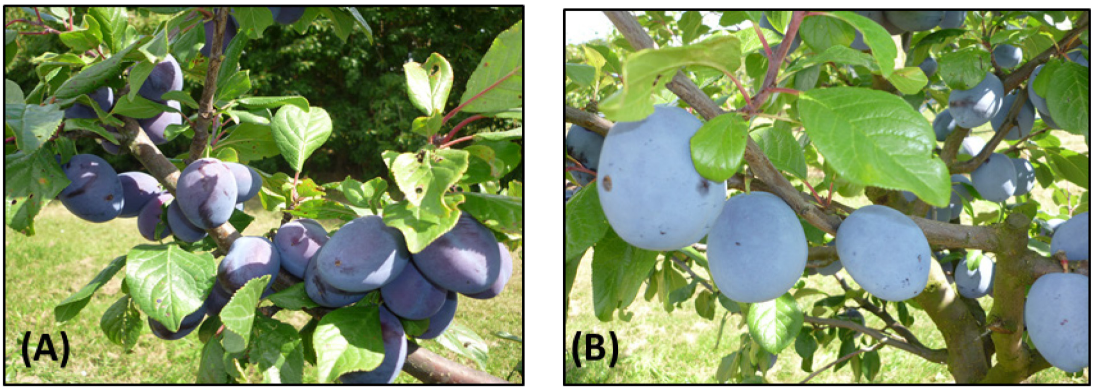


Fig. 1. (A) 'Jojo' and (B) 'Tophit plus' fruit just before harvest

2.1.2. Climate and canopy position

Climate factors, especially adequate light intensities and air temperatures are important for both optimal plant growth and yield (Kays, 1999). Temperature increases can have both positive and negative effects on crop yields. High air temperatures enhance transpiration, which, in turn, indirectly affects the uptake and metabolism of nutrients by plants (Kader, 2002). The effects of air temperature and light intensity as climatic factors on the nutritional quality of fruit have been reviewed in previous years (Kader, 2002). Precipitation is the major source for water availability to the tree. However, most orchards supplement their water supply through drip irrigation.

The canopy light is an important orchard factor that influences plant vegetation, fruit productivity and fruit quality (Taylor et al., 1993b; Crisosto et al., 1997). Increased exposure to light improves both fruit size and soluble solids content (SSC) in stone fruit such as peach and nectarine fruit (Marini et al., 1991; Muleo et al., 1994). Murray et al. (2005) reported that shaded 'Laetitia' and 'Songold' plums showed smaller size and delayed maturation with lower SSC and poor skin colour compared to those exposed to full light.

2.1.3. Mineral nutrition

Plant nutrition is an important factor that potentially affects both the quality and postharvest life of fruit. Optimum plant performance depends on a balanced availability of mineral nutrients that can be limited in many soils around the world (Hewett, 2006).

Nitrogen (N) and potassium (K) are the principal nutrients needed by plants (Cuquel et al., 2011). Excessive N nutrition increases vegetative growth and delays fruit maturation in stone fruit (Daane et al., 1995; Crisosto et al., 1997). In contrast, nitrogen deficiency leads to small-sized fruit, low yield and poor flavour (Daane et al., 1995). Optimal potassium (K) nutrition improves fruit quality by enhancing leaf photosynthesis and the reallocation of sugars and organic acids to fruit (Crisosto and Costa, 2008). Calcium (Ca) is also an essential component for fruit trees, as it is involved in numerous biochemical and morphological processes (Crisosto and Costa, 2008). It plays an important role in delaying fruit senescence (Serrano et al., 2004). Moreover, Ca has a critical role to play in fruit growth and development, positively affecting cell wall structure (Kadir, 2004). Additional, Ca could be applied to fruit through either preharvest foliar sprays or postharvest dips.

2.1.4. Irrigation

Water is retained in the soil and can be extracted by the plant. Sufficient water supply is one of the major factors affecting optimal plant growth (Fereres and Soriano, 2007), successful crop production and fruit composition at harvest and in the postharvest period (Kader, 2002). The total amount of water stored in the soil at a pF- value between 1.8 (field capacity) and 4.2 (permanent wilting point, PWP) is the water available for plants (Ehlers and Goss, 2003). The availability of soil water for plants depends on soil texture and soil structure. In general, a higher percentage of clay leads to a higher water-holding capacity than sand does, due to a much larger surface area of clay particles. The volumetric soil water content at the wilting point is around 5 to 10% for sandy soils, 10 to 15% for loam soils, and 15 to 25% for clay soils (Ratliff et al., 1983). The PWP is defined as the level of soil water content below which plant roots can no longer extract water from the soil matrix (Ehlers and Goss, 2003).

For instance, in Brandenburg almost 62% of the state's territory, mainly consisting of sand and loamy sand, has a water holding capacity lower than 140 mm (Gutzler et al., 2015). In addition, Brandenburg is one of the driest federal states in Germany with an annual average of 554 mm rainfall; this may significantly limit plant yield (Gutzler et al., 2015). For these reasons, irrigation is essential to stabilize and increase yield in Brandenburg.

Irrigation improves soil water availability and, consequently, plant water status, stomatal conductance and fruit quality (Li et al., 1989b; Berman and DeJong, 1996; Naor et al., 1999; Naor et al., 2001). Irrigation requirements are high, especially in the summer season due to the high evaporative demand. Accurate irrigation strategies are needed to conserve water and minimize water wastage. Regarding irrigation, the following three questions must be answered by those who irrigate: 1) how much water should be applied, 2) when should it be applied, and 3) how should it be applied (Fereres et al., 2003b).

Irrigation strategy: Irrigation scheduling is classified into two main strategies, i.e. soil-based (conventional) and plant-based methods (Steppe et al., 2008). The two conventional irrigation strategies are commonly used: 1) direct measurement of 'soil water status', and 2) determination of 'soil water balance' by calculating the water income and water losses during a given period of time (Jones, 2004). The positive and negative points of these methods have been discussed in detail by Jones (2004).

To increase irrigation efficiency today, soil water-based techniques will be progressively replaced with plant-based methods. Relative water content (RWC) and leaf water potential have been widely used to quantify plant water deficits. Although RWC can easily be used because it does not require any complex equipment, leaf water potential measurement is generally more applicable to plant water status (Jones, 1990, 2004). However, leaf water potential measurements are destructive, and time and labour consuming (Fernandez, 2014). Thus, in the past couple of decades, new methods such as sap flow (Intrigliolo and Castel, 2006a; Conejero et al., 2007) and stem diameter measurements (Ortuno et al., 2010) have been developed for the non-destructive and automatic monitoring of plant water status, as alternatives to direct measurement.

Deficit irrigation as water saving: Trees supplied with optimum amounts of water during the season will produce fruit of marketable size and good quality. In contrast, excessive watering of trees may have the opposite influence on fruit quality because it increases vegetative growth and decreases fruit productivity (Pérez-Pastor et al., 2007). In an excess water condition, delayed maturity, decreased fruit firmness and reduced soluble solids content have been reported (Crisosto et al., 1994b; Pérez-Pastor et al., 2007).

It is very important to use a water-saving method with a minimum effect on fruit yield and quality when water resources are limited. One of these methods is regulated deficit irrigation (RDI). In RDI, amounts of applied water are reduced when fruit growth is minimal and, therefore, it is generally not affected by water deficits (Intrigliolo and Castel, 2010). RDI can reduce fruit size and vegetative growth especially in high density plantings, while the content of soluble solids, acidity and ascorbic acid during fruit growth prior to harvest increases (Crisosto et al., 1995; Pérez-Pastor et al., 2007). RDI has been applied successfully to some stone fruits such as plum and apricot (Pérez-Pastor et al., 2007; Intrigliolo and Castel, 2010). However, tree responses to RDI strongly depend on the fruit growth stage (Naor et al., 2001). For instance, stage III is more sensitive than stages I and II of fruit growth because the maximum water consumption occurs in stage III (Boland et al., 1993).

Crisosto et al. (1994b) evaluated the influence of deficit irrigation (starting 4 weeks before harvest) on peach quality at harvest and on postharvest performance. They reported that fruit from deficit irrigation treatments had a higher SSC and lower mass than those in normal and over-irrigation regimes; however, there was no considerable difference in other quality parameters such as flesh firmness, acidity and pH between the irrigation regimes.

The response of fruit trees to water deficit stress probably depends on the interaction between water availability and other factors such as climate, soil, tree nutritional status and crop load (Naor, 2006).

2.1.5. Soil apparent electrical conductivity

2.1.5.1. Soil mapping

Currently, conventional farming involves a uniform treatment of the entire field, with no consideration of spatial variation of various factors (i.e. soil, climate, management, pests, etc.) (Corwin and Lesch, 2005). Precision agriculture methods can help to manage spatial and temporal variability within fields in order to optimize crop productivity and the use of limited natural resources, while minimizing detrimental environmental impacts (Corwin and Lesch, 2005). Precision horticulture studies have yet to be performed on crops such as citrus (Zaman and Schumann, 2006), grapefruit (Nadler, 2004) and wine grape (Bramley and Hamilton, 2004).

In particular, soil mapping has become widely accepted in precision farming because soil plays a critical role in field management. Variations in the physical, chemical and biological properties of soil are the most important factors that affect yield variability (Ping et al., 2005). Although soil-sampling is one of the most precise means of assessing spatial variability of field soil, it is costly, time consuming and labour intensive and does not provide enough information for mapping field differences (Terron et al., 2011). Thus, it is necessary to find a more rapid and cheaper method to collect data for detailed soil mapping (King et al., 2005).

An alternative to sampling on a grid is to use other soil property determination methods such as apparent electrical conductivity (ECa). ECa is one of the simplest, least expensive soil measurement available to precision farmers today and may help to interpret yield variation (Doerge, 2001).

At present, the geospatial measurement of soil electrical conductivity is known as one of most reliable techniques to create zones in order to introduce different management strategies. In this method, areas are grouped by similar electrical conductivity and may respond similarly to different management systems (Barbosa and Overstreet, 2012).

2.1.5.2. Factors affecting soil ECa

Soil apparent electrical conductivity (ECa) is the ability of soil particles to transmit an electrical current (McNeill, 1992). The determination of the ECa of soils gives information about their quality. The ECa itself may be influenced by a combination of soil chemical and physical properties such as water content, soil organic matter, depth of claypans, soil temperature, cation-exchange capacity and salinity (Corwin et al., 2003; Corwin and Lesch, 2005; Terron et al., 2011). Up to now, soil ECa information has been widely used in agriculture to measure various soil physicochemical properties.

Increasing the concentration of salts in soil water will radically increase soil ECa, thus soil ECa is the most extensively-used technique for predicting soil salinity (De Clercq and Van Meirvenne, 2005). However, ECa measurements in non-saline soils are driven primarily by soil texture and soil moisture (Lund et al., 2000). The ECa is usually mostly determined by soil texture because other soil properties, such as water content, are directly affected by soil texture as well (Domsch and Giebel, 2004; Lück et al., 2009). In general, ECa in range of 0 to 30, 5 to 80, 30 to 500 and 100 to 900 mS/m indicate sand, silt, clay and salinity soil, respectively (Barbosa and Overstreet, 2012).

2.1.5.3. Relationship between soil ECa and soil water content

Consequently, soil ECa strongly depends on soil moisture contents, as indicated in many studies. Schumann and Zaman (2003) showed that 81% of the variation in the water table depth in a citrus orchard in Florida could be explained through vertical-dipole electrical conductivity. Moreover, Reedy and Scanlon (2003) confirmed these results and showed that the ECa measurement could explain 70% - 80 % of the water content of the soil. Later, Nagy et al. (2013) found high correlations ($r^2 = 0.87$) between volumetric moisture content data and measured ECa. However, other authors (Sudduth et al., 2003) reported no significant correlation between ECa and soil moisture.

Accepting that ECa is indeed closely related to soil water content, the former parameter should also be strongly linked to crop properties. Therefore it is not surprising that soil ECa maps often visually correspond to patterns on yield maps. Hence, ECa maps can help interpret variations in vegetative growth, yield and fruit properties (Doerge, 2001; Mann et al., 2011). In this regard, Mann et al. (2011) hypothesized that the productivity of citrus groves can be mapped using attributes such as fruit yield, tree canopy volume, NDVI, elevation and soil ECa. They showed a positive correlation between yield and canopy volume, as well as NDVI and ECa.

Gebbers and Zude (2008) found a spatial clustering of the soil and delineated the apple orchard into two soil zones, namely, a dry zone (ECa < 5) and moist zone (ECa > 5), and evaluated the quality of fruit from trees grown within each of these zones using non-destructive and destructive methods during fruit development. They showed that perimeter and osmotic potential were higher in fruit from the moist zone, while SSC and the minimum NAI (Normalized Anthocyanin Index) were higher in those from the dry zone.

2.1.6. Crop load

Tree crop load is usually expressed as the number of fruit per unit branch length, or number per trunk cross sectional area (Webster and Spencer, 2000). Fruit growth is regulated by the relationship between the number of fruit and leaves on a tree competing for available assimilates (Seehuber et al., 2011).

It is necessary to study the source-sink relationships for an understanding of crop physiology and the effect of yield-limiting factors on crop production (Pavel and Dejong, 1993). In plants, the organs of assimilate production (the leaves) and assimilate consumption (roots, construction, generative organs) are referred to as ‘source’ and ‘sink’, respectively. Sinks are indicated by the import and use of assimilates for respiration, growth and storage (Wareing and Patrick, 1975). The fruit act as carbohydrate sinks, and strongly compete with both each other and other vegetative sinks in the tree such as shoots and roots (Webster and Spencer, 2000). High crop loads lead to an imbalance between fruit and leaf area (Intrigliolo and Castel, 2010) caused by an increase in carbohydrate partitioning to the fruit (Palmer, 1992).

In general, high crop loads per tree result in smaller fruit, alternate bearing, premature fruit drop, delayed fruit maturation, poor fruit quality and higher susceptibility to pests (Wünsche et al., 2005). Plum trees are particularly affected by excessive crop load. In these trees, high crop loads are associated with poor fruit quality attributes, e.g. small size and low sugar contents of fruit in the same season (Seehuber et al., 2011) or even a reduced number and quality of flowers in the subsequent season (Webster and Spencer, 2000).

For the reasons mentioned, fruit thinning is a widely-used practice in many fruit crops (e.g. apples, peaches or apricots) and aims to change the sink/source relationship in order to achieve constant yields of high-quality fruit (Rettke and Dahlenburg, 1999; Costa and Vizzotto, 2000; Wünsche et al., 2005). For instance, apples from light-cropping trees (100 fruit per tree) had significantly more advanced maturity indices such as skin colour and soluble solids content than those from high-cropping trees (400 fruit per tree). In addition, flesh firmness and dry matter content of fruit increased with a decreasing crop load (Wünsche et al., 2005).

The effect of thinning on the yield and fruit quality of 'Trevett' apricots was investigated by Rab et al. (2012). They reported that a 40 % thinning increased fruit SSC, ascorbic acid content, sugar and sugar/acid ratio, while the acidity of fruit pulp decreased in comparison to control treatment. Similarly, Roussos et al. (2011) reported that thinning in stage II (pit hardening) improved fruit mass (in 'Nafsika' and 'Niove' apricots) and increased the total phenolic concentration, but decreased fruit firmness at harvest. However, the response of stone fruit trees to thinning depends on the cultivar, as early-maturing cultivars are more sensitive to excessive crop load than late-maturing ones and require more intense thinning (Pavel and Dejong, 1993).

Interactive effects of irrigation deficit and crop load: The variation in the responses of fruit trees to water deficiency might be particularly caused by interactions between water deficit and crop load. It was hypothesized that high crop loads may enhance the sensitivity of fruit growth to water deficit stress (Berman and DeJong, 1996; Girona et al., 2004). Lowering tree crop load, in contrast, might be a helpful method to compensate for the negative effects of severe drought stress on fruit growth (Lopez et al., 2006). This is simply because the lowered plant source capacity due to limited water availability is less detrimental when the crop demand is reduced (Intrigliolo and Castel, 2010).

The effects of drought stress (in stage III) and different crop loads (light, moderate and heavy) on the fresh and dry mass of peaches were investigated by Berman and DeJong (1996). Their results showed that the assimilation rates and midday stem water potential of stressed peach trees decreased with increasing crop level. Water deficit stress reduced fruit fresh mass in all of the crop loads tested. Moreover, the dry mass of fruit grown on trees with light and moderate crop loads was not affected by drought. On the other hand, fruit harvested from trees with a heavy crop load had a significantly reduced dry mass when grown under drought stress.

Lopez et al. (2010) reported that the size of peaches was reduced and skin colouration was lower when grown without irrigation (Stage III) in comparison to cultivation with full irrigation. Fruit produced without irrigation, however, had higher dry matter concentration, fruit firmness, juice acidity and electrical conductivity than that grown with full irrigation. Lopez et al. (2010) concluded that choosing a light crop load was effective at improving fruit size in water-limited trees, but not at improving other fruit quality parameters.

Intrigliolo and Castel (2010) evaluated the effect of regulated deficit irrigation of trees during stage II of fruit development and after harvest, as well as the effect of crop load (medium and low), on tree growth, next season's fruit yield and the quality of Japanese plums. In this study, RDI increased the water-use efficiency of trees by 30 %. Fruit grown on medium crop load trees under deficit irrigation had a low fresh mass. In contrast, medium crop load trees under full irrigation provided the highest fruit yield. Moreover, fruit grown under low crop load and deficit irrigation had the highest SSC.

To the best of our knowledge, there is still a lack of information about the effects of crop load and water deficit on European plum quality at harvest and during storage.

2.1.7. Maximum daily shrinkage

2.1.7.1. Soil and plant water status indicators

Soil water measurements have been used to schedule irrigation mainly because these measurements are not affected by environmental conditions and thus, the information may be used easily (Intrigliolo and Castel, 2006a). However, these methods require adequate knowledge of plant root properties, with the limitation that uncertainties increase because wetted soil volume varies three-dimensionally, as it does under trickle irrigation (Ortuno et al., 2010).

In this respect, the use of plant-based indicators that are directly linked to climatic and soil conditions, and provide more reliable information than abiotic indicators, might be the ideal method for irrigation scheduling (Conejero et al., 2007). For these reasons, the use of plant water status indicators for irrigation management has become very popular during recent years (Goldhamer et al., 2003; Remorini and Massai, 2003).

Plant physiological features such as sap flow, leaf and stem water potential, photosynthesis and/or trunk diameter variations (TDV) might be analysed to indicate plant water status responses to variations in environmental conditions (Huguet et al., 1992; Smith and Allen, 1996; Cohen et al., 2001). The feasibility of each of these water status indicators needs to be characterized specifically during phenological stages particularly sensitive to water shortage (Intrigliolo and Castel, 2006a). Measurements of water potential taken with a pressure chamber (Scholander et al. 1965) on exposed or on bag-covered leaves (often oversimplified and referred to as 'stem water potential') are the most widely used measurements for evaluating tree water status (Shackel, 1997; Naor, 2000). However, a disadvantage of such water potential measurements is the relatively cumbersome measurement procedure, its labour intensity and the need for frequent field trips (Ortuno et al., 2006).

In recent years, the measurement of trunk diameter variations (TDV) has widely been used to estimate changes in the plant water status of trees (Cohen et al., 2001; Intrigliolo and Castel, 2007; De Swaef et al., 2014). Compared to other plant water status indicators, the main advantages of TDV measurement are the low amount of work required and the reliable response to variations in soil water availability

(Goldhamer et al., 1999; Ortuno et al., 2004). TDV are highly sensitive to variations in trunk water content in response to changes in climatic conditions (Cohen et al., 2001). Several studies reported a close correlation between TDV and other water status indicators such as stem water potential (Cohen et al., 2001; Goldhamer and Fereres, 2001). More recently, interest has focused on TDV particularly as a water shortage indicator that is easy to measure with simple linear variable displacement transducer sensors (LVDT; Li et al., 1989b; Huguet et al., 1992; Cohen et al., 1997).

2.1.7.2. Maximum daily shrinkage (MDS) as tree water indicator

Daily trunk diameter variations mainly depend on the hydration of phloem and cambium (Irvine and Grace, 1997). During the day, there is a radial flow of water from the bark into the xylem driven by the more negative water potential in leaves (Parlange et al., 1975) and hence, the trunk diameter decreases. In contrast, when the plant water uptake starts to exceed the transpirational water losses during the late afternoon, this water flow is gradually reversed back to the phloem (Intrigliolo and Castel, 2006a). This leads to an increase in trunk diameter again. The maximum daily trunk diameter (MXTD) and the minimum daily trunk diameter (MNTD) can be determined from trunk diameter measurements taken over a 24-h cycle. Daily MXTD and MNTD are reached just before sunrise and during the afternoon, respectively (Ortuno et al., 2010). The difference between MXTD and MNTD is termed maximum daily shrinkage (MDS; Ortuno et al., 2010). Several studies have shown that MDS is closely linked to those environmental factors that affect evaporative demand (Goldhamer and Fereres, 2001; Ortuno et al., 2004).

In recent years, MDS has been suggested as an appropriate plant water status indicator because it is closely related to stem water potential (Intrigliolo and Castel, 2007; Ortuno et al., 2010). Intrigliolo and Castel (2006b) evaluated different water deficit indicators under various levels of deficit irrigation in a plum orchard. The authors found that midday stem water potential, predawn leaf water potential, stomatal conductance and MDS corresponded to both the timing and the severity of water deficit applied. Cohen et al. (2001) reported a strong relationship between MDS and sap flow, indicating that both parameters were sensitive and reliable indicators of changes in plant water status in peach trees.

2.1.7.3. Relationship between MDS and crop load

The use of MDS as major water status input variable in plant-based irrigation systems may, nevertheless, be somewhat limited. TDV changes are additionally influenced by factors such as tree crop load and the phenological stage of the tree (Conejero et al., 2007; Intrigliolo and Castel, 2007). Furthermore, the finding that the relationship between the MDS of trees and their stem water potential could be affected by tree crop load was reported in several studies (Intrigliolo and Castel, 2007; De Swaef et al., 2014). For instance, crop load effects on MDS were evaluated both under full and deficit irrigation conditions on Japanese plum trees (Intrigliolo and Castel, 2007). In this study, tree MDS was positively correlated with crop load: the MDS was 34% higher in high-cropping than low-cropping trees. This finding implies that crop load must be considered when using MDS to evaluate tree water status.

Crop load can affect tree water relations in different ways. It may either restrict root growth thus reducing water uptake (Williamson and Coston, 1989) or increase transpiration rates due to the need for higher amounts of water that are transported towards the fruit (Blanco et al., 1995; Marsal et al., 2003). Moreover, crop load is assumed to influence the amount of sugars stored in woody tissues (Buwalda and Lenz, 1992) and the tissue elasticity by altering bark turgor pressure (Intrigliolo and Castel, 2004).

To the best of our knowledge, there are no studies available on the relationship between MDS and fruit quality. Therefore, the objectives of this chapter were 1) to analyse how soil ECa (as indicator of soil water availability) and crop load affect MDS in 'Jojo' and 'Tophit plus' plum trees and 2) to assess the usefulness of MDS as a tree water deficit indicator to predict changes in fruit quality before harvest, at harvest and during storage.

2.2. Harvest maturity

The maturity at harvest plays an important role in determining the eating quality and potential postharvest life of stone fruit (Taylor et al., 1993b). Both premature and late harvesting are known to reduce fruit quality (Taylor et al., 1993b; Crisosto et al., 1995). Harvesting plums at an early maturity stage may extend their storability and shelf life by preventing excessive losses in firmness; it will, however, also decrease consumption of early-harvested fruit due to their poorer quality in comparison to more mature fruit (Abdi et al., 1997; Guerra and Casquero, 2008). Un ripe fruit will also lose water more rapidly, and may be prone to physiological deterioration, especially if susceptible to internal breakdown (Crisosto et al., 1995).

On the other hand, there is a large acceptance of late-harvested fruit, being, in particular, rich in taste and flavour; although the postharvest life of these fruit is short and they cannot be stored for a long period (Crisosto et al., 1995). Therefore, it is very important for the grower to be able to precisely determine the harvest date. For this it is indispensable to comprehensively understand which maturity indices consistently reflect the quality of the harvested product (Abdi et al., 1997). In this context, a number of parameters have been used to evaluate the harvest maturity of plums.

2.2.1. Maturity index parameters

Parameters such as fruit size, skin colour, fruit firmness, soluble solids concentration and titratable acidity are used to determine the maturity of fruit at harvest (Robertson et al., 1991; Crisosto, 1994a).

Fruit size may indeed be one index to indicate the state of maturity of fruit. However, it cannot be used alone because fruit size is also strongly affected not only by the type of cultivar investigated, but also by crop load, climatic conditions, and cultural practices (Guerra and Casquero, 2009).

In stone fruits, skin colour is one of the most important criteria for ripeness (Usenik et al., 2008), and an important parameter for consumer acceptance (Daza et al., 2008). However, in some plum cultivars, skin colour develops very early, when fruit are still immature, have inadequate size and taste, and are poor in flavour. Hence in this case, skin colour may only be of limited value for the determination of harvest time (Usenik et al., 2008).

Since the skin colour in most plum cultivars changes to full red or dark violet well before the fruit reaches true maturation, fruit firmness measurement is suggested as an appropriate index for maturity (Crisosto and Kader, 2000). Fruit softening is one of the most important factors for estimating market life potential (Usenik et al., 2008), when considering the latest point that fruit can be harvested and still ensure good quality during postharvest life (Crisosto et al., 2004). However, there is still a lack of references for the usage of fruit firmness as a means to controlling the ripening, particularly for European plums (Usenik et al., 2008).

The soluble solids content (SSC) and amount of titratable acidity (TA) have been suggested as the most reliable maturation indices for the evaluation of consumer acceptance (Crisosto and Crisosto, 2005). In plums, SSC has been correlated with the perception of sweetness, flavour and aroma (Crisosto et al., 2007; Diaz-Mula et al., 2008). Generally, plums with high SSC (>12%) had a high level of consumer acceptance regardless of their level of titratable acidity. It has been claimed, however, that the use of either SSC or TA alone as a maturity index is limited by a pronounced variation among cultivars, production area and season. In contrast, the sugar-to-acid ratio (SSC:TA) has been shown to be more closely related to fruit quality than TA or SSC alone (Casquero and Guerra, 2009). In general, there is still a lack of well-defined maturity indices based on these parameters. It remains therefore, difficult to determine the optimal time for picking.

2.2.2. Physiological and chemical changes during fruit ripening

Based on their fruit ripening characteristics, most plum cultivars have been categorized as climacteric fruit. This, however, is not a uniform behaviour across cultivars. Among the various cultivars, plums may show a great variability in the changes in respiration and ethylene production rates during fruit ripening (Abdi et al., 1997). Consequently, plums can be classified into climacteric cultivars, such as 'Blackamber', 'Amber Jewel', 'Gulfruby', 'Beauty', 'Tegan', 'Santa Rosa' and

'BlackStar', and suppressed climacteric types, such as 'Angeleno', 'Shiro', 'Songold', 'Golden Japan' and 'Rubyred' (Guerra and Casquero, 2008). In climacteric plums, ripening is characterized by a pronounced increase in both ethylene production and respiration rate. In contrast, the production of ethylene in suppressed climacteric plums is not enough to induce a climacteric rise in respiration and ethylene production (Abdi et al., 1997). Plums are generally highly perishable and need special care during the postharvest period. Nevertheless, suppressed climacteric cultivars have longer shelf lives than climacteric ones because the potential postharvest life of fresh fruit is strongly dependent on respiration and ethylene production (Abdi et al., 1998; Khan and Singh, 2007; Diaz-Mula et al., 2009).

Not only during fruit ripening but also after harvest, the respiration and ethylene production of plums increase. Furthermore, the most evident changes, after the appearance of fruit colour, include the enhancement of fruit mass, the increase in soluble solids and anthocyanin content, and the decrease in concentration of total acids and fruit firmness due to cell wall degradation (Guerra and Casquero, 2008; Usenik et al., 2008).

2.3. Postharvest factors affecting fruit quality

2.3.1. Postharvest treatments

Plums are highly perishable and have a relatively short postharvest life. This is mostly because of an accelerated postharvest quality loss as indicated by changes in colour, texture, total soluble solids and total acidity (Crisosto et al., 2007). Plums can quickly pass from ideal ripeness to overmaturity, depending in part on postharvest condition (Kader and Mitchell, 1989). For this reason, several treatments that may maintain fruit quality such as cold storage (Robertson et al., 1991; Larrigaudiere et al., 2009), heat treatment (Serrano et al., 2004), pre- or postharvest application of 1-methylcyclopropene (Khan and Singh, 2007; Lee et al., 2011), or edible coatings (Eum et al., 2009; Valero et al., 2013) were studied.

High temperatures during the postharvest period lead to overripe and/or shrivelled fruit, while storage at low temperatures effectively delayed fruit ripening and extended shelf life by reducing ethylene production, respiration, colour changes, softening, SSC increase and the decrease in TA (Crisosto et al., 2007; Guerra and Casquero, 2008; Diaz-Mula et al., 2009). An acceptable quality of plums can be maintained from 1 to 6 weeks in cold storage, depending on the cultivar (Crisosto et al., 1999). Maximum market life is obtained when fruit are stored at temperatures of -1.1 to 1°C, and high relative air humidity (90–95%; Crisosto and Kader, 2000). However, as mentioned previously, plums of many cultivars are very susceptible to low temperatures and may display physiological disorders such as internal breakdown and gel breakdown. This is attributed to chilling injury, which is particularly pronounced if fruit are held at low temperatures for long time (Taylor et al., 1993b; Abdi et al., 1997; Crisosto et al., 1999; Menniti et al., 2006).

1-Methylcyclopropene (1-MCP) application is one of the most important treatments for decreasing ethylene production in climacteric fruit during storage. 1-MCP inhibits ethylene action by effectively blocking ethylene receptor sites (Blankenship and Dole, 2003). Most 1-MCP applications include mixing the product with water or a buffer solution in order to release 1-MCP gas in enclosed volume (Manganaris et al., 2008). In recent years, extensive research has been conducted to describe the effects of 1-MCP on the ripening of plums of different cultivars. Compared to control fruit, 1-MCP treatment significantly reduced ethylene and CO_2 production, and delayed ripening (Abdi et al., 1998; Dong et al., 2001; Martinez-Romero et al., 2003; Menniti et al., 2004). Moreover, 1-MCP reduced the incidence of chilling injury in climacteric plums (Candan et al., 2008). In recent years, heat treatment application also has been shown to be useful for extending storage life. In this context, heat treatment reduced the physiological changes such as increases in ethylene production and in respiration rate that had been caused by mechanical damage in 'Blackstar' plums (Serrano et al., 2004).

Other postharvest treatments to maintain quality, such as calcium treatments and ozone, have been applied with relatively good results. Hence, these techniques can be helpful under particular circumstances to complement other treatments to conserve postharvest quality (Manganaris et al., 2008).

2.3.2. Edible coatings

Much attention has been paid to the use of edible coatings for the extension of shelf life and food quality retention of whole and fresh-cut fruit (Campos et al., 2011). The application costs of coatings are lower than other postharvest technologies (DiazSobac et al., 1996).

The coatings act as barriers against the migration of water vapour, O_2 and CO_2. Thus, coatings may maintain the appearance and texture of fruit through the modification and control of the internal atmosphere of individual fruit in a fashion similar to controlled or modified atmosphere storage (Vargas et al., 2008; Turhan, 2009). In addition, insect infestation and micro-organism growth can be restricted by the addition of active agents, such as antioxidants, fungicidal or antimicrobial substances, to the coatings (Krochta and DeMulderJohnston, 1997).

Edible coatings can be defined as a layer of edible material formed around the skin of fruit, which can then be eaten together with the fruit (Bal, 2013). The skin morphology and physiology of the fruit commodity are also important to control mass transfer in coated fruit (Navarro-Tarazaga et al., 2011). In general, edible coatings are composed of hydrocolloids, such as proteins, polysaccharides and alginate, or hydrophobic compounds, such as fatty acids, acylglycerol or waxes, while composite coatings contain a blend of these compounds (Donhowe and Fennema, 1993). In a protein coating, the possible main ingredients include gelatin, casein, whey protein, corn zein, wheat gluten, soy protein, mung bean protein and peanut protein (Bourtoom, 2008). These coatings can be placed on fruit surfaces by either dipping or spraying (Bal, 2013). Suitable substances for polysaccharide coatings include cellulose, starch derivatives, pectin derivatives, chitosan and others (Krochta and DeMulderJohnston, 1997). Effective lipid coatings are acetylated monoglycerides and natural waxes. In this context, the most effective lipid substances are paraffin wax and beeswax (Bourtoom, 2008).

Several studies have reported the use of edible coatings for maintenance of fruit quality, e.g. Chitosan used in peaches (Li and Yu, 2001), strawberries (Vu et al., 2011) and plums (Bal, 2013). In other investigations, whey protein was used as a coating for plums (Reinoso et al., 2008), while alginate was applied for sweet cherries (Diaz-Mula et al., 2012), plums (Valero et al., 2013) and peaches

(Maftoonazad et al., 2008). In some cases, however, the edible coating did not produce meaningful results or even resulted in a lower fruit quality. In these cases, the coatings induced fruit disorders by inhibiting O_2 and CO_2 exchange, thus resulting in anaerobic respiration (Yehoshua, 1969).

The use of additives such as anti-browning agents, preservatives, firming agents and plasticizers may improve the properties of coatings (Perez-Gago et al., 2003). The addition of plasticizer modifies the mechanical properties of the coatings, which may improve their application properties, and change their barrier properties as well (Olivas and Barbosa-Canovas, 2005). Sorbitol and glycerol were frequently investigated as plasticizers, because of their stability and edibility (Rindlav-Westling et al., 1998).

Versasheen (National Starch & Chemical Ltd, Hamburg, Germany) is a carbohydrate-based product that adds a high-gloss sheen on food surfaces obtained from waxy maize starch consisting of high amylopectin (99 %; Eum et al., 2009). Versasheen dissolves easily in water, has low viscosity at high solids concentrations and is very simple to use because it requires very little drying time (Sablani et al., 2007; Larrigaudiere et al., 2009). It is suitable for industrial application to enhance the appearance of dry products such as baked products, bread and pastries. Only a few papers, however, have reported on the application of Versasheen coatings to fresh produce. According to Eum et al. (2009), coating 'Sapphire' plums (*Prunus salicina Lindl.)* with Versasheen and sorbitol as plasticizer extended their shelf life by delaying losses of fresh mass, titratable acidity and firmness, as well as changes in the colour parameter L* and hue angle during storage at 20°C for 8 days. However, no information is available about the use of Versasheen on European plums (*Prunus domestica L.).* Hence, the comprehensive evaluation of the application of this edible coating for the maintenance of quality in two cultivars of European plums during cold storage is the main objective of the following chapters.

2.4. Optical properties of fruits

In recent years, the application of non-destructive optical methods has increased in order to evaluate the properties and quality of horticultural products. One of the main benefits of non-destructive methods is that the measurements can be recorded for a certain time interval in an inexpensive and relatively easy way (Zude et al., 2002). These methods are excellent alternatives to destructive techniques. In this regard, near-infrared reflectance spectroscopy (NIRS) and laser light backscattering imaging (LLBI) are two novel techniques that have been developed. NIRS is a commercial technique that has been used for the detection of fruit quality parameters such as soluble solids content (SSC; Lu, 2001; Zude, 2003) or dry matter content (McGlone and Kawano, 1998). However, this technique is expensive and does not provide quantitative information regarding light scattering within the sample (Lu, 2004). On the other hand, LLBI is an inexpensive technique that uses principles of light absorption, scattering and image processing in the visible and near infrared range of the electromagnetic spectrum and provides useful information on light scattering within the sample (Qing et al., 2007a, 2008).

In general, when a light beam hits the fruit, the large part of the light penetrates into the fruit tissue and a small fraction, about 4-5%, is reflected off the surface as external diffuse reflectance (Birth, 1976). One part of the penetrated light is absorbed by the tissue components and the remaining light is scattered toward the exterior tissue (Mollazade et al., 2013). The absorbed light is mostly determined by chemical constituents, e.g. sugar, pigments, water etc. (Udomkun et al., 2014), while scattering is mainly influenced by cell size and the properties of tissue matrices (Lu, 2004). Therefore, the degree of scatter detected by an imaging system can provide useful information for predicting the mechanical and textural properties of fruit such as flesh firmness (Lu, 2004; Qin and Lu, 2009).

Recently, in various studies, lasers have been used as the light source to generate scattering images for the prediction of fruit quality in several types of fresh produce, such as the skin colour of apples (De Belie et al., 1999), moisture content of banana slices during drying (Romano et al., 2008; Romano et al., 2010), SSC in apples (Qing et al., 2007a), as well as the firmness or elasticity in apples (Qing et al., 2007a; Qin and Lu, 2009; Mollazade et al., 2013), kiwifruit (Baranyai and Zude, 2009) and plum and tomato (Mollazade et al., 2013; Mollazade et al., 2015).

In general, LLBI is a promising technique for the replacement of conventional destructive methods; however, further research to assess its suitability for the detection of internal quality properties of fruit needs to be conducted.

2.5. Research objectives

Plums are, in general, valuable for human nutrition. High levels of consumer acceptance could certainly be achieved worldwide if fruit quality and fruit shelf-life can be improved. Fruit quality is produced in the orchard and can then only be maintained during the postharvest period. Consequently, it is necessary to observe preharvest conditions such as soil, cultivar and crop load in order to reach a high quality of plums for optimal consumer satisfaction. Moreover, it has been shown that tree water status is highly correlated with the maximum daily shrinkage of fruit tree trunks (Cohen et al., 2001).Thus, this study evaluates the possible influence of variations in tree water status, as indicated by changes in maximum daily shrinkage, on fruit quality.

Harvest maturity is also important for a plum's acceptance, but it is not as simple as determining the optimal harvest date for plums due to a lack of a meaningful maturity index (Usenik et al., 2008). Furthermore, plums are perishable products and have a short postharvest life. To address this issue, the effects of an edible coating (Versasheen) on the preservation of plum quality were investigated during cold storage and room temperature storage on the shelf.

The specific objectives of the present work are:

1. To investigate the effects of soil ECa (as a soil water availability indicator) and fruit crop load on the quality of 'Jojo' and 'Tophit plus' plums during a) fruit development on the tree and b) during storage, over three growing seasons.
2. To analyse the interaction of changes in MDS in tree groups growing in two soil ECa zones and with two different crop loads, considering in particular the fruit quality of both cultivars a) during fruit development on the tree and b) during storage.
3. To determine the influence of harvest date on the quality of 'Jojo' plums, at harvest, during cold storage and during shelf-life.
4. To comprehensively evaluate the potential of the application of ‘Versasheen’ with sorbitol-based coating for the quality maintenance of 'Jojo' and 'Tophit plus' plums during cold storage and shelf-life period.

5. To use laser light backscattering imaging (LLBI) for testing the potential of additional non-destructive methods to analyse variations in the optical properties of plum tissues during fruit development on the tree and in storage.

3. Material and Methods

3.1. Experimental plot

The experiments were performed on two commercial cultivars of plums, 'Jojo' and 'Tophit plus' (*Prunus domestica L.*), grafted on the rootstock 'Wavit' (*Prunus domestica L.*) in an experimental orchard (4000 m^2area) in Marquardt close to Potsdam (52° 28' 0.48"N, 12° 57' 29.12"E; Fig. 2, 3) over three consecutive years (2011 – 2013). The growing area covers 25 m x 120 m and is located on a hill slope. In 2009, 180 trees were planted in 6 rows at a spacing of 5 m × 4 m. This included 156 trees of the cultivar 'Tophit plus' and 24 trees of 'Jojo'.

Orchard soil texture was predominantly sandy to loamy sand with considerable small-scale variation due to the glacial and post-glacial origin of the parent material.

Trees were trickle irrigated (pipe 50 cm above the ground, dipper distance 50 cm, flow rate 1.6 ± 0.1 l/h, 4 drippers for each tree) during the irrigation season (April to October). The trees were watered 3 times per week (0.8 mm/m^2 for each time), taking the weather conditions into consideration. Climatic data (air temperature and humidity, air pressure and precipitation) were recorded at an automated weather station near the orchard. The annual levels of precipitation in 2011, 2012 and 2013 were 458, 431 and 465 mm, respectively. Moreover, the daily air vapor pressure deficit (the difference between the amount of moisture in the air and how much moisture the air can hold when it is saturated) was calculated.

Fig. 2. Location of the experimental orchard in Marquardt, a top view of the Marquardt orchard including the plum growing area obtained from google map. https://www.google.de/maps/place/Marquardt,+Potsdam/@52.4677757,12.9579235,522m/data=!3m1!1e3!4m2!3m1!1s0x47a8f0e2f8852413:0xebe8805afc614c7f.

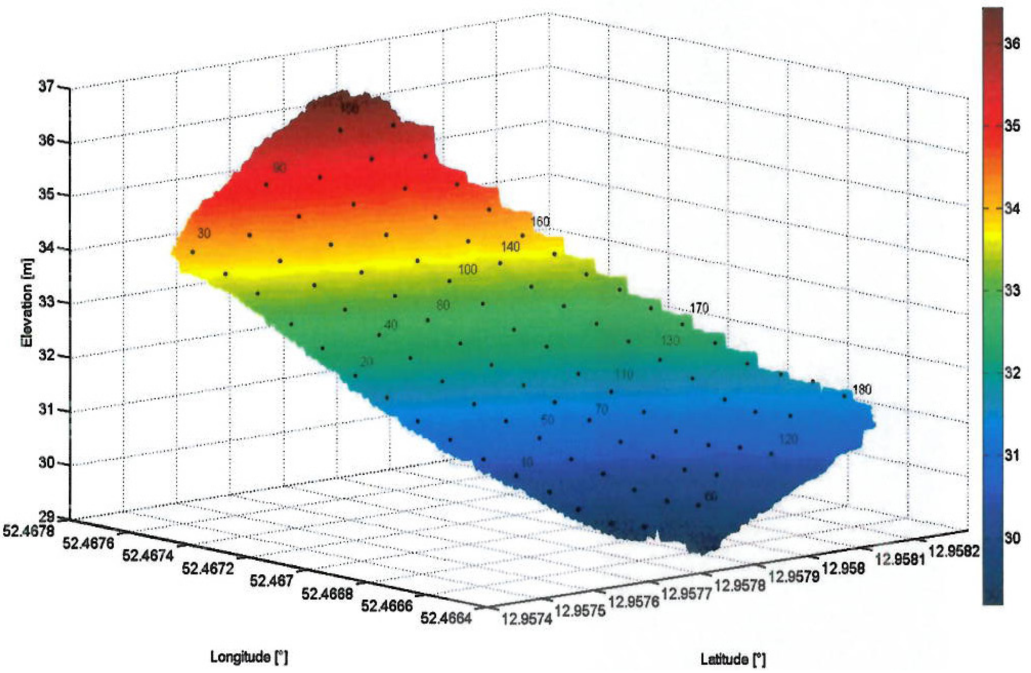


Fig. 3. Topographic map of plum growing area.in Marquardt orchard (52° 28' 0.48"N, 12° 57' 29.12"E) (Jana Käthner, 2011).

3.2. Experimental design

3.2.1. Soil ECa

There are two types of sensors commercially available for the measurement of soil ECa in the field. These include non-contact sensors based on electromagnetic induction and direct contact sensors (Sudduth et al., 2001). ECa is generally given in units of millisiemens per meter (mS/m). For this study, the variability of the soil ECa (0 - 0.25 m depth) adjacent to each tree was characterized by means of geoelectrical readings with four electrodes (4-point light, LGM, Schaufling, Germany). Soil ECa was calculated according to Telford et al. (1990), applying Ohm's law to data from the equidistant electrodes, with an (equal) electrode, spacing of 0.5 m (Mancuso, 2012). The electrodes were placed east-west of the tree with the tree stem in the centre of this Wenner array (Käthner et al., 2014). The soil ECa measurements were performed in 2011 (9th June), 2012 (16th August) and 2013 (2nd August) by Kathner and Zude-Sasse (2015).

In 2011 and 2012, soil electrical conductivity varied between 2 to 12 mS/m as sandy to loamy sandy, respectively. However, the data in 2013 varied between 1 to 6 mS/m and were lower than those in 2011 and 2012. This may be due to higher precipitation during measuring time in 2011 and 2012 (Tab. A. 5), resulting in higher soil water content in these years than in 2013. According to ECa, all 180 orchard trees were divided into two soil quality zones. The first area with low soil ECa (Tab. 2), was covered with 86 trees (marked as blue in Fig. 4). The second area with high ECa (Tab. 2), was covered with 94 trees (marked as green in Fig. 4). As can be seen in the topographic map of the orchard (Fig. 3), these two zones are distributed along the slope of the growing area.

6 and 8 trees from 'Jojo' and 'Tophit plus', respectively, from the low ECa (LECa) zone and 6 and 7 trees from the high ECa (HECa) zone were selected for investigation in 2011 (Fig. 4). In 2012, 6 trees from eachzone were chosen (Fig. 4). Finally, in the third year (2013), 3 'Jojo' and 4 'Tophit plus' trees from the low ECa (LECa) zone and 3 trees of each cultivar from the high ECa (HECa) zone were selected (Fig. 4).

For the fruit of each group, various quality parameters were determined to evaluate the effect of soil ECa on fruit quality during the preharvest period, at harvest and during the postharvest period in all three years.

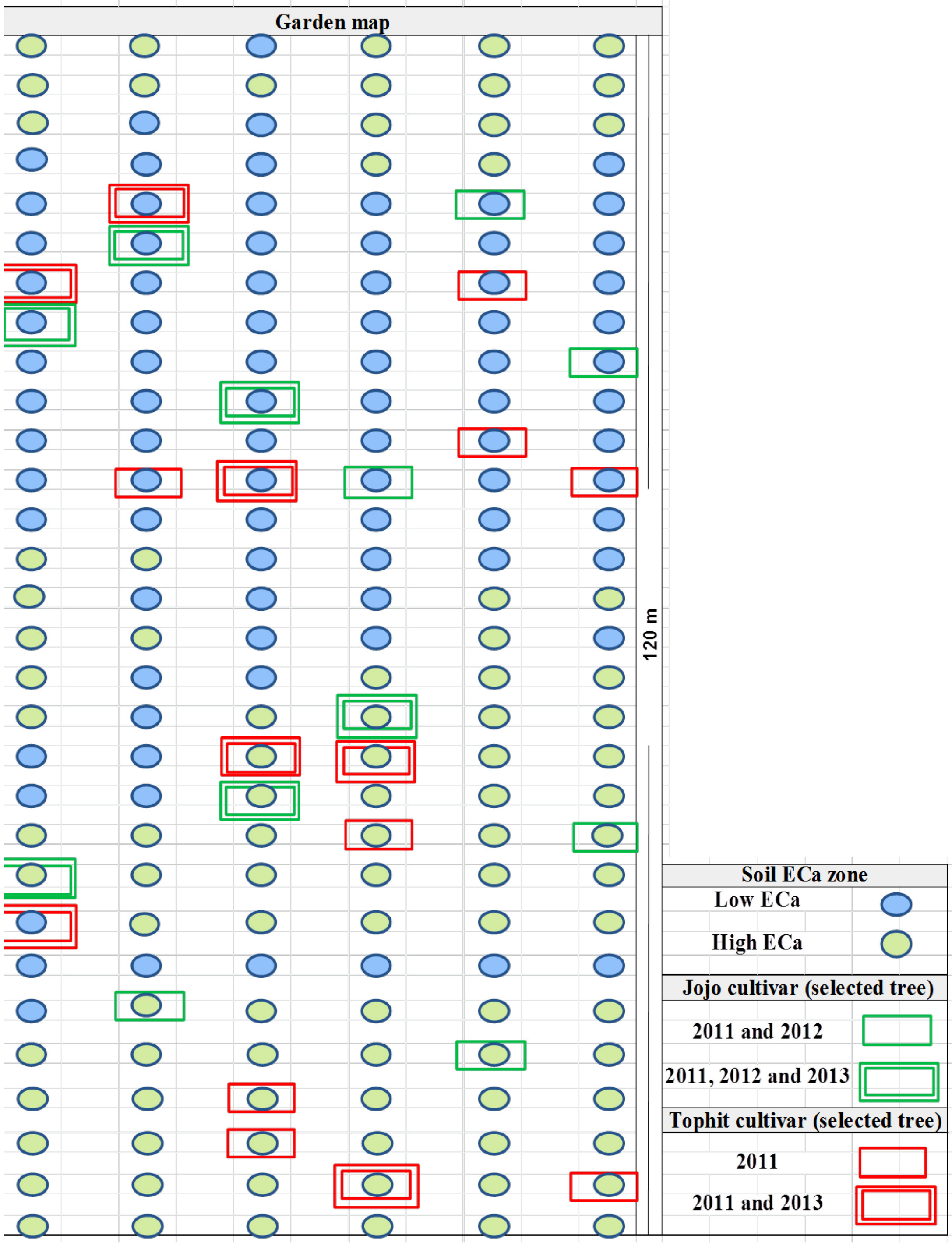


Fig. 4. Classification of plum trees according to relative apparent soil electrical conductivity (ECa) over three years (2011 to 2013). Rectangle boxes around the tree number indicate the years of measurement.

3.2.2. Crop load

Tree crop load was expressed as number of fruit per cm^2 of trunk cross-sectional area (TCSA; Intrigliolo and Castel, 2006b). To determine the TCSA of all trees of each cultivar, their trunk circumference was determined in spring of each year. Similarly, the number of all fruit, i.e. total crop load per tree was recorded at final harvest. Finally, the selected trees were classified according to their crop load into low crop load (LCL) and high crop load (HCL) trees independently for each year (Tab. 2). Then, fruit quality parameters of all samples of each group were analysed to evaluate the effect of crop load on fruit quality during the preharvest period, at harvest and during the postharvest period in all three years.

For the evaluation of both soil ECa and crop load effects, the same trees as in 3.2.1 were used.

Tab. 2. Classification of plum orchard trees according to their soil ECa (mS/m) crop load (fruit per cm^2 of TCSA) in 2011, 2012 and 2013.

Year	Soil ECa (mS/m)				Crop load (fruit per cm^2 of TCSA)			
	Low		High		Low		High	
	Jojo	Tophit plus	Jojo	Tophit plus	Jojo	Tophit plus	Jojo	Tophit plus
2011	1.0 to 6.0	1.0 to 6.0	6.1 to 12.0	6.1 to 12.0	1.0 to 4.0	0.5 to 1.7	4.1 to 12.0	1.8 to 3.0
2012	1.0 to 6.0	-	6.1 to 12.0	-	5.0 to 10.0	-	10.1 to 15.0	-
2013	1.0 to 3.4	1.0 to 3.4	3.5 to 6.0	3.5 to 6.0	15.0 to 20	1.5 to 3.5	25.0 to 30.0	3.06 to 5.0

3.2.3. Maximum daily shrinkage

In 2013, on the same trees used for the evaluation of soil ECa and crop load effects, the micrometric trunk diameter variation (TDV) was measured continuously using a dendrometer with a set of linear variable displacement transducers (LVDT) of Ecomatic type DD-L (UP GmbH, Ibbenbüren, Germany; accuracy ± 10 µm) (Fig.5). Trunk diameter was measured in all the trees assessed for fruit quality from the end of May to end of harvest.

Fig. 5. Installation of dendrometer sensor to measure maximum daily shrinkage (MDS) together with dynagage sensor for sap flow measurement (covered by aluminum foil; left figure).

The calibrated sensors were attached to the trunk by an Invar (metal alloy with a minimal thermal expansion) frame, located approx. 70 cm above ground (Fig. 5). Measurements were taken every minute with a data logger (CR10X with AM416 multiplexer, Campbell Scientific, Logan, USA), which automatically recorded the mean every 15 min.

From the TDV readings, three different indices were deduced (Goldhamer and Fereres, 2001):

1. Maximum daily trunk diameter (MXTD) was reached between midnight and early morning when tree transpiration was close to zero (Fig. 6).
2. Minimum daily trunk diameter (MNTD) was obtained when transpiration was at its maximum at about 2 o'clock in the afternoon (Fig. 6).
3. Maximum daily trunk shrinkage (MDS = MXTD – MNTD) was calculated from the difference between MXTD and MNTD (Fig. 6).

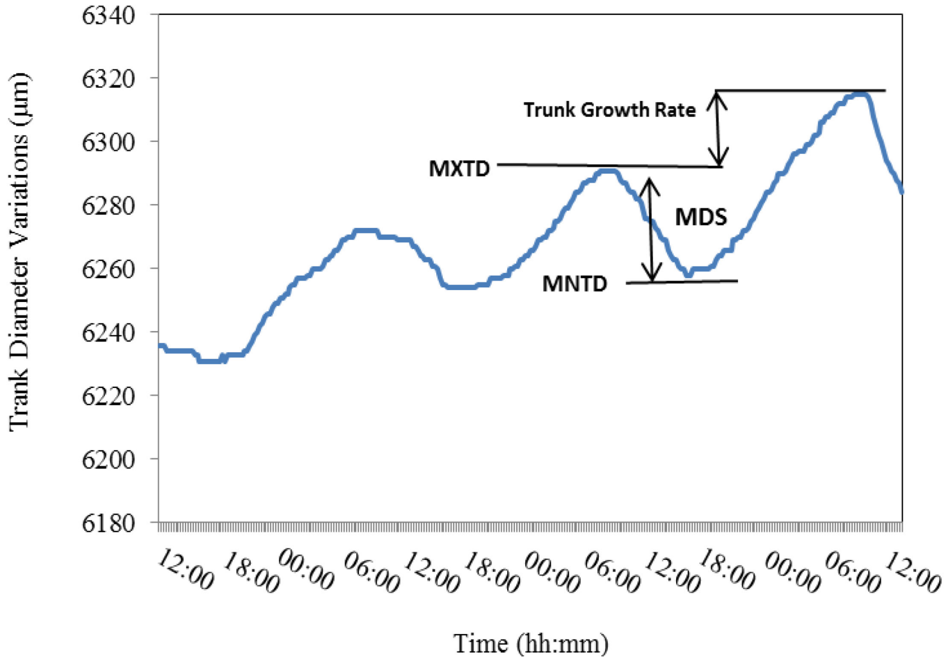


Fig. 6. Trunk diameters during three days. Shown are also parameters extracted, such as maximum daily shrinkage (MDS) expressed as daily differences in maximum daily trunk diameter (MXTD) and minimum daily trunk diameter (MNTD).

Finally, according to their MDS, the selected trees of each cultivar were classified as low MDS (LMDS; below 170 µm on average) and high MDS (HMDS; above 170 µm on average), as shown in Fig. 7. Then, the effects of MDS on various fruit quality parameters of samples of each group were evaluated during the preharvest period, at harvest and during the postharvest period.

.

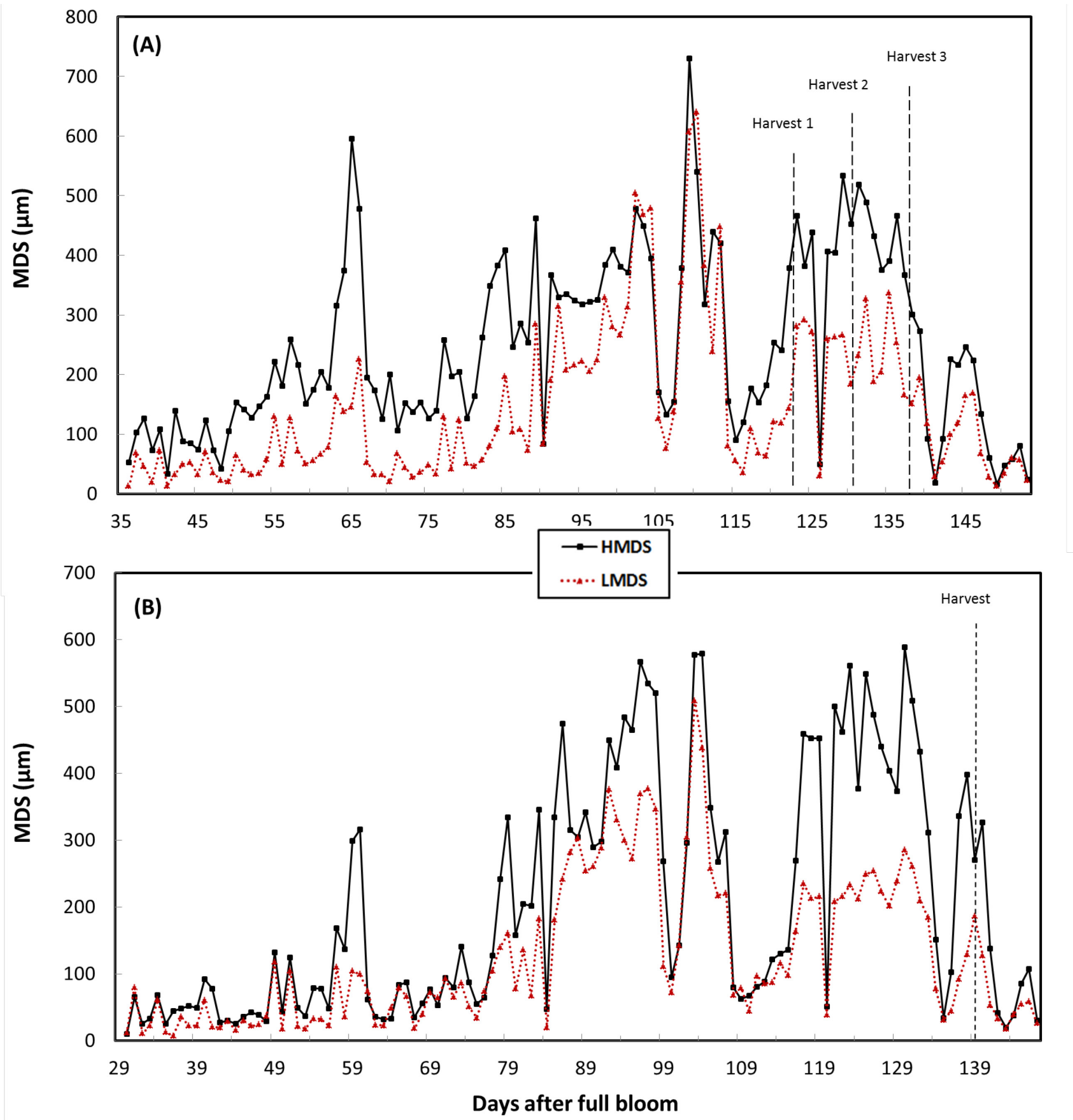


Fig. 7. Seasonal variations of maximum daily shrinkage (MDS) in low (LMDS) and high (HMDS) of 'Jojo' (A) and 'Tophit plus' (B) fruit. Each value is the mean of three and four measurements in 'Jojo' and 'Tophit plus' fruit, respectively.

3.2.4. Fruit samples and storage condition

During preharvest: For the evaluation of the effects of preharvest factors on 'Jojo' and 'Tophit plus' plums' quality, the fruit of the selected trees were sampled randomly (manually picked) at three dates before commercial harvest (Tab. 3). After sampling, fruit were immediately transferred to the laboratory and subjected to various investigations (see below).

At harvest and storage time: Fruit free of visual defects were harvested manually, selected, and subjected to initial analyses of various physicochemical properties and then stored in plastic boxes (3-5 kg) at 2 ± 0.5 °C and 90 ± 2% RH for up to 28 d plus 2 d at 20 °C. During storage, fruit in each treatment group were removed after 7, 14, 21, 28 and 30 days of storage and analysed.

- The number of selected trees, fruit samples and sampling dates, during the preharvest period and at harvest, are shown in Tab. 3.

Tab. 3. The number of selected trees, fruit samples and sampling dates (DAFB = days after full bloom) of 'Jojo' and 'Tophit plus' plums, during preharvest and at harvest in 2011, 2012 and 2013.

Year	Cultivar	No. of selected trees	During preharvest (fruit development on the tree)		At harvest	
			Sampling date (DAFB)	Total No. of fruit	Harvest date (DAFB)	Total No. of fruit
2011	Jojo	n = 12	116, 124,131 and 137	n = 88	137	n = 250
	Tophit plus	n = 15	110, 125,132 and 139	n = 120	139	n = 260
2012	Jojo	n = 12	105, 112,127 and 140	n = 150	140	n = 350
2013	Jojo	n = 6	93, 105,117 and 137	n = 225	137	n = 252
	Tophit plus	n = 7	99, 112,121 and 140	n = 189	140	n = 252

- The measurements were performed in triplicates.

3.2.5. Different harvest dates

To analyse the effects of harvest date on fruit quality at harvest and during storage, 'Jojo' plums were harvested at three different days after full bloom (DAFB) in 2013. Samples were treated further as stated above. Number of fruit and dates of harvest are shown in Tab. 4.

Tab. 4. Number of harvested fruit and date of harvests (days after full bloom = DAFB) for 'Jojo' plums in 2013.

Year	1st harvest date		2nd harvest date		3rd harvest date (as commercial harvest)	
	Date (DAFB)	No. of fruit	Date (DAFB)	No. of fruit	Date (DAFB)	No. of fruit
2013	127	n = 252	130	n = 252	137	n = 252

- The measurements were performed in triplicates and for each harvest date and each sampling time during storage, 42 fruit were used.

3.2.6. Edible coating treatment

In 2013, the effects of edible coatings (Versasheen plus sorbitol as plasticizer) on changes in fruit quality during storage (conditions as stated above) were analysed on 'Jojo' and 'Tophit plus' plums from all treatment groups. Fruit free of visual defects were selected and half of the batches of plums (n = 252 for each cultivar) were dipped in a solution of 5% Versasheen plus 0.2% sorbitol as a plasticizer for 60 s. Afterwards, treated fruit were laid separately on metal nets to dry at 20 °C for 3 h. The other half of the batch was dipped in distilled water as a control.

- The measurements were performed in triplicate and 42 fruit were used for each treatment and each sampling time during storage.

3.2.7. Fruit quality analysis

Fresh mass and fruit yield

To analyse the effects of preharvest factors on fresh mass during the preharvest period (3 times) and at harvest, fruit was individually weighed and results averaged for each tree (CPA2202S-OCE, Sartorius AG, Göttingen, Germany).

Fruit 'Jojo' and 'Tophit plus' were harvested between mid-August and the beginning of September. Total yield (expressed as kg/tree) at harvest was obtained by adding together the masses of all fruit of each tree.

Moreover, the average fresh mass and yield per tree for all trees in each group of main factors (soil ECa, Crop load, MDS and harvest date) were calculated.

Dry matter content

To determine the dry matter content (DMC, %), samples were weighed (FM, given in g) and then dried in an oven at 105°C for 24 h. The dry mass (DM, given in g) was recorded after cooling to room temperature. Dry matter content was determined as:

$$DMC\ (\%) = \frac{DM}{FM} \times 100$$

Equation 1

Fruit flesh firmness

Flesh firmness was determined by a standard destructive Magness Taylor test with a TA.XTplus Texture Analyser (Stable Micro Systems Ltd., Godalming, U.K.). For measurements, approx. 1 cm^2 of the fruit skin of samples was removed and a cylindrical probe (diameter: 6 mm) was inserted into the fruit tissue. The penetration rate was 200 mm/min after the point of contact with the flesh. The maximum force was recorded as a measure of fruit firmness, which was expressed as the deformation force (N).

Soluble solids content and titratable acidity

For the analysis of both the soluble solids content (SSC) and titratable acidity (TA) of each fruit sample (during the preharvest period, at harvest and during storage time) tissue sap was squeezed out from fresh fruit materials with a garlic press. In the resulting juice, SSC was determined with a calibrated digital refractometer (PR-1, Atago Co., LTD, Tokyo, Japan) at room temperature (20 °C). SSC values were expressed as °Brix. The titratable acidity was measured by diluting 1 mL of fresh juice with 25 mL distilled water and titrating with a standard solution of 0.1 M NaOH to a pH of 8.2 using a T50M Titrator with Rondo 20 sample changer (Mettler-

Toledo GmbH, Gießen, Germany). The NaOH solution was normalized before titration measurements every week. Titratable acidity is always given in grams of malic acid (acid factor = 0.67) per 100 ml of tissue sap using the following formula.

$$Malic\ \ Acid\ \ (g/100\,ml) = \frac{Titer\ \times\ acid\ \ factor\ \ \times\ 100}{10\ (ml\ \ Juice)}$$

Equation 2

Fruit transpiration

In horticultural science, the transpiration rate usually denotes the amount of water (e.g. g) per time unit (e.g. s) that is lost from horticultural produce into the atmosphere. The transpiration rates (E) of produce directly depend on the difference between the water potential of the air in their intercellular space and that of the atmosphere (Von Willert et al., 1995; Yehoshua and Rodov, 2003). In a good approximation, E is inversely related to the resistance for water vapour transfer (referred to as "total resistance") of the produce's outer tissue (Von Willert et al., 1995).

During storage, the fruit of both 'Jojo' and 'Tophit plus' were withdrawn from storage 2 h before the transpiration measurement at regular intervals of 7 days. All samples were laid separately on metal nets for up to 1 h (Δt) to allow water vapour losses in a condition of unrestricted free convection. The climate conditions during the transpiration measurements are shown in Tab. A.6.

At the beginning (FM_1) and the end of the measurement (FM_2), fruit fresh mass was recorded with an analytical balance (WPS 2100/C/2, Radwag, Radom, Poland). With relation to the fruit surface area* (cm^2), the rates of transpiration (E, mg/cm^2h) were calculated according to Linke (1997) as

$$E = \frac{(FM_1 - FM_2) \times 1000}{A \cdot \Delta t}$$

Equation 3

* The surface of the fruit sample was obtained with an automatic 3D-scanner (3D Scanbook, Scanbull GmbH, Hameln, Germany).

Skin colour

The changes in fruit skin colour of each plum were determined using a portable colourimeter (CM-2600d, Konica Minolta, Inc., Tokyo, Japan). Assessments of fruit colour as well as their changes during the preharvest and storage periods were based on the parameters of the CIE (International Commission on Illumination) colour space, L* (lightness coordinate), a* (green to red) and b* (blue to yellow) as indicated by (HunterLab., 1996). The colourimeter was calibrated with white and black tiles before a measurement series. Measurements were performed on opposite sides of each fruit and their means were used for the analysis.

Evaluation of normalized anthocyanin index (NAI)

During the preharvest and postharvest periods, the normalized anthocyanin index (NAI) was estimated from non-destructive spectral remission measurements taken with a portable spectrometer (Fig. 8; Pigment analyser PA1101, Control in applied Physiology (CP) GbR, Falkensee, Germany). The measuring head of the instrument contains seven LEDs (4 white LEDs, 2 red LEDs, 1 reference LED) arranged circularly around the receiving fibre. The pigment analyser measures remission spectra in the wavelength range of 450 nm to 1100 nm. During measurements, the radiation from the LED light sources enters the fruit matter and interacts with the tissue. Some photons are diffusely scattered from the fruit and then reach the receiving fibre placed in the centre of the measuring cup (Solornakhin and Blanke, 2007; Rutkowski et al., 2008). Finally, the remittances at the respective wavelengths of 570 nm (I_{570} = maximum of anthocyanin absorption) and 780 nm (I_{780} = no anthocyanin absorption) were obtained from the raw spectral data and used to calculate the NAI according to Solornakhin and Blanke (2007) and Rutkowski et al. (2008). In this study, spectral data were recorded on opposite sides of each fruit and their mean was used for the analysis.

$$NAI = \frac{(I780 - I570)}{(I780 + I570)} \qquad \text{Equation 4}$$

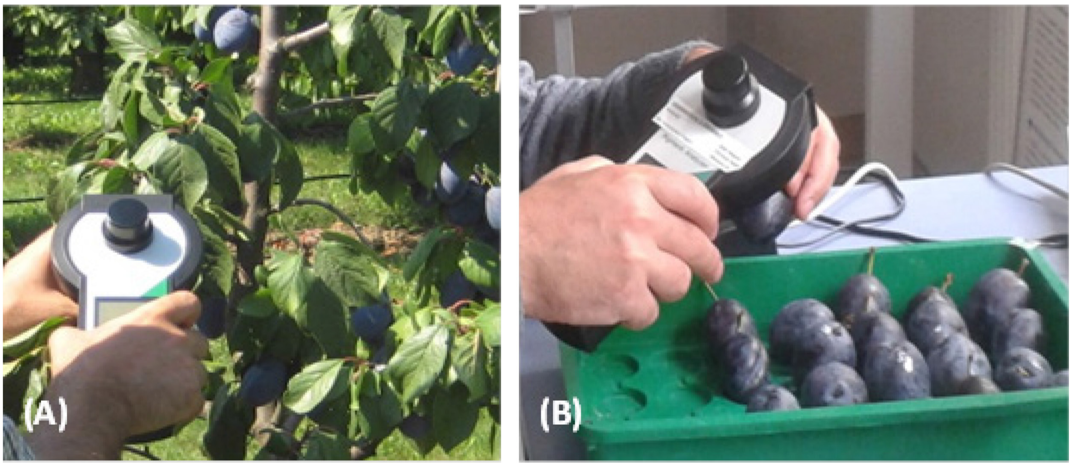
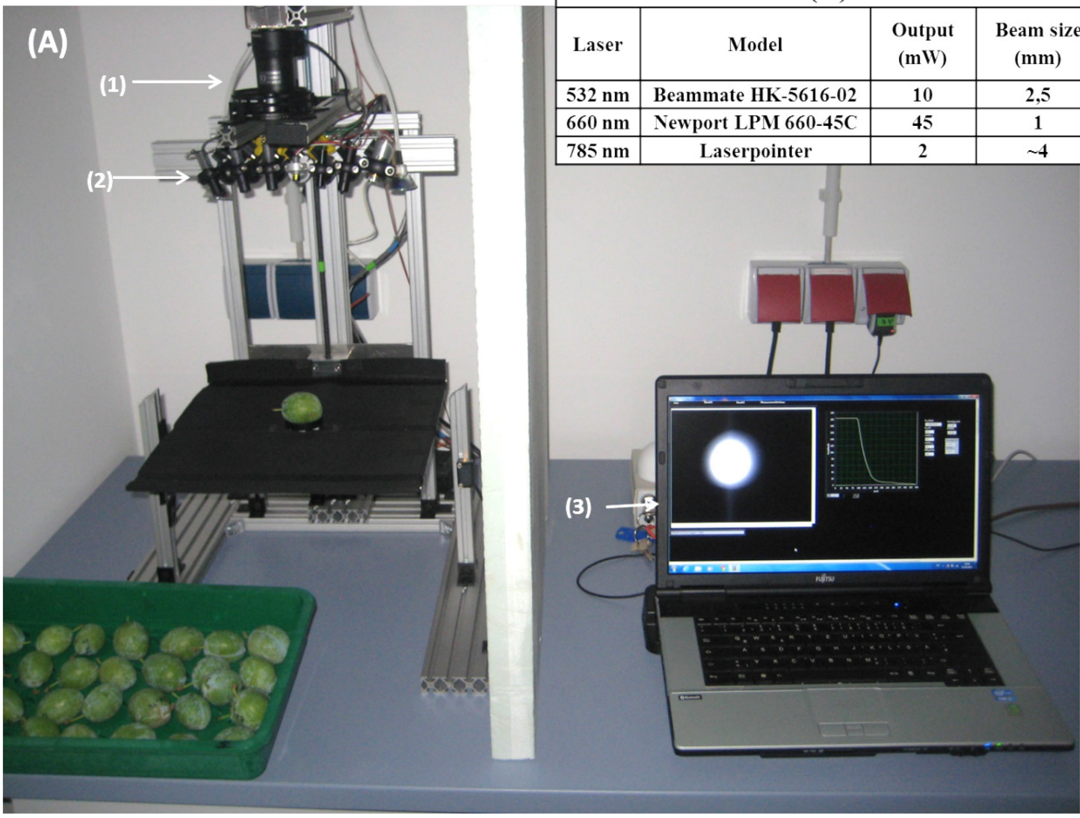


Fig. 8. Measurement of remission spectra of fruit samples (A) on tree and (B) during postharvest in the lab.

3.2.8. Laser light backscattering imaging

Laser light backscattering imaging (LLBI) is a non-destructive optical method that can be used to predict fruit quality. In generally, the LLBI system used (Fig. 9), consists of a monochrome charge-coupled device (CCD) camera (Model CV-A50IR, JAI A/S, Glostrup, Danmark) with a 1/2" TAMRON zoom lens (Varioobjektiv 10-40 mm, TAMRON Europe GmbH, Köln, Germany) and three lasers of 532 nm, 660 nm and 785 nm wavelengths as excitation light sources. The light scattering in fruit tissue for wavelengths of 532 and 660 nm is mainly related to the absorption of light by the anthocyanin and chlorophyll respectively. However, scattering for 785 nm is related to the textural properties of the fruit.

The Backscattering Analyser software (v.1.3) was used (Fig. 9) for the operation of the system and the evaluation of the obtained images (Baranyai and Zude, 2009; Hashim et al., 2014).



(B)			
Laser	**Model**	**Output (mW)**	**Beam size (mm)**
532 nm	Beammate HK-5616-02	10	2,5
660 nm	Newport LPM 660-45C	45	1
785 nm	Laserpointer	2	~4

Fig. 9. (A) The LLBI system measuring unripe plums, (1) CCD camera with lens; (2) laser sources; and on the other side of the security wall (3) Backscattering Analyser software.

The CCD camera was placed above and perpendicular to the samples (approx. 30 cm). The lasers were fixed in such a position that the incident angle of the laser beam could be adjusted between 5 to 15° as shown in Fig. 9. The light beam hits the fruit and illuminates a part of the fruit as a result of photon migration within the tissues. Then the backscattering image generated at the surface of the fruit is recorded by CCD camera (Fig. 9). The obtained images were saved in the computer for further analysis in BMP format (720 × 576 pixel at 8 bit colour depth per pixel).

The experiments were conducted in a dark room to remove the effect of noise in the backscattering images. Two images from two opposite sides of each fruit were taken and the results were averaged. Three replications were performed for each treatment during the preharvest period (in 3 times), at harvest and during storage time (every 7 days).

Fig. 10. Laser induced backscattering images of a plum sample at (A) 785 nm, (B) 660 nm and (C) 532 nm wavelength.

The backscattering images obtained are characterized by a pronounced variation in brightness in the backscattered light, with maximum light intensity in the centre (Fig. 2). The Gaussian–Lorentzian cross product (GL) function was used to fit the changes in intensity. GL is often used in spectroscopy; as well as in the description of laser profiles (Limandri et al., 2008). The GL function used here is explained in detail by Lorente et al. (2015). Average values of intensity were calculated in radial averaging relative to the incident point. The highest intensity of light scattering appears at the centre of the image and the intensity of photons decreases radially outwards with the increase in distance from the image centre, thus providing a backscattering profile (Fig. 11. B). In the backscattering profiles, full width at half maximum (FWHM) is an interesting landmark. The FWHM was computed based on radial average relative to the incident point (Fig. 11. B). The FWHM was obtained in pixels and the value was converted to relative value (%), which at the 1st measurement time was equal to 0 %. The changes in FWHM during measuring times in each year were compared in relative values (%).

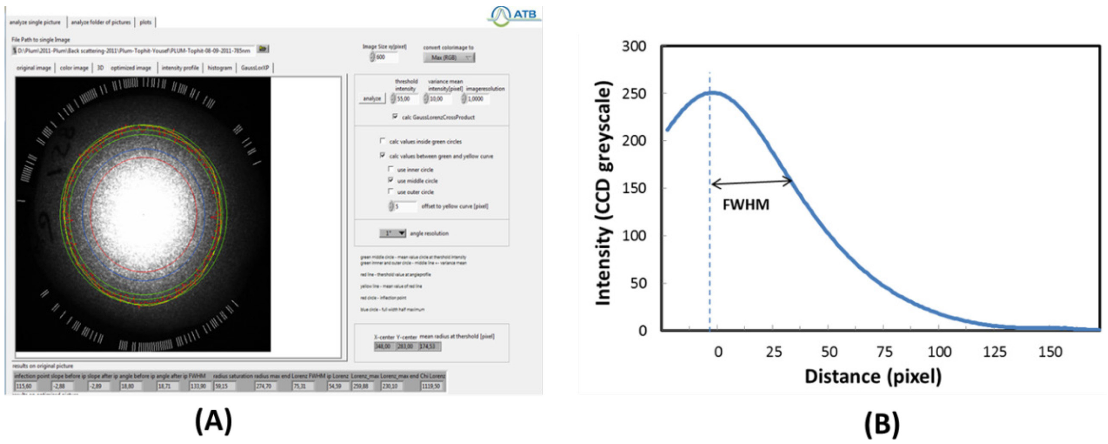


Fig. 11. Image analysis by Backscattering Analyser software, and (B) a backscattering profile fitted by Gaussian–Lorentzian cross product distribution.

All analyses of fruit samples in this study were performed at the Leibniz Institute for Agricultural Engineering (ATB).

3.3. Statistical analysis

Analyses of variances (ANOVA) were performed using SAS software (SAS Institute Inc. Version 9.3., Cary, USA). The main effects of preharvest factors (Crop load, Soil ECa and MDS) on the quality of 'Jojo' and 'Tophit plus' plums for each year and different measurement periods (i.e. before harvest, at harvest and during storage) were individually analysed as a factorial ANOVA, using the 'GLIMMIX' procedure (PROC GLIMMIXED). A linear model was developed and tested to find the significance of the different preharvest factors' influence on fruit quality (significance level of $\alpha = 0.05$).

The main effects of harvest time and duration of storage on fruit quality were analysed individually for 2013 as a factorial ANOVA. In addition, the main effects of cultivars, edible coating and storage time on changes in fruit quality during storage in 2013 were analysed as a factorial ANOVA.

Differences between mean values were tested by least significant difference (LSD) for all significant factors with the SIMULATE option in the LSMEANS statement in SAS procedure GLIMMIX (permutation test) for means at a global $\alpha = 0.05$ (after adjustment for multiple testing). Means with different letters show significance through the LSD test. *, ** and ns indicate significance at $p < 0.05$, 0.01 or not significant, respectively. Bars represent the 95% confidence interval of the means.

Pearson's correlation (r) and coefficient of determination (r^2) analyses were performed with SPSS (Version 16.0., Release 2007, SPSS Inc., Chicago, USA).

4. Results

4.1. Effects of soil ECa and crop load on fruit quality of plums

Fruit fresh mass and yield

During the preharvest period, fresh mass increased notably in plums of both cultivars in all years (data not shown). Soil ECa only affected fresh mass in 'Jojo' plums (2013) (Tab. 5). Here, the fresh mass of the fruit from high soil ECa (HECa) grown trees was larger than in those from low soil ECa (LECa). Crop load significantly affected fresh mass in both 'Jojo' and 'Tophit plus' fruit. Here, the fresh mass was 6% ('Jojo' 2011), 6% (2012), 12% (2013), and 8% ('Tophit plus' 2013) higher in fruit from low crop load (LCL) trees than in those from high crop load (HCL) trees.

At harvest, the fresh mass of 'Tophit plus' plums was 46% and 41% higher than that of 'Jojo' fruit in 2011 and 2013 (Tab. 5). Soil ECa only affected the fresh mass of 'Jojo' and 'Tophit plus' fruit in 2013, as the fresh mass in fruit of LECa was 5% and 6% lower than in HECa plums (Tab. 5). The effect of crop load on the fresh mass in 'Jojo' (2011, 2012 and 2013) and 'Tophit plus' (2013) plums was consistent (Tab. 5). Here, the fresh mass of fruit grown on LCL trees was 7%, 11%, 11% and 7% higher than the mass of those harvested from HCL trees. At this time, the interaction between soil ECa and crop load only had a significant effect on fresh mass in 'Jojo' plums (2012; Tab. 5).

Tree yield increased remarkably from the first (2011) to the last year of experiments (2013) in both cultivars, due to an increasing crop load over the years (Tab. 5). Crop load affected tree yield, as LCL trees had a lower yield than HCL ones over all three years (Tab. 5). In contrast, soil ECa did not have any effect on tree yield. Tree yield in response to crop load was similar in the two different soil ECas (Tab. 5).

Tab. 5. Statistical analysis of the effects of soil ECa and crop load on fresh mass and yield of 'Jojo' and 'Tophit plus' plums during preharvest and at harvest in 2011, 2012 and 2013.

Quality parameters	Cultivar	Year	Treatment				Factor					
			LECa		HECa		ECa	CL	T	ECa × CL	CL × T	ECa × T
			LCL	HCL	LCL	HCL						
During preharvest												
Fresh mass (g)	**Jojo**	**2011**	51.7	50.2	51.2	48.9	NS	*	**	NS	NS	NS
		2012	44.2	41.8	44.7	41.9	NS	*	**	NS	NS	NS
		2013	30.0	26.2	33.1	28.3	**	**	**	NS	NS	**
	Tophit plus	**2011**	73.8	72.5	76.4	74.6	NS	NS	**	NS	NS	NS
		2013	45.1	42.7	45.9	43.6	NS	*	**	NS	NS	NS
At harvest												
Fresh mass (g)	**Jojo**	**2011**	56.2	53.6	56.6	54.7	NS	*	-	NS	-	-
		2012	52.1 b	48.6 c	56.7 a	48.3 c	NS	**	-	**	-	-
		2013	39.2	35.9	41.1	37.0	*	**	-	NS	-	-
	Tophit plus	**2011**	80.5	79.1	80.7	77.3	NS	NS	-	NS	-	-
		2013	56.2	54.5	61.0	55.2	*	**	-	NS	-	-
Yield (kg/tree)	**Jojo**	**2011**	2.7	4.9	1.4	5.4	NS	**	-	NS	-	-
		2012	11.4	11.9	9.7	12.0	NS	**	-	NS	-	-
		2013	18.1	33.1	20.5	30.5	NS	**	-	NS	-	-
	Tophit plus	**2011**	0.9	1.7	1.2	2.1	NS	**	-	NS	-	-
		2013	3.5	6.6	4.3	4.9	NS	*	-	NS	-	-

Values are means of each treatment. Statistical significant (LSD test, $p<0.05$) differences between means are indicated by different letter. Significance of effects of treatments (ECa, soil ECa; LECa, low soil ECa; HECa, high soil ECa; CL, crop load; LCL, low crop load; HCL, high crop load; T, time of measurements) and their interactions on the various parameter are also indicated (*: $p<0.05$; **: $p<0.01$; ns: not significant).

Soluble solids content

Over the preharvest period, the soluble solids content (SSC) of plums increased remarkably, irrespective of cultivar and year of investigation (Fig. 12; Tab. 6). With the exception of 'Tophit plus' fruit in 2011, SSC did not significantly increase during cold storage and shelf life, again irrespective of cultivar and year of investigation (Fig. 12; Tab. 6). In total, SSC was higher in 'Tophit plus' than in 'Jojo' plums, in 2011 (7%) and 2013 (10%; Tab. 6).

Soil ECa only significantly affected SSC in 'Jojo' plums during the preharvest period in 2012 and over the entire experimental period in 2013 (Tab. 6). In 'Jojo' plums (2013), SSC in LECa fruit was approx. 6% higher than in HECa plums before, at and after harvest (Tab. 6). Crop load also significantly affected SSC in both 'Jojo' and 'Tophit plus' plums before, at and after harvest in 2012 and 2013 (Tab. 6). Fruit grown on LCL trees had a higher SSC than those from HCL trees. The interactive effect between soil ECa and crop load on SSC was significant for 'Tophit plus' over the entire experimental period of 2013 and for 'Jojo' before harvest in 2012 (Tab. 6).

Tab. 6. Statistical analysis of the effects of soil ECa and crop load on SSC of 'Jojo' and 'Tophit plus' plums during preharvest, at harvest and during 28 days at 2°C plus 2 days at 20°C in 2011, 2012 and 2013.

Cultivar	Year	Treatment				Factor					
		LECa		HECa		ECa	CL	T	ECa × CL	CL × T	ECa × T
		LCL	HCL	LCL	HCL						
During preharvest											
Jojo	**2011**	16.6	16.0	16.3	15.2	NS	NS	**	NS	NS	NS
	2012	15.1 a	12.1 b	13 b	12.6 b	*	**	**	**	*	NS
	2013	14.1	12.7	13.4	12.1	**	**	**	NS	NS	NS
Tophit plus	**2011**	16.0	16.3	16.7	15.2	NS	NS	**	NS	NS	NS
	2013	15.6 a	12.7 c	14.8 b	14.3 b	NS	**	**	**	NS	NS
At harvest											
Jojo	**2011**	19.4	18.1	18.2	17.7	NS	NS	-	NS	-	-
	2012	18.5	15.9	17.6	16.0	NS	**	-	NS	-	-
	2013	18.1	17.4	18.0	15.7	*	*	-	NS	-	-
Tophit plus	**2011**	19.5	18.9	20.3	19.2	NS	NS	-	NS	-	-
	2013	20.5 a	18.0 b	18.8 b	19.0 ab	NS	*	-	**	-	-
During storage											
Jojo	**2011**	19.2	18.2	18.5	18.2	NS	NS	NS	NS	NS	NS
	2012	18.8	16.5	18.0	16.8	NS	**	NS	NS	NS	NS
	2013	18.5	17.6	17.8	16.6	**	**	NS	NS	NS	NS
Tophit plus	**2011**	19.9	19.8	20.5	19.3	NS	NS	*	NS	NS	NS
	2013	20.3 a	17.2 c	19.0 b	18.6 b	NS	**	NS	**	NS	NS

Values are means of each treatment. Statistical significant (LSD test, $p<0.05$) differences between means are indicated by different letter. Significance of effects of treatments (ECa, soil ECa; LECa, low soil ECa; HECa, high soil ECa; CL, crop load; LCL, low crop load; HCL, high crop load; T, time of measurements) and their interactions on the various parameter are also indicated (*: $p<0.05$; **: $p<0.01$; ns: not significant).

In 2013, SSC continuously increased during the preharvest period in the fruit of both cultivars (Fig. 12). During the entire experiment, the SSC of 'Jojo' plums was higher in fruit from low crop load trees than in those grown with a high crop load, independent of soil ECa (Fig. 12. A). However, the effect of crop load on SSC did depend on soil ECa in 'Tophit plus' plums (Fig. 12. B). Under LECa conditions, the SSC of fruit from LCL trees was significantly higher than that grown under HCL conditions; whereas under HECa, LCL fruit contained a similar SSC to HCL fruit (Fig. 12. B). Overall, fruit obtained from low crop load trees under LECa had the highest SSC during the preharvest period, at harvest and during most of the postharvest period in both cultivars (Fig. 12. A, B).

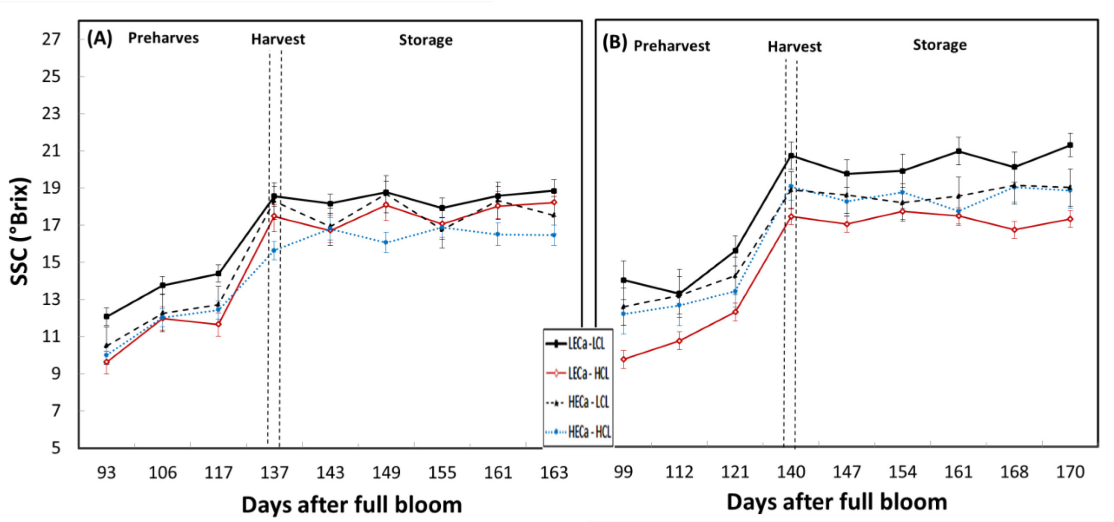


Fig. 12. Effects of soil ECa and crop load on SSC of (A) Jojo and (B) Tophit plus plums during preharvest, at harvest and during 28 days at 2°C plus 2 days at 20°C in 2013. Vertical bars represent 95% confidence interval of the means. LCL, low crop load; HCL, high crop load; LECa, low soil ECa; HECa, high soil ECa.

Dry matter content

During preharvest, the dry matter content (DMC) of all plums increased remarkably irrespective of cultivar and year of investigation (Fig. 13; Tab. 6). Soil ECa significantly affected DMC only in 'Jojo' (2013) plums (Tab. 6). Here, DMC was 9% higher in plums from LECa soil than in those from HECa. Crop load significantly affected DMC in both 'Jojo' and 'Tophit plus' plums (2013; Tab. 6). In these cultivars, DMC was 10% and 6% higher in fruit from LCL trees than in those from HCL trees. During the preharvest period, interactive effects of soil ECa and tree crop load on DMC were significant in both 'Jojo' (2012) and 'Tophit plus' (2013) fruit (Tab. 6).

In 2011 and 2013, DMC at harvest was higher in 'Tophit plus' than in 'Jojo' fruit with 20% and 16%, respectively (Tab. 6). At harvest, soil ECa only affected DMC in

'Jojo' plums (2013; Tab. 6), where the DMC in fruit grown on HECa soil (16.7%) was lower than that in plums grown on LECa soil (17.5%). Moreover, fruit from LCL trees of both 'Jojo' (2012 and 2013) and 'Tophit plus' (2013) had a higher DMC than those from HCL trees (Tab. 6).

During cold storage and shelf life, DMC in the fruit of both cultivars did not increase significantly (Tab. 6). In 'Jojo' (2013), DMC in fruit grown on LECa soils was significantly higher than in those grown on HECa soils (Tab. 6). Moreover, fruit grown on LCL trees had a higher DMC than those grown under HCL conditions in both 'Jojo' (2012 and 2013) and 'Tophit plus' (2011 and 2013) plums (Tab. 6). The effect of the interaction between soil ECa and crop load on DMC was only significant in 'Jojo' plums in 2011 and in 'Tophit plus' in 2013 (Tab. 6).

Tab. 7. Statistical analysis of the effects of soil ECa and crop load on dry matter content of 'Jojo' and 'Tophit plus' plums during preharvest, at harvest and during 28 days at 2°C plus 2 days at 20°C in 2011, 2012 and 2013.

Cultivar	Year	Treatment				Factor					
		LECa		HECa		ECa	CL	T	ECa × CL	CL × T	ECa × T
		LCL	HCL	LCL	HCL						
During preharvest											
Jojo	**2011**	20.8	20.6	20.0	19.3	NS	NS	**	NS	NS	NS
	2012	16.1 a	14.6 b	14.1 b	15.1 ab	NS	NS	**	**	NS	NS
	2013	15.5	13.8	14.1	12.9	**	**	**	NS	**	NS
Tophit plus	**2011**	20.0	19.9	19.7	18.2	NS	NS	**	NS	NS	NS
	2013	17.7 a	15.8 b	17.2 a	17.1 a	NS	**	**	**	NS	NS
At harvest											
Jojo	**2011**	22.0	21.5	21.3	21.1	NS	NS	-	NS	-	-
	2012	19.3	17.5	18.7	17.6	NS	*	-	NS	-	-
	2013	18.4	16.6	17.6	15.9	*	**	-	NS	-	-
Tophit plus	**2011**	27.3	25.8	27.1	25.2	NS	NS	-	NS	-	-
	2013	21.5 a	19 b	20.4 a	20.4 a	NS	**	-	**	-	-
During storage											
Jojo	**2011**	22.3 a	20.8 b	20.9 b	21.8 ab	NS	NS	NS	**	NS	NS
	2012	19.5	18.2	18.8	18.0	NS	**	NS	NS	NS	NS
	2013	19.0	17.3	18.1	16.5	**	**	NS	NS	NS	NS
Tophit plus	**2011**	26.6	25.6	26.4	24.7	NS	*	NS	NS	NS	NS
	2013	21.7 a	19.8 c	20.7 b	20.6 b	NS	**	NS	*	NS	NS

Values are means of each treatment. Statistical significant (LSD test, $p<0.05$) differences between means are indicated by different letter. Significance of effects of treatments (ECa, soil ECa; LECa, low soil ECa; HECa, high soil ECa; CL, crop load; LCL, low crop load; HCL, high crop load; T, time of measurements) and their interactions on the various parameter are also indicated (*: $p<0.05$; **: $p<0.01$; ns: not significant).

During the entire experiment, 'Jojo' plums grown on LCL trees had higher DMC than HCL-grown ones, independent of soil ECa (Fig. 13 A). In 'Tophit plus' plums, however, the effect of crop load on DMC depended on soil ECa (Fig. 12. B). Under LECa conditions, DMC was significantly higher in fruit from LCL trees than in those from HCL trees; whereas under HECa conditions, fruit from LCL trees showed a similar DMC to fruit from HCL trees (Fig. 13. B). In both cultivars, fruit obtained from low crop load trees grown on LECa soils had the highest DMC in nearly all cases (Fig. 13. A,B).

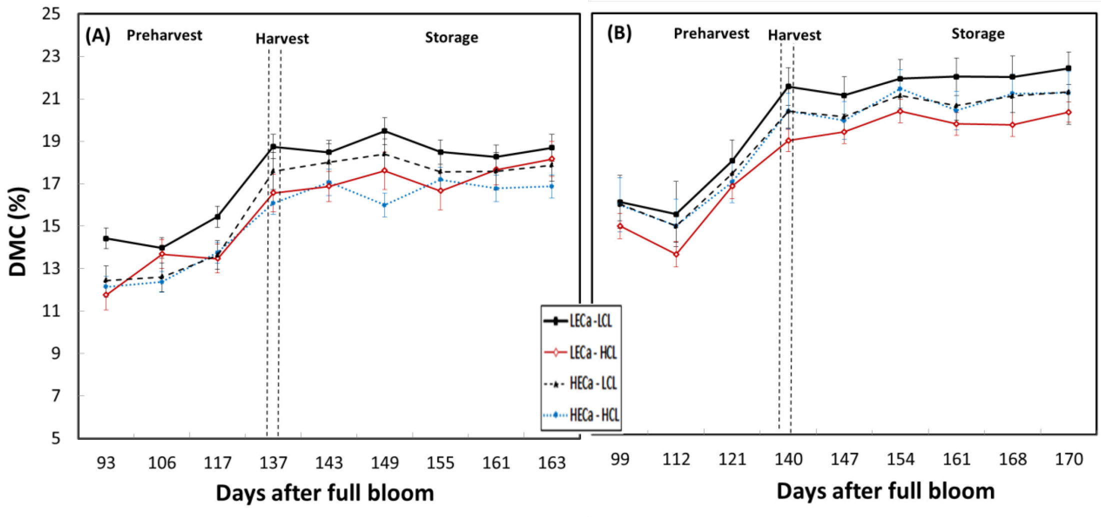


Fig. 13. Effects of soil ECa and crop load on DMC of (A) Jojo and (B) Tophit plus plums during preharvest, at harvest and during 28 days at 2°C plus 2 days at 20°C in 2013. Vertical bars represent 95% confidence interval of the means. LCL, low crop load; HCL, high crop load; LECa, low soil ECa; HECa, high soil ECa.

Titratable acidity

TA declined in plums of both cultivars during the preharvest period, irrespective of the year of investigation (Fig. 14). However, the decline of TA in 'Jojo' plums in 2012 (from 3.5 to 1 g/100ml) was sharper than that in 2011 and 2013 (Fig. 14). During the preharvest period in all years, no significant effect of soil ECa and crop load was found in plums of both cultivars in all years (Tab. A. 1).

At harvest, the average TA in 2011 and 2013 was substantially higher in plums of 'Jojo' than in those of 'Tophit plus' by 36% and 23%, respectively (Fig. 14). At this time, soil ECa affected TA only in 'Jojo' plums (2012; Tab. A. 1). Here, the TA in fruit of LECa was higher than those of HECa. Crop load significantly affected TA in both 'Jojo' and 'Tophit plus' plums only in 2011 (Tab. A. 1). In this year, TA was higher in fruit of LCL than those of HCL at percentages of 17% and 19% for 'Jojo' and 'Tophit plus', respectively.

During cold storage and shelf life, TA declined in plums of both cultivars, irrespective of treatment and year of investigation (Fig. 14). TA value varied between the years in the 'Jojo' cultivar: for instance, the average TA in the fruit from 2012 was 30% lower than those from 2013 (Fig. 14. A). However, in 'Tophit plus' plums, TA was not significantly affected by year (Fig. 14. B). In this case, crop load only significantly affected TA in the fruit of 'Tophit plus' trees in 2011 (Tab. A. 1). Here, TA was higher in LCL than in HCL fruit.

Except in 'Tophit plus' plums in 2011, no significant effect of the interaction between crop load and soil ECa on TA was found over the entire experimental period in fruit of both cultivars (Tab. A. 1).

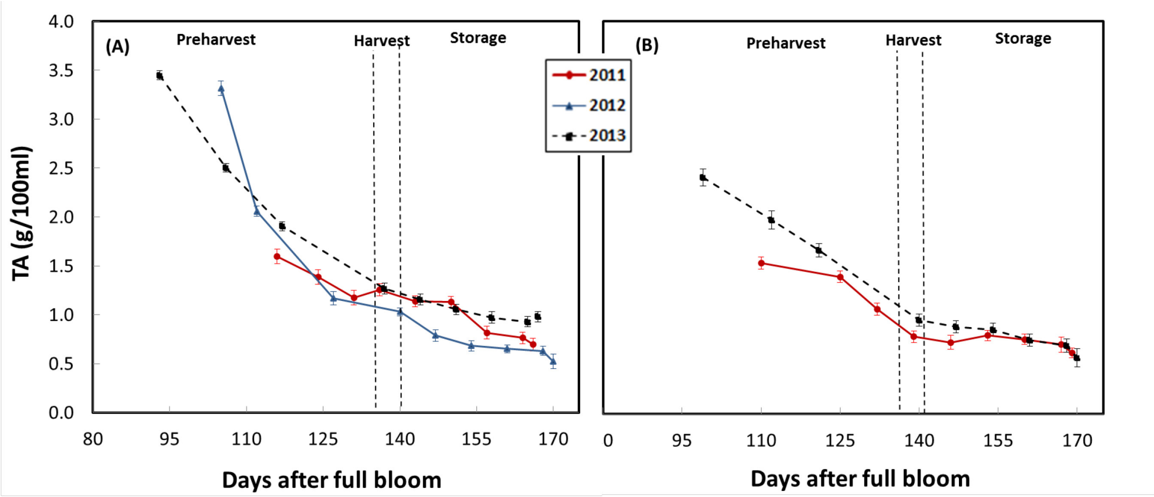


Fig. 14. Changes in titratable acidity (TA) of (A) 'Jojo' and (B) 'Tophit plus' plums during preharvest, at harvest and during 28 days at 2°C plus 2 days at 20°C in 2011, 2012 and 2013. Vertical bars represent 95% confidence interval of the means.

Fruit flesh firmness

During the preharvest period, fruit firmness of both cultivars declined in all years (Fig. 15). However, flesh firmness was slightly affected by year in 'Jojo' plums, because the reduction of firmness in fruit grown in 2012 was sharper than those grown in 2011 and 2013 (Fig. 15. A). During this period, no significant effect of soil ECa on flesh firmness was found in fruit of both cultivars in all years (Tab. A. 1). Crop load, however, significantly affected the flesh firmness in 'Jojo' plums in 2012 (Tab. A. 1). In this year, LCL fruit were less firm than HCL fruit. In general, the average flesh firmness at harvest was substantially less in 'Jojo' (4.5 N) than in 'Tophit plus' plums (7.1 N) in 2013 (Fig. 15; Tab. A. 1).

During storage, the fruit firmness considerably declined in fruit of both cultivars (Fig. 15). At harvest and during storage, soil ECa affected flesh firmness only in 'Tophit plus' plums (2013; Tab. A. 1). In this case, flesh firmness in HECa fruit was higher than that in LECa fruit. Additionally, crop load only significantly affected the flesh firmness of 'Jojo' plums in 2012 (Tab. A. 1). Here, LCL plums were less firm than HCL plums. In these times, interactions between soil ECa and crop load were only significant in the two groups of 'Jojo' (2011) and 'Tophit plus' (2013) plums. 'Jojo' plums were almost completely soft (< 2 N) after 14 (154 DAFB), 21 (161 DAFB), and 28 days of storage (165 DAFB) in 2012, 2011 and 2013, respectively (Fig. 15. A).

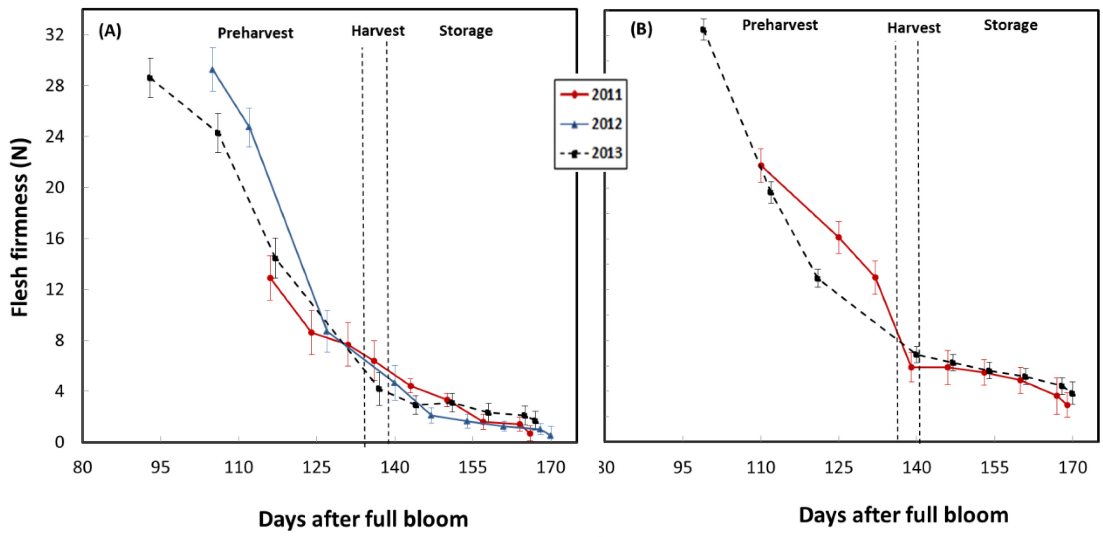


Fig. 15. Changes in flesh firmness of (A) 'Jojo' and (B) 'Tophit plus' plums during preharvest, at harvest and during 28 days at 2°C plus 2 days at 20°C in 2011, 2012 and 2013. Vertical bars represent 95% confidence interval of the means.

Skin colour

Beginning with a negative value, the CIE a* of plums of both cultivars rapidly increased to positive a* during the early phase of the experiment. They then slightly decreased again towards the end of the preharvest period and during the postharvest period (Fig. 16). In 2011, however, the 1st sampling was at a late date when fruit had already lost their green colour and appeared violet. Hence, no increase in a* was found in the fruit of both cultivars. Maximum of a* (i.e. maximum de-greening) was reached with 6.8 (116 DAFB), 7.6 (112 DAFB) and 8.2 (117 DAFB) in 2011, 2012 and 2013 in 'Jojo' plums (Fig. 16. A) and 4.0 (110 DAFB) and 5.2 (125 DAFB) in 'Tophit plus' plums in 2011 and 2013, respectively (Fig. 16. B).

During the preharvest period, soil ECa did not considerably influence a*. The crop load of trees, in contrast, significantly affected a*, but only in 'Jojo' plums in 2011 (Tab. A. 2). Here, the a* of fruit grown on LCL trees was lower than of those grown on HCL trees.

At harvest, a* in 'Jojo' plums in 2011, 2012 and 2013 was 2.7, 3.9 and 2.5, respectively (Fig. 16. A). In contrast, in 'Tophit plus' plums, a* was generally lower than in 'Jojo' fruit in 2011 (0.2) and 2013 (0.3) (Fig. 16. B). At harvest, tree crop load and soil ECa did not have any considerable effect on a* in the fruit of both cultivars in all years (Tab. A. 2).

During cold storage and shelf life, the a* of fruit of both cultivars did not significantly change (Fig. 16; Tab. A. 2). In 'Jojo' plums (2012), however, a* tended to be lower at the end of shelf life (Fig. 16. A). Only in 2012 soil ECa and tree crop load did affect a* in stored 'Jojo' fruit (Tab. A. 2). Here, a* of fruit from LCL trees grown on LECa soils was lower than those from HCL trees grown on HECa soils. No significant interactive effect of crop load and soil ECa on a* was found before harvest, at harvest and during the postharvest period (Tab. A. 2).

During the preharvest period in all years, b* of both 'Jojo' and 'Tophit plus' plums initially decreased notably (from positive to negative value) and then remained constant (Fig. 16). The minimum values of b* in all years were reached some days before harvest, irrespective of cultivar or year of investigation (Fig. 16). However, the b* values were more negative in the fruit of 'Tophit plus' than in 'Jojo' plums both at harvest and during storage. The b* value measured on the 1st sampling date of 2011 was lower than that obtained in 2012 and 2013 because the 1st picking was carried out later in 2011 than in 2012 and 2013 (Fig. 16).

During the preharvest period, soil ECa significantly affected b* only in 'Jojo' plums (2012) (Tab. A. 2). Here, b* was lower in fruit grown under LECa conditions than in those under HECa conditions. In all years, the crop load of trees significantly affected b* in plums of both cultivars, except in 'Tophit plus' fruit in 2011 (Tab. A.

2). Here, the b* of fruit grown on LCL trees was lower than that of HCL-grown plums.

At harvest, 'Jojo' plums showed the same value of b* in all years (Fig. 16). In contrast, 'Tophit plus' plums had higher value of b* in 2011 than in 2013 (Fig. 16). There was no effect of soil ECa on the b* value of freshly-harvested fruit (Tab. A. 2). Moreover, the effects of the crop load of trees on b* value was only significant in 'Jojo' plums (2011). Here, the b* value of fruit from LCL trees was lower (-2.5) than that of HCL-grown plums (-0.8).

Throughout cold storage and shelf life, b* value did not change significantly. In addition, soil ECa and crop load did not have any considerable effect on b* value in fruit of both cultivars (Tab. A. 2). In general, b* was more negative in 'Tophit plus' plums than in 'Jojo' fruit at harvest and during storage (Fig. 16).

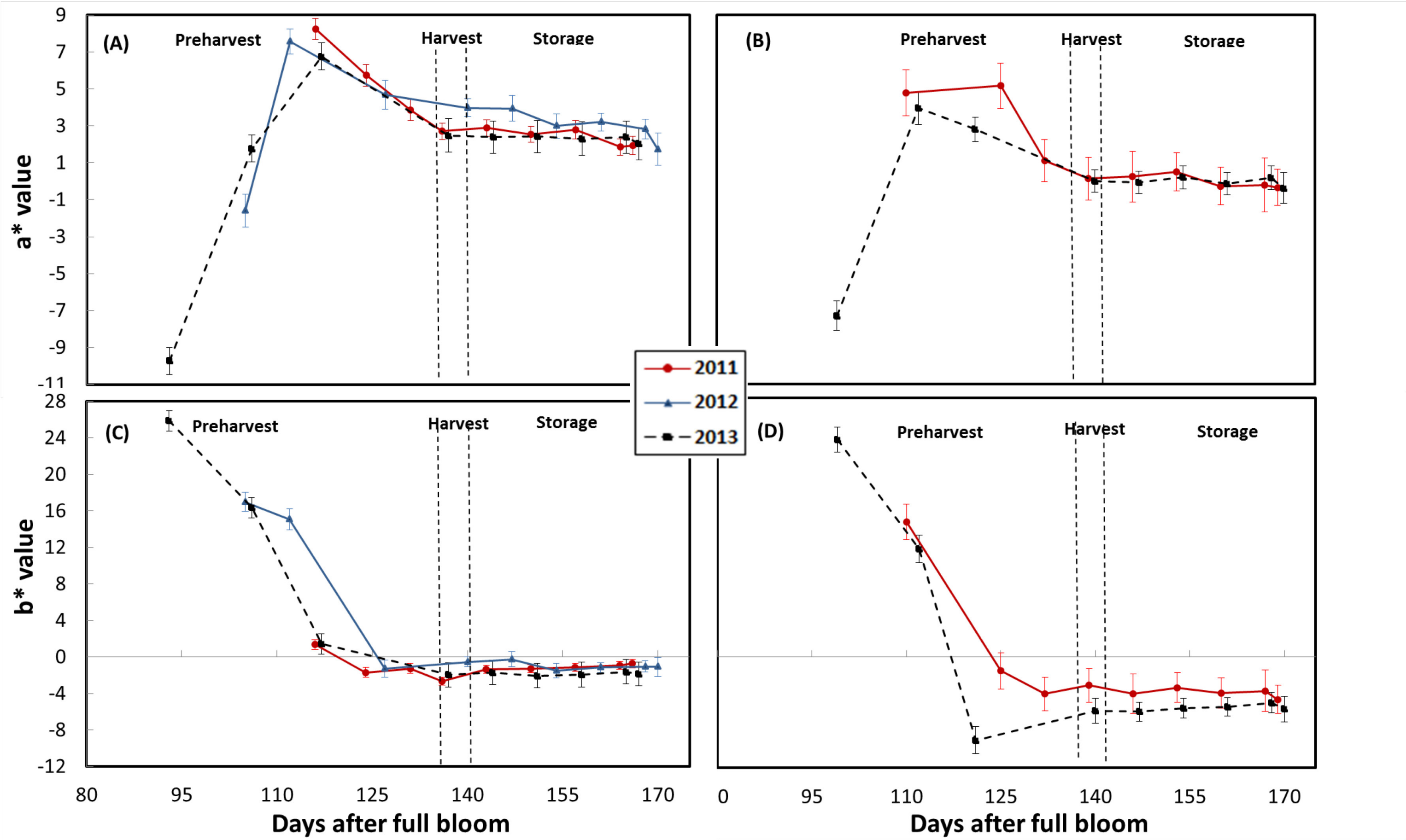


Fig. 16. Changes in a* value of fruit skin in (A) 'Jojo' and (B) 'Tophit plus' cultivars, and b* value in (C) 'Jojo' and (D) 'Tophit plus' plums during preharvest, at harvest and during 28 days at 2°C plus 2 days at 20°C in 2011,2012 and 2013. Vertical bars represent 95% confidence interval of the means.

Normalized anthocyanin index

During the preharvest period, NAI increased remarkably in fruit of both cultivars. On the 1st sampling date of 2011, NAI was higher than that measured in 2012 and 2013 (data not shown). This was, again, due to the fact that, in 2012 and 2013, the 1st picking was performed earlier than in 2011. During fruit development, soil ECa affected the NAI of 'Jojo' plums in 2012 and 2013. In fruit grown on LECa soils, NAI was higher than in those grown on HECa (Tab. 8). Crop load also significantly affected NAI in 'Jojo' fruit in 2012 and 2013 and in 'Tophit plus' plums in 2013 (Tab. 8). Here, the NAI in fruit from LCL trees was higher than that in fruit from HCL trees. An interactive effect of crop load and soil ECa on NAI was only found in 'Jojo' plums in 2013 (Tab.8). The maximum NAI (88 to 90) was reached before harvest, and remained almost constant during cold storage and simulated shelf life in the fruit of both cultivars (Fig. 17).

Tab. 8. Statistical analysis of the effects of soil ECa and crop load on NAI of 'Jojo' and 'Tophit plus' plums during preharvest in 2011, 2012 and 2013.

Cultivar	Year	Treatment				Factor					
		LECa		HECa		ECa	CL	T	ECa × CL	CL × T	ECa × T
		LCL	HCL	LCL	HCL						
Jojo	2011	0.89	0.86	0.87	0.86	NS	NS	**	NS	NS	NS
	2012	0.82	0.77	0.76	0.73	**	*	**	NS	NS	NS
	2013	0.77 a	0.67 b	0.66 b	0.68 b	**	*	**	*	NS	**
Tophit	2011	0.72	0.66	0.76	0.70	NS	NS	**	NS	NS	NS
	2013	0.58	0.44	0.56	0.44	NS	**	**	NS	NS	NS

Values are means of each treatment. Statistical significant (LSD test, $p<0.05$) differences between means are indicated by different letter. Significance of effects of treatments (ECa, soil ECa; LECa, low soil ECa; HECa, high soil ECa; CL, crop load; LCL, low crop load; HCL, high crop load; T, time of measurements) and their interactions on the various parameter are also indicated (*: $p<0.05$; **: $p< 0.01$; ns: not significant).

In all treatments, the NAI of fruit increased during development (Fig. 17). It remained constant in 'Jojo' plums after 117 DAFB, except in fruit grown on HCL trees in HECa soils (Fig. 17. A). Moreover, NAI did not change in LCL-grown

'Tophit plus' fruit after 121 DAFB (Fig. 17. B). In 'Jojo' plums, effect of crop load on NAI depended on soil ECa (Fig. 17. A). NAI was higher in fruit from LCL trees than those from HCL when these grew on LECa soils. Whereas, fruit in LCL presented a similar NAI to that in HCL plums under HECa during the preharvest period. In 'Tophit plus', NAI was higher in fruit grown with low crop load than those grown with high crop load, independent of soil ECa (Fig. 17. B).

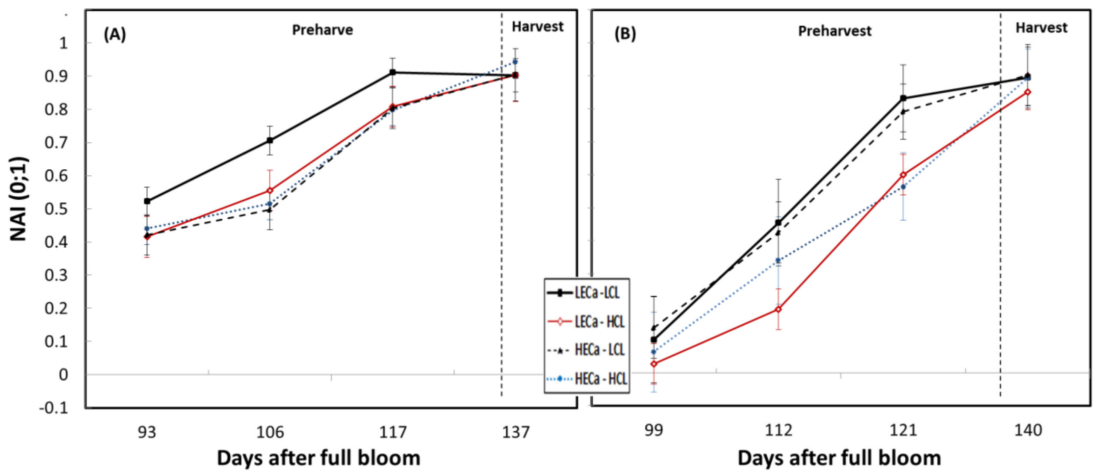


Fig. 17. Effects of soil ECa and crop load on normalized anthocyanin index (NAI) of (A) 'Jojo' and (B) 'Tophit plus' plums during preharvest and at harvest in 2013. Vertical bars represent 95% confidence interval of the means. LCL, low crop load; HCL, high crop load; LECa, low soil ECa; HECa, high soil ECa.

Transpiration rate

In fruit of both cultivars, transpiration continued to decline slightly during storage (Fig. 18). Stored 'Tophit plus' fruit had substantially higher transpiration than 'Jojo' plums in both 2011 and 2013 (Fig. 18). The transpiration of 'Jojo' plums was not largely affected by year during the entire storage duration (Fig. 18. A), while 'Tophit plus' plums grown in 2011 had a lower range of transpiration than those grown in 2013 (Fig.18. B). With the exception of 'Jojo' plums (2012), the lowest transpiration was found at the end of shelf life (Fig. 18). Soil ECa only affected transpiration in 'Jojo' plums in 2013 (Tab. A. 1). Here, the transpiration in fruit grown under HECa conditions was 8% higher than in those from trees planted on LECa soils. Crop load affected transpiration only in 'Tophit plus' plums in 2013 (Tab. A. 1). Here, plums from LCL trees had a higher transpiration rate (6%) than those from HCL trees. No significant interactive effect of crop load and soil ECa on transpiration was found (Tab A. 1).

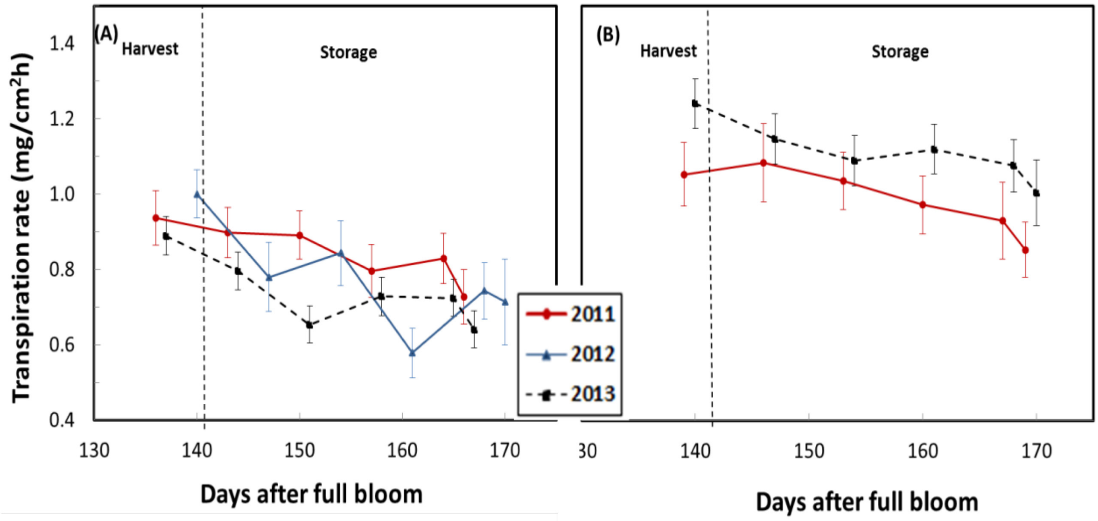


Fig. 18. Fruit transpiration of (A) 'Jojo' and (B) 'Tophit plus' plums during 28 days at 2°C plus 2 days at 20°C in 2011, 2012 and 2013. Vertical bars represent 95% confidence interval of the means. The climate condition during transpiration measurements are shown in Tab. A.6.

4.2. Effect of maximum daily trunk shrinkage on plum tree and fruit quality

4.2.1. Climate condition, tree crop load and soil ECa on MDS of plum trees

During the experiments in 2013, the total amount of precipitation was 465 mm. Rainfall mainly occurred in late May (40 - 48 DAFB of 'Jojo) and early August (110 - 118 DAFB; Fig. 19). Mean daily air temperature increased from the beginning of the experiment in mid-May, and reached its maximum in mid-June (65 DAFB of Jojo; 28°C) and late July (104 DAFB of 'Jojo; 28°C). Mean daily vapour pressure deficit (VPD) followed the seasonal variation in air temperatures, ranging between 0.5 and 16 kPa/MPa, with maximum values occurring between early June and late August (50 - 135 DAFB of 'Jojo; Fig. 19). In addition, solar radiation presented a similar seasonal trend showing maximum values in June and July and minimum values in November and December (data not shown).

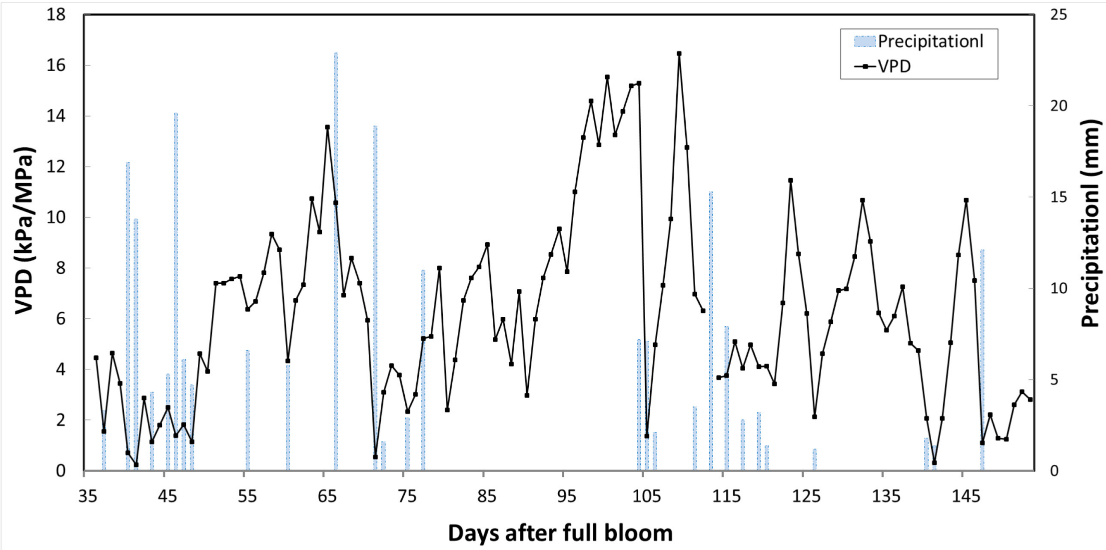


Fig. 19. Seasonal variations of water vapour partial pressure deficit (VPD) and daily precipitation at the orchard area during 35 days after full bloom to harvest time in 2013.

In the present study, the MDS of 'Jojo' trees ranged between 20 and 700 µm and that of 'Tophit plus' trees between 15 and 600 µm (Fig. 20). MDS increased from the beginning of the experiment (35 and 30 DAFB for 'Jojo' and 'Tophit plus', respectively) to early-August. In trees of both cultivars, MDS dropped after harvest, especially in 'Tophit plus' (Fig. 20).

During the experiment, the MDS differed in trees with different crop loads (Fig. 20. A, C). This, again, was valid for both cultivars. Before July, the MDS of 'Tophit plus' trees was almost similar and very low in trees of both crop load treatment (Fig. 20. C). Both in 'Jojo' and 'Tophit plus', the MDS, averaged over the entire experimental period, was 27% and 30% higher in high crop load-treatment trees (HCL) than in low crop load-treatment (LCL) trees (Fig. 20 A, C). After final harvest, similar MDS values were observed in both LCL and HCL trees. The highest MDS values were found in HCL trees of 'Jojo' and 'Tophit plus' with 780 µm (109 DAFB) and 758 µm (103 DAFB), respectively (Fig. 20. A, C).

Only on a few days of the experiment in 'Jojo', the effects of soil ECa on MDS variation were significant (Fig. 20. B). Here, the MDS was slightly higher in low soil ECa (LECa) trees than in LECa trees. MDS values of 'Tophit plus' trees were similar in both soil ECa groups during almost the entire experiment (Fig. 20. D). However, between 58 and 60 DAFB, MDS was higher in LECa than in HECa trees.

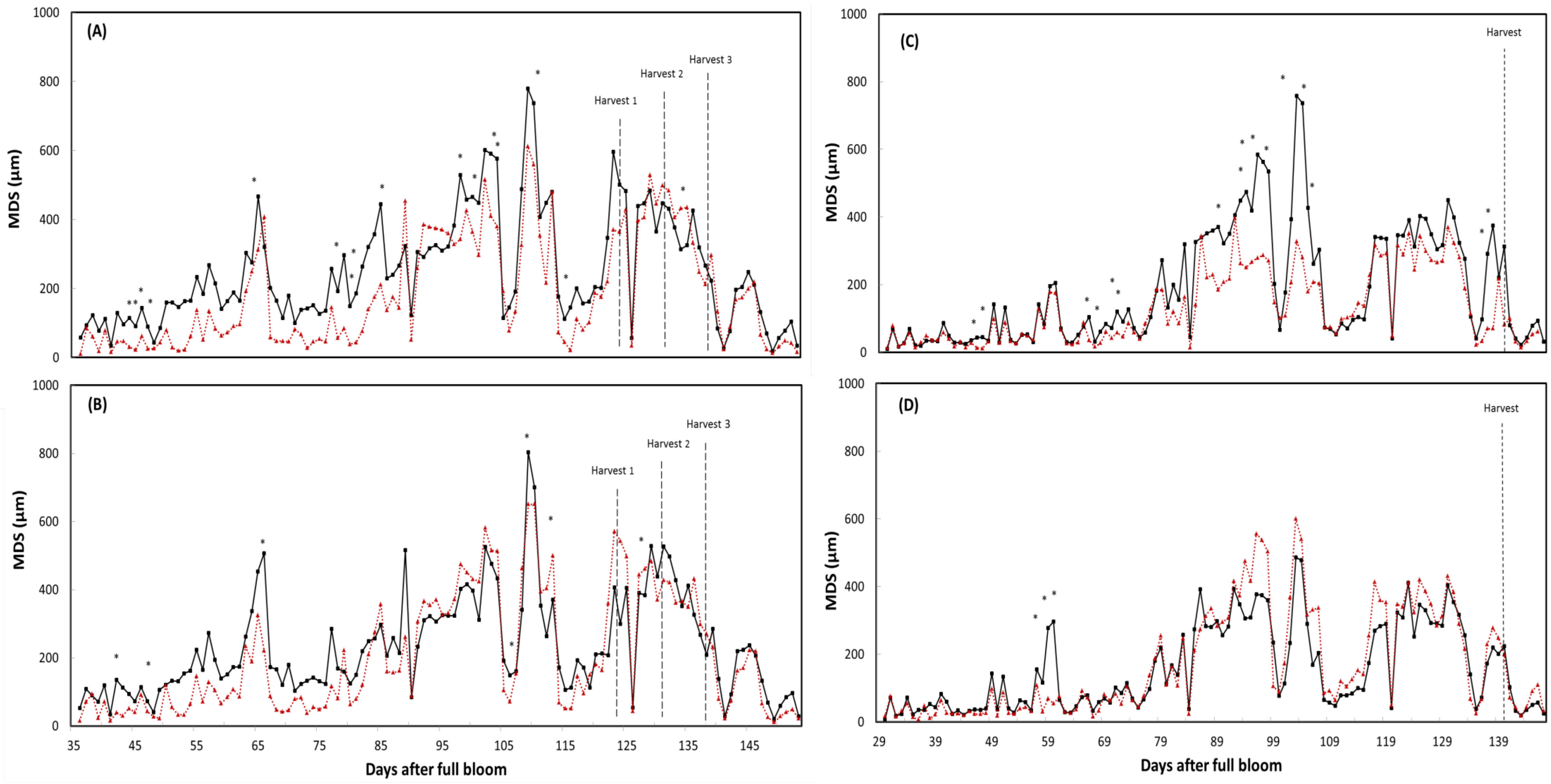


Fig. 20. Comparison of maximum daily shrinkage (MDS) of plum trees (A, B; LCL, low crop load; HCL, high crop load) of different crop load groups, (C, D; LECa, low soil ECa; HECa, high soil ECa) of different soil ECa and of different cultivars, 'Jojo' (A, C) and 'Tophit plus' (B, D). Values are means of 3 to 4 trees in 2013.

During the experiment period (2013), day-to-day variations of MDS in trees of both cultivars were closely and positively correlated with both VPD and tree crop load (Fig. 21). During experiment time, correlations of MDS with VPD (r^2 = 0.59) and crop load (r^2 = 0.49) were higher in 'Jojo' trees than in 'Tophit plus' trees (Fig. 21; VPD: r^2 = 0.53 and crop load: r^2 = 0.37). In 'Tophit plus' trees, however, the correlation between MDS and VPD at the beginning of the experiment was weak and only became strong after 60 DAFB (data not shown).

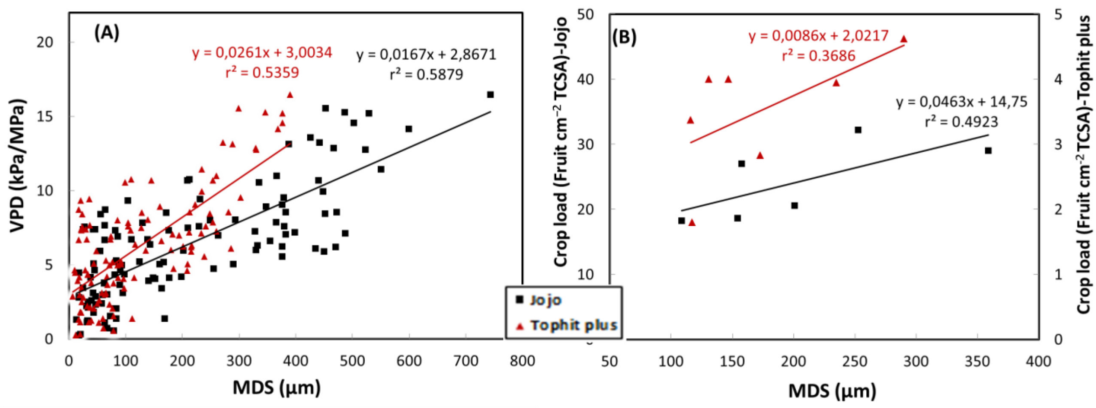


Fig. 21. Relationship between maximum daily shrinkage (MDS) of 'Jojo' (squares) and 'Tophit plus' (triangles) trees and (A) air vapour pressure deficit (VPD), and (B) tree crop load.

4.2.2. Relation between MDS and physicochemical properties of plums

Fruit fresh mass and yield

Despite the fact that fruit grown on trees with low MDS (LMDS) had slightly higher fresh mass than those grown on those showing high MDS (HMDS) during the preharvest period and at harvest, there was no statistically significant difference between these groups (Tab. 9). This response was irrespective of the plum cultivar. Furthermore, the respective tree MDS affected fruit yields in both cultivars. Here, fruit yields of HMDS were 19% and 12% higher than that of LMDS (Tab. A.1).

Tab. 9. Statistical analysis of effects of maximum daily shrinkage (MDS on fruit fresh mass of 'Jojo' and 'Tophit plus' plums during fruit development and at harvest in 2013.

Period measurement	Treatment				Factor			
	Jojo		Tophit plus		Jojo		Tophit plus	
	LMDS	HMDS	LMDS	HMDS	MDS	MDS × T	MDS	MDS × T
During preharvest	30.1	28.7	44.2	43.3	NS	NS	NS	NS
At harvest	40.3	38.2	57.8	55.8	NS	-	NS	-

Values are means of each treatment. Significance of effects of treatments (MDS, maximum daily shrinkage; LM, low maximum daily shrinkage; HM, high maximum daily shrinkage; T, time of measurement) and their interactions on the fruit fresh mas and yield are also indicated (*: $p < 0.05$; **: $p < 0.01$; ns: not significant).

Skin colour and normalized anthocyanin index

MDS significantly affected colour development (indicated by CIE b* value) in 'Jojo' fruit during the preharvest period (Tab. 3. A; Fig. 22. A). In that period, the b* value in LMDS plums was higher than in fruit grown on HMDS. In contrast, the effects of MDS on a* value were insignificant during the entire experiment in the fruit of both cultivars (Tab. 3. A).

Normalized anthocyanin index (NAI) increased remarkably during the development of 'Jojo' and 'Tophit plus' fruit. During this time, MDS only affected NAI in 'Jojo' plums (Fig. 22. B). Here, the NAI of fruit grown on HMDS was higher than that of those grown on LMDS. However, there were no treatment effects on NAI at harvest (Fig. 22. B).

At harvest and during storage, fruit of both LMDS and HMDS had almost the same skin colour and hence, NAI values, with the maximum NAI (88 to 90) and the final dark blue colour reached well before harvest (Fig. 22).

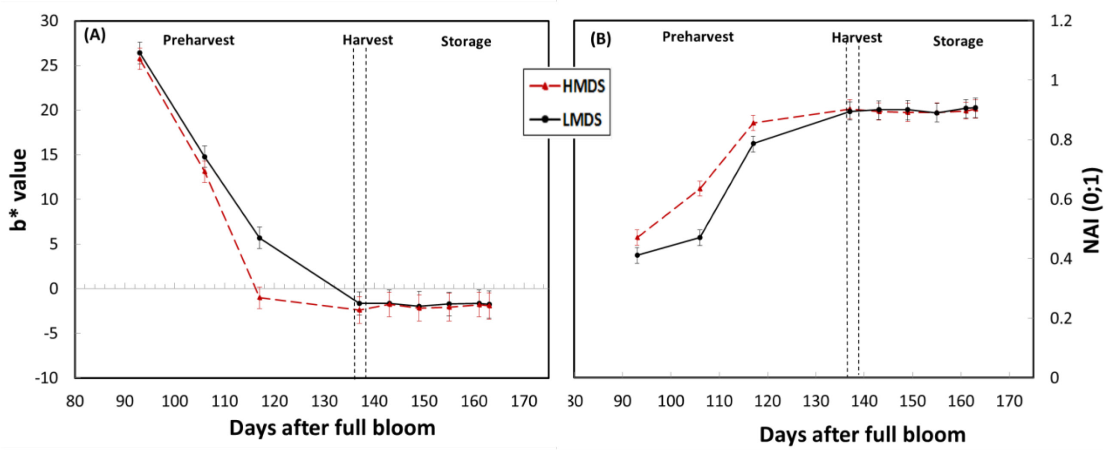


Fig. 22. Effect of maximum daily shrinkage (MDS) on (A) b* value and (B) NAI of 'Jojo' plums during preharvest, at harvest and during 28 days at 2°C plus 2 days at 20°C (2013). Vertical bars represent 95% confidence interval of the means. LMDS, trees showing low MDS; HMDS, trees showing high MDS.

Soluble solids content and dry matter content

During the preharvest period, soluble solids content (SSC) and dry matter content (DMC) increased remarkably in fruit of both LMDS and HMDS, except at the 2nd measurement for 'Tophit plus' plums (113 DAFB; Fig. 23. A). Nevertheless, the most pronounced increase occurred during the last 3 weeks of the preharvest period, i.e. during the final phase of fruit development (Fig. 23. A). In contrast, during cold storage and shelf life, SSC and DMC did not change significantly (Tab. 9; Fig. 23. A). However, at the end of shelf life, DMC was slightly higher than at harvest in 'Tophit plus' plums (Fig. 23. A).

MDS affected SSC in fruit of both cultivars over the entire experimental period (Fig. 23. A). Here, SSC in HMDS fruit was 10% and 8% higher than LMDS plums at harvest for 'Jojo' and 'Tophit plus' plums, respectively. In general, the effect of MDS on SSC in ‘Jojo’ plums was more pronounced than in 'Tophit plus' fruit (Fig. 23. A).

Dry matter content was affected by MDS in 'Jojo' plums (Tab. 9; Fig. 23. B). In this case, DMC in LMDS fruit was higher than in HMDS plums over the entire experimental period. In 'Tophit plus' plums, however, DMC tended to be higher in fruit grown in HMDS than in LMDS plums, especially during the preharvest period, although the differences were not statistically significant (Fig. 23. B). In general, the

DMC was substantially higher in 'Tophit plus' plums than in 'Jojo' fruit during the preharvest period, at harvest and during storage (cold storage and shelf life), at levels of 19, 15 and 18%, respectively (Fig. 23. B).

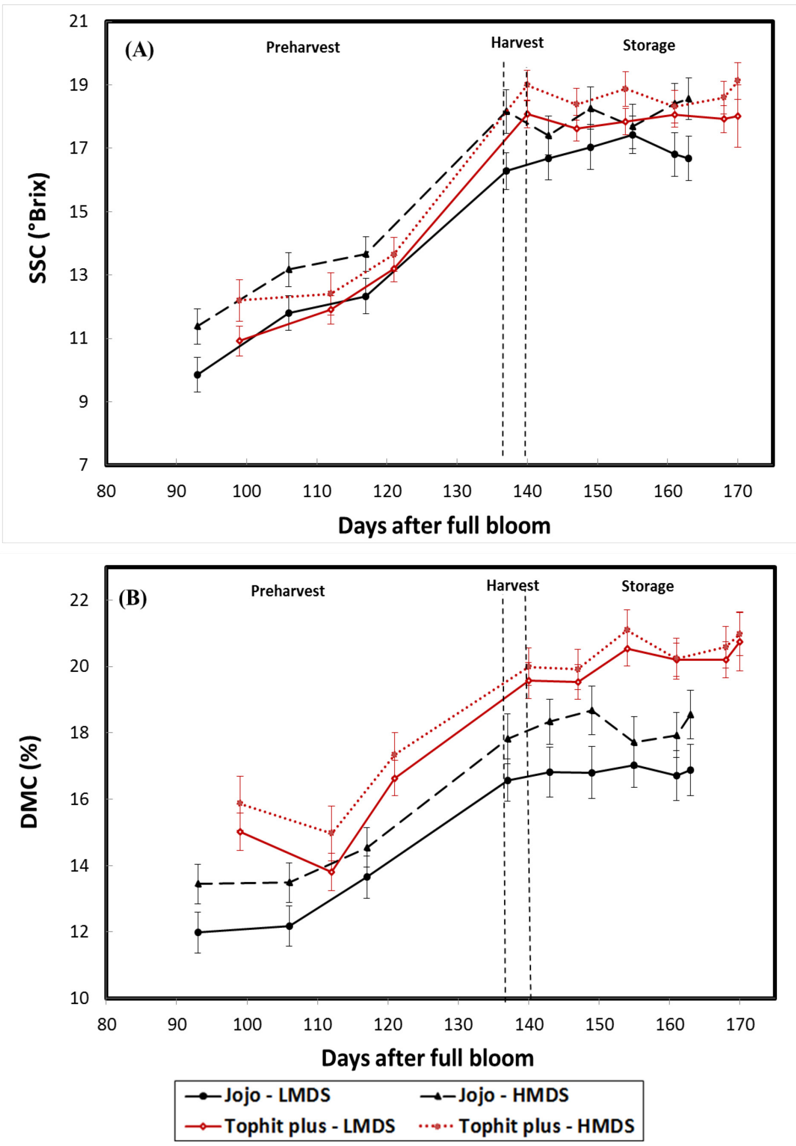


Fig. 23. Effect of maximum daily shrinkage (MDS) on (A) SSC and (B) dry matter content of 'Jojo' and 'Tophit plus' plums during preharvest, at harvest and during 28 days at 2°C plus 2 days at 20°C (2013). Vertical bars represent 95% confidence interval of the means. LMDS, trees showing low MDS; HMDS, trees showing high MDS.

Fruit flesh firmness and titratable acidity

Firmness and titratable acidity (TA) decreased markedly in fruit of both cultivars during the preharvest period and storage (data not shown). The effect of MDS on flesh firmness was only significant in 'Tophit plus' plums (Tab. A. 3). Here, LMDS fruit were less firm than HMDS fruit only during the preharvest period. However, MDS did not significantly affect flesh firmness at harvest and during storage (Tab. A. 3).

Despite the fact that TA was slightly higher in HMDS plums than in LMDS fruit for 'Jojo' over the entire experimental period; there was no statistically significant difference between these groups (Tab. A. 3).

Fruit transpiration rate

In plums of both cultivars, transpiration rates slightly decreased during cold storage and shelf life (Fig. 24). However, this decline occurred mostly during the initial 2 weeks of storage. During storage time, the transpiration of 'Tophit plus' plums was 21% higher than that of 'Jojo' fruit (Fig. 24). Moreover, the transpiration of fruit was affected by MDS irrespective of the cultivar (Tab. 25). In this set, the transpiration rates of LMDS plums were 17 and 19% higher than that of HMDS in 'Jojo' and 'Tophit plus', respectively. At the end of cold storage and the following simulated shelf life of 'Jojo' plums, however, there was no difference in transpiration rate between fruit grown on LMDS and HMDS (161 and 163 DAFB; Fig. 24).

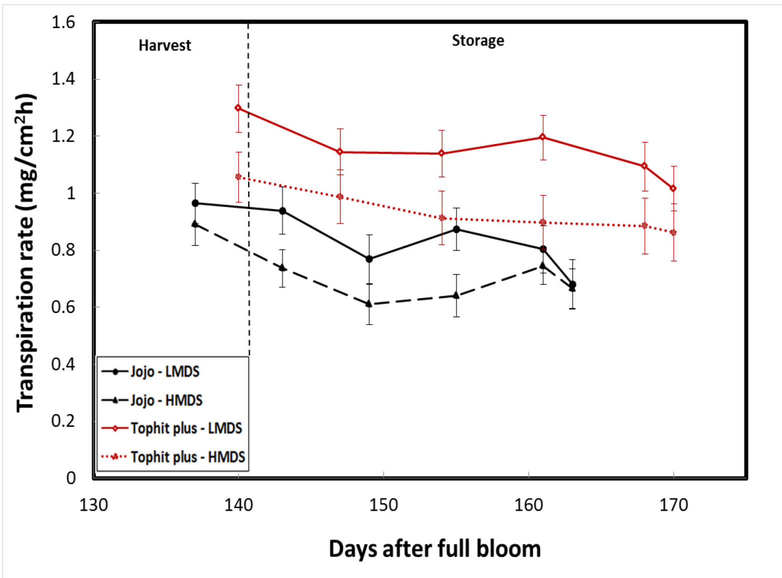


Fig. 24. Effect of maximum daily shrinkage (MDS) on transpiration rates of 'Jojo' and 'Tophit plus' plums at harvest and during 28 days at 2°C plus 2 days at 20°C (2013). Vertical bars represent 95% confidence interval of the means. LMDS, trees showing low MDS; HMDS, trees showing high MDS. The climate condition during transpiration measurements are shown in Tab. A.6.

4.3. Interaction of harvest dates and fruit quality of 'Jojo' plum

Fruit mass and dry matter content

In 2013, fruit fresh mass increased during the harvesting period (Tab. A.4). Here, fruit fresh mass continuously increased by 11% in the time between the 1st and 3rd harvest, finally obtaining a mean maximum fresh mass of 39 g.

Delaying harvest also resulted in significantly higher dry matter content (DMC) of fruit (Tab. A.4). Here, the DMC of harvested plums from the 3rd harvest was 24% higher than that from the 1st harvest date.

These differences in DMC between fruit harvested at the three different dates were maintained until the end of both cold and room temperature storage (data not shown). DMC of fruit did not significantly change during 28 days of storage at 2 ºC and 2 days of simulated shelf life at 20 ºC (Tab. A.4). However, the DMC of plums from the 2nd harvest at the end of shelf life was slightly higher (7%) than that DMC at harvest (data not shown).

Skin colour

Fruit harvested at the last date had significantly lower a* and b* values than those obtained at 1st and 2nd harvest dates (Fig. 25. A, B). During cold storage and shelf life, a* and b* values did not significantly change further in fruit from the 2nd and the 3rd harvest date (Fig. 25. A, B). In contrast, in early-harvested fruit, the a* and b* considerably declined during cold and simulated shelf life (Fig. 25. A, B). Fruit harvested at the 1st and the 2nd date had similar a* and b* values after 21 and 14 days of storage (Fig. 25. A, B).

Fruit flesh firmness

Mean flesh firmness of the freshly-harvested plums significantly declined by 48% from the 1st to the 3rd harvest date (Fig. 25. C). Irrespective of the date of harvest, flesh firmness further decreased during cold storage and shelf life (Fig. 25. C). The rate of reduction, however, was not independent of harvest date. During cold storage and shelf life, flesh firmness in plums from the 3rd was 61% lower than that from the

1st harvest date (Tab. A.4). At the end of storage (cold storage and shelf-life), the reduction of flesh firmness was higher in the fruit that was harvested late (43%, 53% and 60% in fruit from 1st, 2nd and 3rd harvest dates, respectively) (Fig. 25. C). However, during simulated shelf life, firmness reduction was higher in fruit from the 1st than in those from the 2nd and the 3rd harvest dates (Fig. 25. C).

Soluble solids content and titratable acidity

The soluble solids content (SSC) of fresh fruit increased remarkably from the 1st (13.2 °Brix) to the 3rd harvest date (17.0 °Brix) (Fig. 25. D). These harvest date-related differences in the SSC of plums remained during cold storage and shelf life. (Fig. 25. D). During cold storage and shelf life, the SSC in fruit from the 3rd (17.4 °Brix) was significantly higher than that from the 2nd (15.3 °Brix) and the 1st (13.7 °Brix) harvest dates (Tab. A.4). SSC did not change during cold storage and shelf life in fruit from all harvest dates (Fig. 25. D), however, SSC slightly increased during the initial 14 days of storage and remained constant thereafter (Fig. 25. D).

Titratable acidity (TA) in fruit harvested on the 3rd date was significantly lower, at levels of 16 and 28%, respectively, than in plums harvested earlier (Fig. 25. E). Irrespective of the harvest date, TA declined notably during cold storage and shelf life (Fig. 25. E). In very early harvested fruit (1st harvest date), the reduction in TA started only after 14 days of storage (Fig. 25. E). In comparison to cold storage and shelf life, the highest TA levels were measured at the 1st, 2nd and 3rd harvest dates, respectively (Fig. 25. E). At the end of cold storage and subsequent simulated shelf life, the reduction of TA was measured at levels of 20%, 23% and 22% for fruit from the 1st, 2nd and 3rd harvest dates, respectively (Fig. 25. E).

The pattern of changes in the SSC:TA ratio was based on the changes in SSC and TA (Fig. 25. F). Because late harvesting resulted in significantly higher SSC and a lower TA of fruit, it increased the SSC:TA ratio (Fig. 25. F). The SSC:TA ratio further increased during cold storage and shelf life irrespective of the harvest date (Fig. 25. F). Hence, at the end of cold storage and after shelf life period, the lowest SSC:TA ratios were found in plums harvested on the 1st date (Fig. 25. F).

Transpiration rate

There were significant differences in transpiration rate between harvest dates at the time of harvest (Fig. 25. G). Transpiration rates of very early harvested fruit was significantly higher than those found in plums harvested at a later date (Fig. 25. G). Although fruit transpiration generally slightly decreased during cold storage and shelf life, these harvest dates related differences remained constant during storage and shelf life (Fig. 25. G).

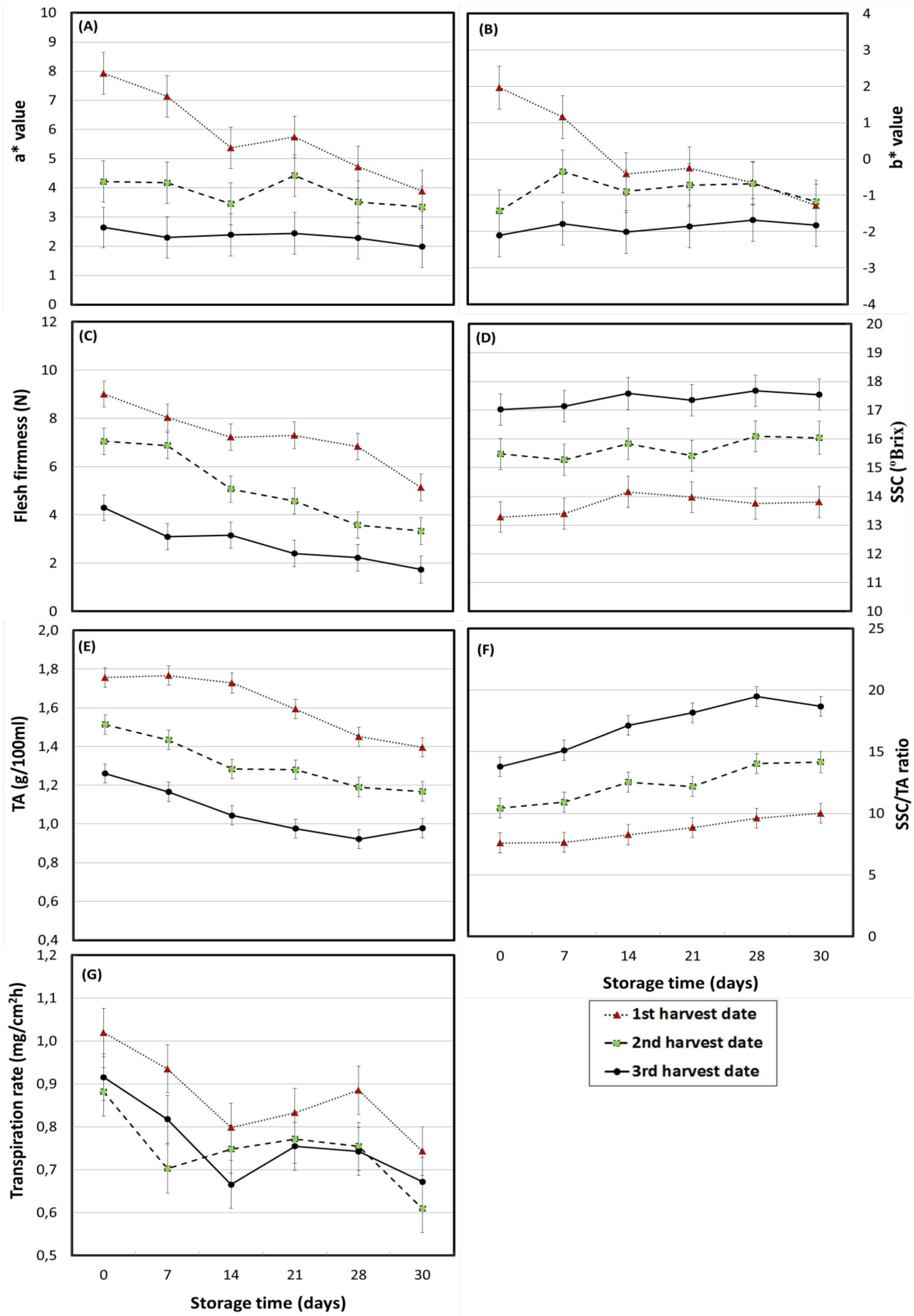


Fig. 25. Effect of different harvest dates on (A) a* and (B) b* values, (C) flesh firmness, (D) SSC, (E) TA, (F) SSC/TA ratio and (G) transpiration rate of 'Jojo' plums during 28 days at 2°C plus 2 days at 20°C. Vertical bars represent 95% confidence interval of the means (n=42). 1st harvest date = 123 DAFB, 2nd harvest date = 130 DAFB and 3rd harvest date = 137 DAFB in 2013.

4.4. Effect of edible coating on the preservation of fruit quality during storage

Transpiration rate

In fruit of both cultivars, transpiration decreased during storage in 2°C and in simulated shelf life (Fig. 26). However, the transpiration of 'Tophit plus' fruit was always higher than that of 'Jojo' plums (Fig. 26). During these times, the transpiration of coated plums was significantly lower than that of control fruit in both 'Jojo' and 'Tophit plus' plums (Tab. 10; Fig. 26), except on day 7 in 'Tophit plus' (Fig. 26). At the end of shelf life, the lowest value was observed in coated plums with Versasheen and sorbitol treatment (0.46 mg/cm^{2}h and 0.77 mg/cm^{2}h), whereas the highest transpiration rate was measured in control fruit (0.77 mg/cm^{2}h and 1.01 mg/cm^{2}h) for 'Jojo' and 'Tophit plus' plums, respectively (Fig. 26).

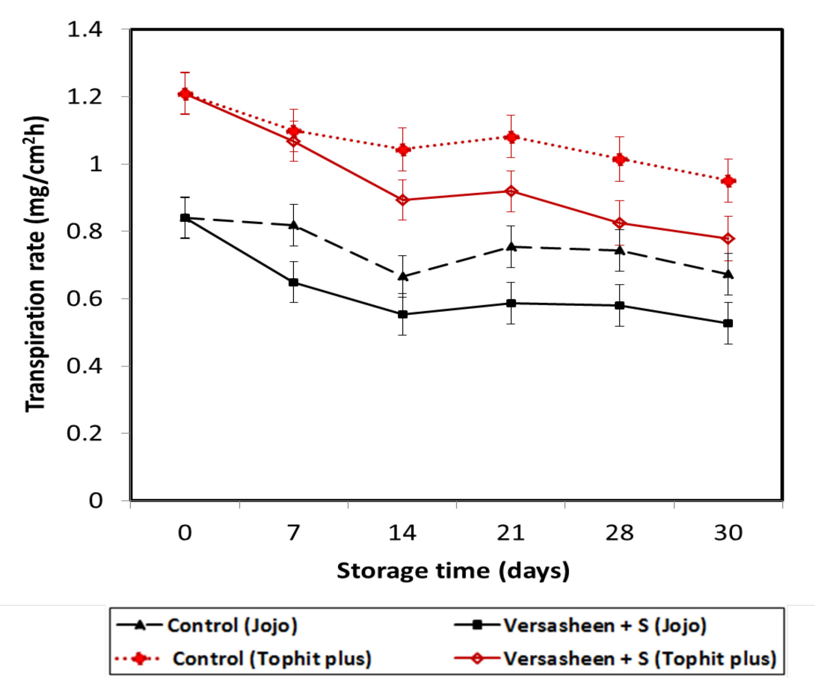


Fig. 26. Effects of edible coating and storage time on transpiration rate of 'Jojo' and 'Tophit plus' plums during 28 days at 2°C plus 2 days at 20°C. Vertical bars represent 95% confidence interval of the means (n=42). S, sorbitol. The climate condition during transpiration measurements are shown in Tab. A.6.

Fruit flesh firmness

At harvest, the flesh firmness of 'Jojo' and 'Tophit plus' plums was 4.1 N and 7.4 N (Fig. 27). It continuously decreased during cold storage and shelf life, and reached final values of 1.7 N and 3.8 N at the end of shelf life (Fig. 27). The coating reduced softening in both 'Jojo' and 'Tophit plus' plums (Fig. 27). However, the effects of coating were no longer significant on storage day 21 for 'Tophit plus' and after this 21^{st} day for 'Jojo' plums (Fig. 27).

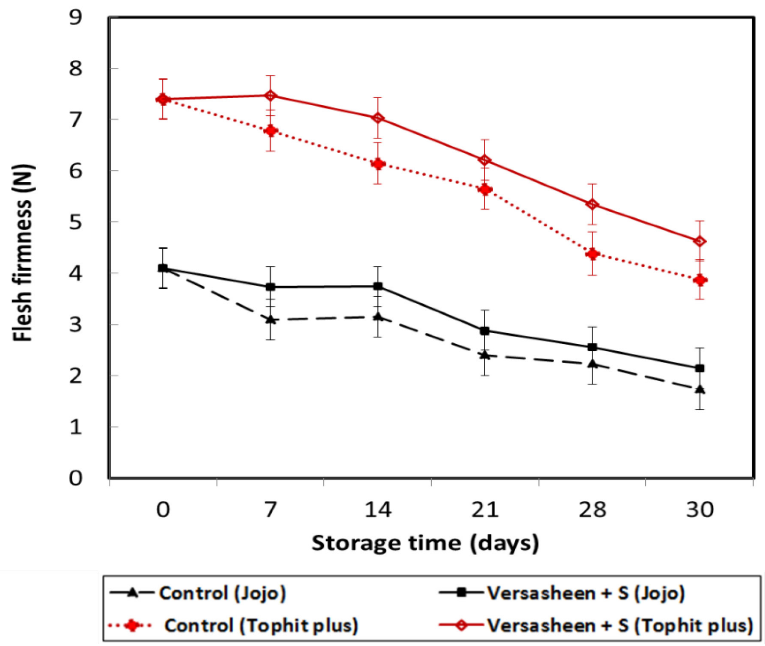


Fig. 27. Effects of edible coating and storage time on flesh firmness of 'Jojo' and 'Tophit plus' plums during 28 days at 2°C plus 2 days at 20°C. Vertical bars represent 95% confidence interval of the means (n=42). S, sorbitol.

Soluble solid content and titratable acidity

During storage in 2°C and in simulated shelf life, the soluble solid content in fruit of 'Tophit plus' was generally 8% higher than that in 'Jojo' plums (Tab. 10). In plums of both cultivars, SSC did not change significantly during these times (Tab. 10). In addition, SSC was not affected by the coating.

During cold storage and shelf life, TA was always higher in 'Jojo' plums than in those of 'Tophit plus' (Fig. 28). During these times, TA gradually decreased in fruit of both cultivars (Fig. 28). Despite the fact that coated 'Jojo' plums had slightly higher titratable acidity than control fruit after 21 days of storage, there was no statistically significant difference between coated and control plums (Fig. 28).

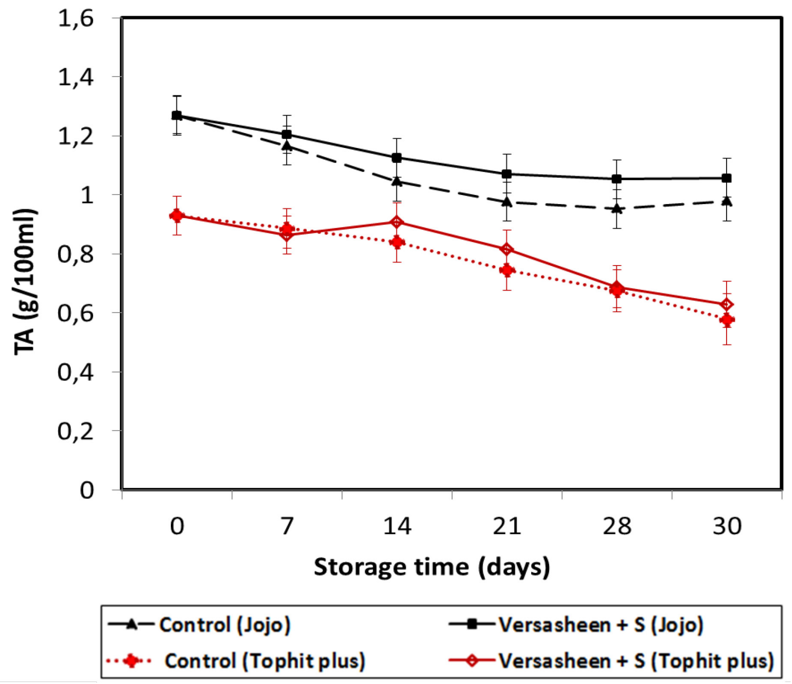


Fig. 28. Effects of edible coating and storage time on TA of 'Jojo' and 'Tophit plus' plums during 28 days at 2°C plus 2 days at 20°C. Vertical bars represent 95% confidence interval of the means (n=42). S, sorbitol.

Skin colour

Changes in a* and b* values were minimal during cold storage and shelf life (data not shown). In general, values of a* and b* were lower in 'Tophit plus' than 'Jojo' plums (Tab. 10). Moreover, no significant differences between coated fruit and controls were found, irrespective of the cultivar (Tab. 10).

Tab. 10. Statistical analysis of the effects of edible coating and storage time on postharvest quality parameters and LLBI properties of 'Jojo' and 'Tophit plus' plums during 28 days at 2°C plus 2 days at 20°C (2013).

	Parameters	Treatment				Factor				
		Jojo		Tophit plus		VS	CV	T	VS × CV	VS × T
		Control	VS	Control	VS					
Fruit quality parameters	Transpiration rate (mg/cm^2h)	0.76 c	0.63 d	1.05 a	0.95 b	**	**	**	NS	**
	Flesh firmness (N)	2.8 d	3.2 c	5.7 b	6.3 a	**	**	**	NS	*
	SSC (°Brix)	17.4	17.1	18.6	18.7	NS	**	NS	NS	NS
	TA (g/100ml)	1.06	1.13	0.78	0.80	NS	**	**	*	*
	a* value	2.3	2.6	0.4	0.5	NS	**	NS	NS	NS
	b*value	-1.8	-1.5	-5.4	-5.7	NS	**	NS	**	NS
Optical properties	$FWHM_{660}$ (%)	2.2	3.2	-25.3	-24.2	NS	**	**	NS	NS
	$FWHM_{785}$ (%)	54.2 a	50.9 b	37.2 c	35.3 c	*	**	**	*	NS

Values are means of each treatment. Statistical significant (LSD test, p<0.0.5) differences between means are indicated by different letter. Significance of effects of treatments (VS, Versasheen plus sorbitol; CV, cultivar: T, storage time) and their interactions on the various parameter are also indicated (*: p<0.05; **: p< 0.01; ns: not significant).

Interactive effect of preharvest factors and edible coating on fruit quality

According to an analysis of data, there was no significant interactive effect between preharvest factors (ECa, crop load and MDS) and edible coating on all quality parameters of both 'Jojo' and 'Tophit plus' cultivars during cold storage and shelf life in 2013 (data not shown).

4.5. Optical properties of 'Jojo' and 'Tophit plus' plums

4.5.1. Optical properties of plum during development on the trees and storage

LLBI reading in the green wavelength range

Variations in the value of full width half maximum obtained with a laser emitting at 532 nm ($FWHM_{532}$) during the preharvest and storage periods in 2013 of 'Jojo' and 'Tophit plus' plums are shown in Fig. 29. The value of $FWHM_{532}$ markedly decreased from the 2nd measurement during fruit development in fruits of both cultivars (relative FWHM at 1st measurement = 0). However, in 'Jojo' and 'Tophit plus' fruit, the reduction of $FWHM_{532}$ stopped at the 3rd (117 DAFB) and 4th measurements (140 DAFB), respectively, and then the value of this parameter remained constant at harvest and during storage for both cultivars. The total reduction of $FWHM_{532}$ was greater in 'Tophit plus' (46%) than 'Jojo' plums (33%) by the time of harvest. There were no significant changes in $FWHM_{532}$ in fruits of both cultivars during storage.

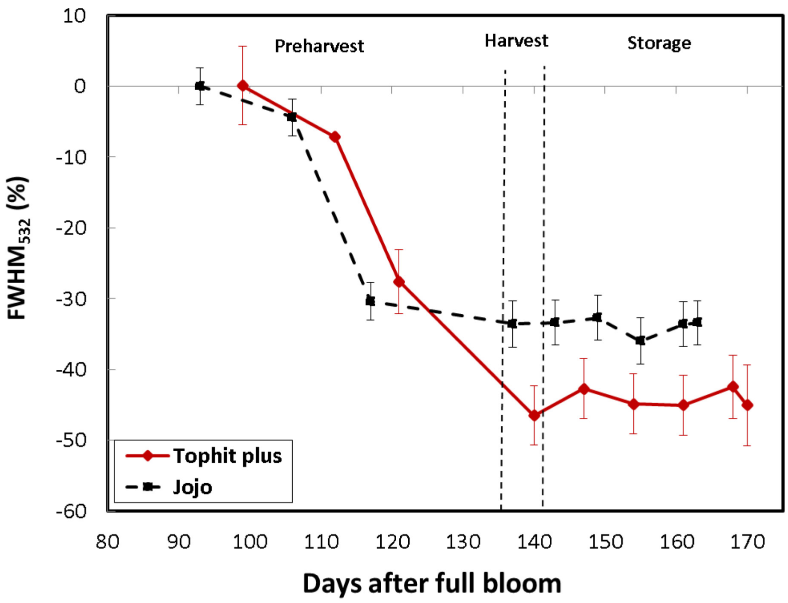


Fig. 29. Changes of relative full width at half maximum (FWHM) obtained from 532 nm laser in 'Jojo' and 'Tophit plus' plums during preharvest, at harvest and storage time of 2013. The relative FWHM at start of measurement was considered as 0%.Vertical bars represent 95% confidence interval of the means.

LLBI readings in the red wavelength range

Variations in the value of full width half maximum obtained with a laser emitting at 660 nm ($FWHM_{660}$) during the preharvest and storage periods in 2013 of 'Jojo' and 'Tophit plus' plums are shown in Fig. 30. A, B. Unlike the $FWHM_{532}$ behaviour, the value of full $FWHM_{660}$ in both cultivars significantly decreased from the 2nd measurement to the end of experiment period of 2011 (relative FWHM at start of measurement = 0) (Fig. 30. A, B). However, this value slightly increased at the beginning of the measurement period, and then decreased to the end of storage in plums in 2013. As a consequence, the value of $FWHM_{660}$ in 'Jojo' plums was reduced between 0% and 21% by the harvests of 2011 and 2013, respectively (Fig. 30. A). Whereas, these reductions in 'Tophit plus' plums were between 21% and 63% in 2011 and 2013, respectively (Fig. 30. B).

During storage, the $FWHM_{660}$ decreased slightly in both plum cultivars, however this reduction varied between the different years in 'Jojo' plums (Fig. 30. A, B). During storage of 'Jojo' fruit, the reduction of $FWHM_{660}$ was 13 and 5% in 2011 and 2013, respectively (Fig. 30. A). Whereas, the trend of reduction for $FWHM_{660}$ in 'Tophit plus' plums was very low (approx. 5%) in both years (Fig. 30. B).

LLBI readings in the near infrared wavelength range

Variations in the value of full width half maximum obtained with a laser emitting at 785 nm ($FWHM_{785}$) during the preharvest and storage periods of both cultivars in 2011 and 2013 are shown in Fig. 30. C, D. During the preharvest period, the changes in $FWHM_{785}$ varied between years and cultivars. The $FWHM_{785}$ had significantly increased by 49, 32 and 12% by the time of harvest in plums of 'Jojo' (2013), 'Tophit plus' (2013) and 'Jojo' (2011), respectively. However, no difference was observed in the $FWHM_{785}$ of 'Tophit plus' plums during the preharvest period in 2011.

During storage, the $FWHM_{785}$ increased in both cultivars' plums; however, this increase varied between years for both cultivars (Fig. 30. C, D). By the end of the storage period of 2011 and 2013, the $FWHM_{785}$ of 'Jojo' plums had increased by 20 and 15%, respectively (Fig. 30. C). These increases in 'Tophit plus' plums were 12 and 7%, respectively (Fig. 30. C, D).

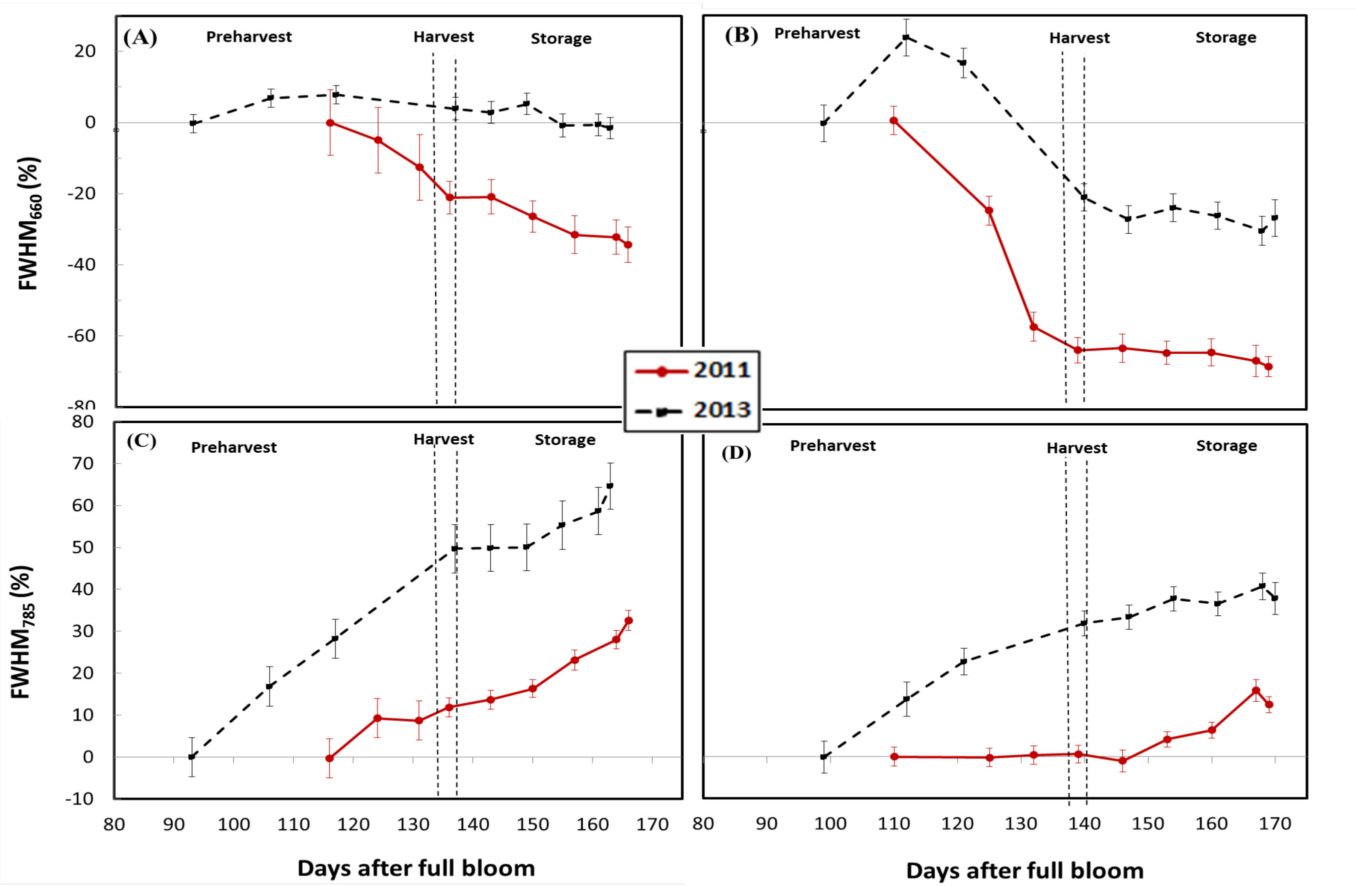


Fig. 30. Changes in relative full width at half maximum (FWHM) obtained from 660nm laser in (A) 'Jojo' and (B) 'Tophit plus' plums, and 785 nm lasers in (C) 'Jojo' and (D) 'Tophit plus' plums during preharvest (fruit development), at harvest and storage time of 2011 and 2013. The relative FWHM at start of measurement was considered as 0%. Vertical bars represent 95% confidence interval of the mean.

4.5.2. Effects of pre- and postharvest factors on the optical properties of plum fruit

4.5.2.1. Crop load, soil ECa and MDS effects

LLBI readings in the green wavelength range

Among the effects of preharvest factors, crop load significantly affected the $FWHM_{532}$ in both cultivars during the preharvest period of 2013 (Tab. 11). Here, the average reduction of $FWHM_{532}$ in fruit from LCL (18.6 and 23%) was higher than that from HCL trees (both 16%) in 'Jojo' and 'Tophit plus' respectively (data not shown). Moreover, MDS significantly affected the $FWHM_{532}$ in both cultivars during the preharvest period in 2013 ((Tab. 11). Here, the average reduction of $FWHM_{532}$ in fruit from LMDS (18 and 24%) was higher than that from HMDS (15 and 16%) in 'Jojo' and 'Tophit plus' respectively (data not shown). Soil ECa and interaction between preharvest factors did not affect the $FWHM_{532}$ in plums of both cultivars during the preharvest period in 2013 (Tab. 11).

LLBI readings in the red and near infrared wavelength range

Preharvest factors did not have any considerable interactive effect on $FWHM_{660}$ and $FWHM_{785}$ (Tab. 11). However, the interaction between time of sampling and crop load had a statistically significant effect on $FWHM_{660}$ (in 'Jojo' and 'Tophit plus' plums' in 2011) and $FWHM_{785}$ (in 'Jojo' plums' of 2013) (Tab. 11). Moreover, an interactive effect between time of sampling and MDS on $FWHM_{660}$ (in 'Jojo' plums' of 2013) was also observed (Tab. 11).

Tab. 11. The effects of preharvest factors (soil ECa, crop load and MDS) on relative full width at half maximum (FWHM) obtained from 532, 660 and 785 nm lasers in 'Jojo' and 'Tophit plus' plums during preharvest and storage of 2013.

LLBI Parameters	Cultivar	Year	T	ECa	CL	MDS	T × ECa	T × CL	T × MDS	ECa × MDS	ECa × CL
$FWHM_{532}$ (%)	Jojo	2013	**	NS	*	**	NS	NS	NS	NS	NS
	Tophit plus	2013	**	NS	*	**	NS	NS	NS	NS	NS
$FWHM_{660}$ (%)	Jojo	2011	**	NS	NS	-	NS	*	-	-	NS
		2013	**	NS	NS	NS	NS	NS	**	NS	NS
	Tophit plus	2011	**	NS	NS	-	NS	*	-	-	NS
		2013	**	NS	NS	NS	NS	NS	NS	NS	NS
$FWHM_{785}$ (%)	Jojo	2011	**	NS	NS	-	NS	NS	-	-	NS
		2013	**	NS	NS	NS	NS	**	NS	NS	NS
	Tophit plus	2011	**	NS	NS	-	NS	NS	-	-	NS
		2013	**	NS	NS	NS	NS	NS	NS	NS	NS

Values are mean of each treatment in different cultivar and year Means with different letter shows significantly by LSD test. *, ** and ns indicate significance at p<0.05, 0.01 or not significant respectively. LECa, soil ECa; LECa, low soil ECa; HECa, high soil ECa; CL, crop load; LC, low crop load; HC, high crop load; MDS, maximum daily shrinkage; LM, low maximum daily shrinkage; HM, high maximum daily shrinkage; T, time of measurements; FWHM, full width at half maximum.

4.5.2.2. Harvest date and edible coating effects

The FWHM obtained from both lasers of 660 nm and 785 nm were affected by harvest maturity. Here, these values were higher (660 nm) and lower (785 nm) in fruit of the 1st than in those from the 3rd harvest date (Tab. A.4). These harvest date-related differences in the FWHM of plums remained constant during cold storage and shelf life (Tab. A.4). Late-harvested fruit have the lowest $FWHM_{660}$ and the highest $FWHM_{785}$ measurements (Tab. A.4).

Moreover, the $FWHM_{785}$ in fruit of 'Jojo' was affected by coating, but the measurement at 660 nm during cold storage and shelf life was not (Tab. 10). The $FWHM_{785}$ in coated plums of both cultivars was lower than that in the control (Tab. 10), which means that the increase of $FWHM_{785}$ in control fruit was faster than in coated fruit during storage.

4.5.3. Correlation between fruit quality and optical properties

A correlation analysis between the $FWHM_{53}$ and quality parameters of 'Jojo' and 'Tophit plus' plums during the preharvest period in 2013 was conducted and the results are presented in Tab. 12. These relationships showed that there was a positive correlation between $FWHM_{532}$ and fruit firmness, TA and b* and a negative correlation between $FWHM_{532}$ and fruit SSC, DMC and NAI in both cultivars. However, the highest correlation coefficients were found for NAI at r = 0.76 and r = 0.85 (Tab. 12 and Fig. 31. A), followed by those found for b* value at r = 0.73 and r = 0.68 for 'Jojo' and 'Tophit plus', respectively.

The relationship between $FWHM_{660}$ and quality parameters of both cultivars during the preharvest and storage time in 2011 and 2013 showed that the $FWHM_{660}$ was correlated (r > 0.58) with almost all quality parameters of 'Tophit plus' plums in both years (except a* and b* value in 2013) (Tab. 12). However, in this cultivar, the highest correlation was found for flesh firmness (r = 0.84) and SSC (r = 0.74) for 2011 and 2013, respectively (Tab. 12). There was no significant relationship between $FWHM_{660}$ and the quality parameters of 'Jojo' plums, except for a* value in 2011 (r = 0.72) (Tab. 12).

Moreover, the relationship between $FWHM_{785}$ and the quality parameters of 'Jojo' and 'Tophit plus' plums showed (Tab. 12) that the fruit firmness had the highest value of correlation to $FWHM_{785}$ with r = 0.73 (2011) and r = 0.72 for 'Jojo' and r = 0.50 (2011) and r = 0.79 (2013; Tab. 12 and Fig. 31. B) for 'Tophit plus' plums.

Tab. 12. Pearson correlations coefficient matrix between full width at half maximum (FWHM) obtained from 532 nm, 660 nm, and 785 nm lasers and quality parameters of 'Jojo' and 'Tophit plus' plums in 2011 and 2013.

LLBI parameters	Year	Cultivar	Flesh firmness	SSC	TA	DMC	a* value	b* value	NAI
$FWHM_{532}$ (%)	2013	Jojo	.72**	-.61**	.72**	-.62**	-.55**	**.73****	**-.76****
		Tophit plus	.60**	-.68**	.67**	-.66**	-.34**	**.68****	**-.85****
$FWHM_{660}$ (%)	2011	Jojo	.49**	-.42**	.40**	-.33**	.72**	0.2	-.43*
		Tophit plus	.84**	-.82**	.83**	-.73**	.72**	.74**	-.76**
	2013	Jojo	0.1	-0.11	0.15	-.18*	.19*	0.1	-0.01
		Tophit plus	.58**	-.74**	.71**	-.72**	.15*	.41**	-.62**
$FWHM_{785}$ (%)	2011	Jojo	**-.73****	.40**	-.67**	.17**	-.42**	0.1	.32**
		Tophit plus	**-.50****	.40**	-.43**	.31**	-.31**	-0.22	.26**
	2013	Jojo	**-.72****	.63**	-.71**	.54**	.35**	-.64**	.58**
		Tophit plus	**-.79****	.65**	-.75**	.61**	.22**	-.67**	.72**

**** and * indicates correlation is significant at the 0.01 and 0.05 level respectively (2-tailed).**

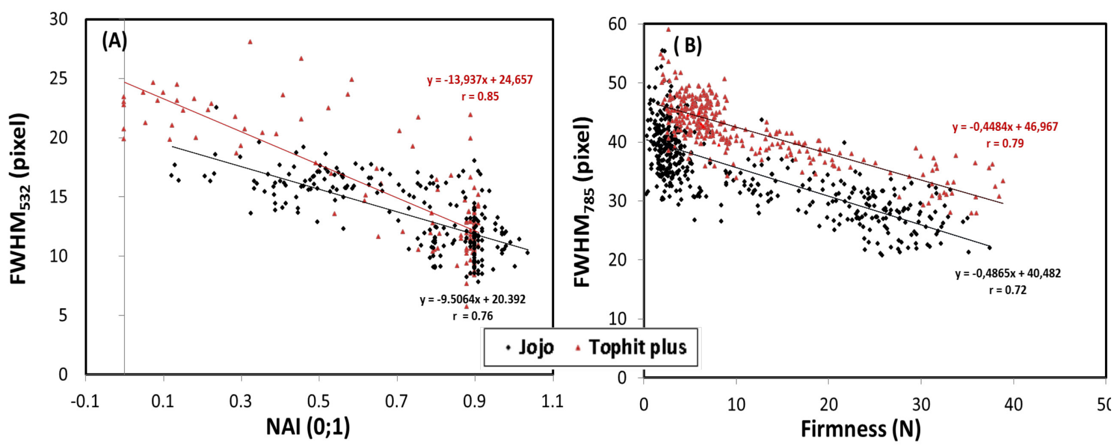


Fig. 31. Relationship between (A) full width at half maximum (FWHM) obtained from 532 nm laser and normalized anthocyanin index (NAI) during preharvest, and (B) FWHM obtained from 785 nm laser and of flesh firmness during preharvest and storage in 'Jojo' and 'Tophit plus' plums in 2013.

5. Discussion

5.1. Quality changes of 'Jojo' and 'Tophit plus' during pre- and postharvest periods

During the development of 'Jojo' and 'Tophit plus' plums, fruit fresh mass, SSC and dry matter content experienced a pronounced increase, as also reported for plums of other cultivars (Zuzunaga et al., 2001; Daza et al., 2008; Usenik et al., 2008). In contrast, SSC and dry matter content did not markedly change during storage. In this context, the concentrating effects of fruit water loss can be assumed to seemingly compensate for sugar losses due to respiration (Kluge et al., 1996). Similarly in 'Green Gage' plums, SSC did not change during cold storage (Guerra and Casquero, 2008).

During pre- and postharvest periods, flesh firmness and titratable acidity decreased in fruit of both cultivars in all years. During the postharvest period, however, the decline in both firmness and acidity seems to be slightly smaller in the 'Tophit plus' than the 'Jojo' fruit (Fig. 15; Fig. 16). Fruit softening is mainly caused by the conversion of insoluble proto-pectins into water-soluble pectins (Krishna and Rao, 2014). The reduction of TA may be explained by the preferred consumption of organic acids as substrates for respiration in detached fruit (Diaz-Mula et al., 2009). Several studies have reported a reduction in firmness and acidity during the cold storage and shelf life of plums (Guerra and Casquero, 2008, 2010; Valero et al., 2013). The variations in a* values at the beginning of the experiment in fruit of both cultivars (2013; Fig. 16. A, B) were related to the change in the skin colour from green to violet. Afterwards, however, the reduction of a* value with progressing fruit ripeness can be caused by the development of the blue colour in the fruit skin in plums of both cultivars (Sekse et al., 2013). This is similar to results reported for other blue-coloured plums (Valero et al., 2003; Usenik et al., 2008). During fruit development, b* value decreased from the beginning of the experiment (positive value) until harvest (negative value) resulting in the development of the blue/yellow colour in fruit of both cultivars, as previously reported in other plum cultivars (Valero et al., 2003; Usenik et al., 2008).

With the exception of 2011, the normalised anthocyanin index (NAI) increased (Fig. 17) with maturity indicating that anthocyanins constantly accumulated during development in fruit of both cultivars. Usenik et al. (2008) evaluated fruit quality changes during fruit development for four plum cultivars ('Jojo', 'Valor', 'Cˇacˇanska rodna' and 'Cˇacˇanska najbolja'). These authors showed that anthocyanin concentration increased during fruit development from the first pick (17th of August) to fifth pick (11th of September) in all cultivars. Moreover, similar findings have also been reported for plums of other cultivars (Diaz-Mula et al., 2008; Miletic´ et al., 2012).

5.2. Effects of preharvest factors on quality changes of 'Jojo'and 'Tophit plus'

5.2.1. Crop load

Fruit fresh mass and tree yield

Except in 'Tophit plus' (2011), a high crop load of trees was accompanied by a low fresh mass of individual plums during both fruit development and at harvest. This may be a consequence of the increased demand of all fruit per tree for assimilates. Similar findings were previously reported for plums of other cultivars (Berman and DeJong, 1996; Intrigliolo and Castel, 2010) and for other stone fruit such as apricot (Roussos et al., 2011), peach (Alcobendas et al., 2012) and nectarine (Naor et al., 1999). In this study, there was an inverse relationship between crop load and tree yield in both cultivars. HCL trees always had higher yields than LCL trees; thus, the balance between yield and fruit size must be maintained Crisosto and Costa (2008), Intrigliolo and Castel (2010) and Rab et al. (2012) reported that the tree yield decreased with fruit crop load in peach, plum and apricot fruit, respectively.

Soluble solids content and titratable acidity

At a high crop load, the SSCs of plums of both 'Tophit plus' and 'Jojo' were lower than in fruit from LCL trees (2012 and 2013; Tab. 6). Similar findings were also reported for plums of other cultivars (Intrigliolo and Castel, 2010; Intrigliolo et al., 2014). This may be due to delayed fruit maturation as a consequence of the increased fruit demand for assimilates (Chapman et al., 1991).

As with altering the leaf to fruit ratio in light-cropping trees, more assimilates are available for fruit growth and, hence, quality development in LCL trees. Thus, fruit of LCL trees show higher individual fresh mass and SSC (Lakso et al., 1995; Klages et al., 2001; Stopar et al., 2002). They may also show improved taste and appearance, and better marketing quality.

Moreover, the titratable acidity of fruit was not related to crop load during pre- and postharvest periods, except in 2011. This is in accordance with findings of (Intrigliolo and Castel, 2010), who reported a non-significant effect of crop load on the acidity of plums at harvest and during the postharvest period. Furthermore, similar to the results presented for 2011, fruit thinning enhanced the malic acid content of 'Priana' and 'Beliana' apricots at harvest (Son, 2004).

Dry matter content

Fruit dry matter content was significantly higher in plums from low crop load trees (2012 and 2013; Tab.7). These results were consistent with other studies, which reported increased fruit dry matter content following thinning, e.g. in apple (Wünsche et al., 2005). However, Lopez et al. (2010) showed that the DMC of peaches was not affected by crop load under full irrigation; but it was affected under drought stress. Under such conditions, fruit DMC increased with the reduction of crop load.

Transpiration rate and fruit firmness

In this study, with the exception of 'Tophit plus' in 2013, crop load did not have notable effects on fruit transpiration.

Moreover, firmness in fruit of both cultivars was not related to crop load in 2011 and 2013. Nevertheless, 'Jojo' plums from low crop load trees were softer than those from HCL trees during both pre- and postharvest periods in 2012 (Tab. A.1). Roussos et al. (2011) also reported a significant decrease of firmness in apricots harvested from thinned 'Nafsika' and 'Niove' trees. However, similar to the results presented for 2011 and 2013, Lopez et al. (2010) did not find any difference in fruit firmness between peaches obtained from heavily, commercially and non-thinned full irrigated trees.

Fruit skin colour and anthocyanin

During the preharvest period, there was a clear crop load effect on skin colour (b* value), showing that a light crop load leads to advanced maturity (Tab. A.2). These findings are in agreement with those from Usenik et al. (2010). These authors reported a better colouration of sweet cherry fruit from thinned trees, probably as a result of better carbohydrate partitioning. Moreover, compared to light crop load (thinned trees), heavy crop load delayed fruit maturation in 'O'Henry' peaches (Johnson and Handley, 1989).

At harvest, fruit colour was not significantly affected by crop load in fruit of the cultivars assessed in this study. Similar responses were observed in peaches (Lopez et al., 2010) and apricots (Roussos et al., 2011).

Colour parameters determined preharvest showed that fruit from low cropping trees had a higher proportion of blue colour in skin (i.e. lower b* value). This is probably confirmed by the fact that the NAI and, hence, the anthocyanin content was higher in fruit from low crop load trees than in those from high crop load trees. Similarly, in 'Royal Gala' apples, anthocyanin concentration was higher in fruit from low crop load trees (Mata et al., 2006).

5.2.2. Soil ECa

The apparent electrical conductivity (ECa) of soils is positively correlated to their moisture content (Telford et al., 1990; Nagy et al., 2013). Thus, the effects of soil ECa can be considered as soil water effects, i.e. low soil ECa (LECa) and high soil ECa (HECa) can be related to low and high soil water availability, respectively.

In this study, soil ECa only affected SSC, dry matter and NAI in 'Jojo' plums in 2013. However, the effect of soil ECa on fresh mass was found in fruit of both cultivars in 2013.

Fruit fresh mass and yield

In 2013, low ECa caused a significant decrease in fruit fresh mass at harvest in both cultivars (Tab. 5). These results are in agreement with previous reports for peach cultivars (i.e. Crisosto et al., 1994b; Berman and DeJong, 1996; Lopez et al., 2010; Alcobendas et al., 2012), where fruit size and fruit mass were reduced by drought stress. This confirms that water inflow into the fruit under drought conditions is greatly reduced. Reduced fruit fresh mass as a result of water shortage was explained by the lower water potentials of stressed trees in comparison to the controls, as well as lower whole-plant relative water content (Berman and DeJong, 1996). Overall, in 2013, variations in fruit fresh mass in response to soil ECa were similar under the two crop load, which means that the effect of the soil ECa and crop level interaction was not statistically significant. Moreover, although fruit fresh mass in LECa was lower than in HECa, the total tree's yield was not significantly affected by soil ECa.

Soluble solids content and titratable acidity

SSC was only significantly higher in fruit of LECa than in that of HECa for 'Jojo' in 2013 (Tab. 6). This is probably due to either an active accumulation of solutes or to fruit dehydration (Intrigliolo and Castel, 2010). Similarly, Gebbers and Zude (2008) reported that fruit SSC was higher in the low ECa zone than in the high ECa zone for apples. These results are also in accordance with several field studies that reported an enhancement of SSC under low soil water availability. For instance, Li et al. (1989a) and Perez-Sarmiento et al. (2010) both reported that water shortage during fruit maturation led to an increased SSC in peaches and apricots. With the exception of 'Jojo' plums in 2012 (at harvest), the level of TA was equal in fruit from both soil ECa zones, during both the pre- and postharvest periods, and in all years. Similarly, Intrigliolo and Castel (2010) observed that deficit irrigation increased the total soluble solids content of plums without any effect on TA at harvest and after 14 days of cold storage.

In fact, both low crop level and low soil ECa increased the SSC of 'Jojo' plums at harvest (2013). Further, the effect of soil ECa on fruit SSC was similar under the two crop levels investigated for 'Jojo' plums (2013). The observed differences were also maintained during storage in the presented study. Similar effects of soil water deficits and high crop loads on the SSC of plums at harvest and after 14 days of storage were reported by Intrigliolo and Castel (2010).

Dry matter content

DMC in fruit under LECa conditions in 'Jojo' (2013) was higher than those under HECa conditions over the entire experimental period (Tab.7). This might be explained by a similar effect of drought stress as that reported Marsal et al. (2006) and Lopez et al. (2010) for peaches. DMC of fruit grown on drought-stressed trees was higher than that of controls. DMC of fruit from non-irrigated trees may indicate partial dehydration of fruit under water shortage. In peaches, an increase in fruit DMC could produce a lack of fruit juiciness, which may impair the quality of the fruit in the end (Lopez et al., 2010). Fruit fresh mass was more affected by soil ECa than dry mass. Thus, fruit dry matter content increased in LECa, which indicates that water inflow in fruit was more restricted than carbohydrate import for trees under drought conditions (Rahmati et al., 2015). The differences in DMC between fruit from different soil ECa and crop load levels observed at harvest were maintained during the storage. Overall, variation in fruit DMC in response to soil ECa was similar under both crop levels for 'Jojo' plums (2013).

Transpiration rate and fruit firmness

During storage of 'Jojo' plums in 2013, transpiration in fruit from LECa was lower than from HECa for both trees with low and high crop loads (Tab. A.1). The lower transpiration of plums grown under LECa conditions could probably be explained by the presence of a thicker fruit cuticle formed in response to water shortage. Thicker cuticles can significantly reduce the amount of water loss in fruit (Crisosto et al., 1994b). In a previous study, Pérez-Pastor et al. (2007) found that mass loss was significantly lower in deficit irrigated apricots than in controlled irrigated fruit during cold storage. Similarly, Crisosto et al. (1994b) reported that peaches under excess irrigation showed higher water losses than fruit grown under deficit and optimum irrigation during 4 days of storage. These authors assumed that fruit from excess irrigation with thinner cuticles had a lower resistance to water vapour transfer than those from deficit and optimum irrigation.

Except in 'Tophit plus' plums in 2013, fruit firmness was equal in fruit from both soil ECa zones. However, in previous studies, Pérez-Pastor et al. (2007) and Alcobendas et al. (2012) observed that deficit irrigation increased fruit firmness at harvest in peach and apricot fruits.

NAI and skin colour

The NAI of fruit was only affected by soil ECa (Tab. 8) in 'Jojo' plums (2012 and 2013). It seems that the development of anthocyanins in the skin of LECa grown fruit was faster than that grown under HECa conditions. A similar effect was reported by Gebbers and Zude (2008) for apples. This might be due to higher light penetration into the tree canopy due to reduced vegetative growth in water limited trees (Thakur and Singh, 2013). This agrees with the findings of Buendia et al. (2008) and Thakur and Singh (2013). These authors found a high accumulation of anthocyanins and improved colour in peaches and nectarines that were subjected to deficit irrigation.

In the present study, the development of blue colour in fruit under LECa conditions only tended to be slightly faster than in those under HECa in 'Jojo' (2012), although fruit colour was not significantly affected by soil ECa in other years.

In general, in contrast to 2013, soil ECa did not have considerable effects on fruit quality in 2012 and 2011. This is probably due to either the fact that, in 2011 and 2012, younger trees with less root growth in deeper soil layers were studied, or it may also be due to the higher amount of precipitation during final fruit development (July and August) in 2011 and 2012 (Tab. A. 5), or a combination of both.

5.2.3. Maximum daily trunk shrinkage

5.2.3.1. Relation between MDS and climatic conditions, tree crop load and soil ECa

In the present study, MDS was highly correlated with VPD in both 'Jojo' and 'Tophit plus' trees. This confirms earlier reports that MDS not only reflects plant water status but could also be influenced by weather conditions (Fereres and Goldhamer, 2003a; Ortuno et al., 2006; Conejero et al., 2007). The increase of VPD by 1 kPa/MPa enhanced MDS by 20 and 35 µm in 'Jojo' and 'Tophit plus' trees, respectively (Fig. 21. A). Based on the evaluation of the relationship between MDS and VPD, it can be concluded that MDS was more closely associated with the changes in VPD in 'Jojo' than in 'Tophit plus' trees. This is probably due to the general differences in vegetative biomass and crop load between 'Jojo' and 'Tophit plus' trees. In the present experiment, the higher MDS in July and August compared to that in May and June can be attributed to an increase in leaf transpiration as a result of higher VPD.

MDS values were higher for high crop load trees when compared to trees with low crop load (Fig. 20. A,C). This finding is in close agreement with previous reports (Intrigliolo and Castel, 2007; De Swaef et al., 2014). The effect of crop load on MDS may result from transpiration-induced changes in water uptake, which, in turn, may directly affect stem water status (Intrigliolo and Castel, 2007; De Swaef et al., 2014). Besides this, any reduction in the phloem tissue's sugar content in response to a high carbohydrate sink strength of fruit (high crop load) led to an increase in the osmotic potential and, consequently, in the water potential. This, in turn, decreases the water potential gradient between phloem and xylem, which was caused by the lower trunk water content in high crop load trees compared to low crop load trees (Intrigliolo and Castel, 2007). In contrast, the osmotic potential in phloem tissues decreased with increasing solute contents in low crop load trees, as a consequence of their lower canopy sink strength for sugars (Flore and Layne, 1997). This should increase the water potential gradient between phloem and xylem. This may explain why the MDS of plum trees reached its lowest value after fruit harvest in early September.

In the present study, soil ECa did not clearly affect MDS for 'Tophit plus' plum trees. However, in some periods of experiments for 'Jojo', the MDS in LECa trees was higher than in HECa trees (Fig. 20. B, D). This could be explained by a higher soil water deficit in LECa trees. Soil ECa in non-saline soils is strongly dependent on the soil moisture content (Telford et al., 1990). According to previous studies by Huguet et al. (1992) and Intrigliolo and Castel (2006a). MDS notably changed with the variation of water availability in the soil. The MDS in deficit irrigated trees was consistently higher than that in well-irrigated ones.

5.2.3.2. Effect of MDS on physicochemical properties of fruit

Compared to several other plant and soil water status indicators, MDS has been shown to respond earlier to soil water shortage (Goldhamer et al., 1999). Previous studies report a negative linear relationship between MDS and stem water potential as a tree water status indicator in almonds (Fereres and Goldhamer, 2003a), lemons (Ortuno et al., 2006), and plums (Intrigliolo and Castel, 2004, 2006a, 2007). MDS increases with tree water deficits, in particular during fruit growth and can, hence, be considered a reliable drought stress indicator for trees (Intrigliolo and Castel, 2004, 2006a). Stage III of fruit growth is more sensitive than stages I and II, because the maximum level of water consumption occurs in stage III (Boland et al., 1993). Therefore, trees classified as low maximum daily shrinkage (LMDS) and high maximum daily shrinkage (HMDS) in the present study (Fig. 7) might also be indicative of low and high water deficits, respectively.

In this study, Colour parameters measured preharvest showed that 'Jojo' plums of HMDS trees had a deeper blue skin colour (i.e. lower b* value) and a higher NAI than those of LMDS trees. This may show that high MDS potentially indicates advanced maturity. In this context, effects of drought stress on fruit quality have also been reported for peaches (Buendia et al., 2008) and nectarines (Thakur and Singh, 2013). These authors reported a higher accumulation of anthocyanins and improved colour in fruit grown under deficit irrigation compared to those grown under full irrigation.

Moreover, transpiration rate in LMDS fruit was higher than in HMDS plums during cold storage and simulated shelf life. Crisosto et al. (1994b) assumed that fruit developed under a water deficit had lower water losses than controls due to a thicker cuticle with higher resistance to water losses.

HMDS fruit also had higher SSC and higher dry matter content than those grown in LMDS over the entire experimental period. This can be associated with a decrease in fruit water content under a water deficit. There are several field studies that reported an enhancement of SSC under low soil water availability. Deficit irrigation increased fruit SSC at harvest and after the 14-day cold storage period in plums (Intrigliolo and

Castel, 2010). This is probably due to either an active accumulation of solutes or to fruit dehydration (Intrigliolo and Castel, 2010).

5.3. Interactions of postharvest factors with regard to quality changes in plums

5.3.1. Harvest maturity

Fresh mass and dry matter content

The increase in fresh mass and DMC observed in plums of both cultivars during the harvesting period could indicate that fruit harvested early are still in an initial phase of fruit ripening. Thus, the fruit had not reached their final size (Zuzunaga et al., 2001). In European plums it has been established that fruit mass is affected significantly by harvest date (Valero et al., 2003; Guerra and Casquero, 2008; Usenik et al., 2008; Casquero and Guerra, 2009).

Fruit flesh firmness

As expected, flesh firmness declined significantly during the final phase of fruit development. Hence, the level of flesh firmness was much lower in late harvested fruit when compared with the early harvested ones (Fig. 25. C). Crisosto et al. (2004) previously reported that flesh firmness decreased during the 18 days of the harvest period between the 1st harvest date (31.6 N) and the 4th harvest date (12.9 N) for 'Blackamber' plums, and during the 12 days from the 1st harvest date (69.2 N) to the 5th harvest date (31.5 N) for 'Green Gage' plums (Guerra and Casquero, 2008).

The harvest date-related differences in fruit flesh firmness were also maintained during cold storage and shelf life. Thus, our results confirm those reported by Guerra and Casquero (2010). However, in another study (Guerra and Casquero, 2008), fruit harvested too early (1st harvest) stayed firm during the 40 days of storage. This indicates, in the present investigation, that fruit from all harvest dates were sufficiently mature at harvest to ripen further off the tree in cold storage (Guerra and Casquero, 2010). The increased activity of hydrolytic enzymes such as polygalacturonase, pectin methylesterase and endo–1,4–β–D–glucanase is reportedly responsible for cell–wall modifications, leading to decrease fruit firmness during cold storage in 'Tegan Blue' plums (Khan et al., 2008).

Skin colour

Changes in skin colour during the harvesting period have been reported for many cultivars of Japanese and European plums (Taylor et al., 1993a; Taylor et al., 1995; Abdi et al., 1997; Crisosto et al., 2004; Casquero and Guerra, 2009). In the present study, the surface colour of 'Jojo' plums changed initially from green to violet to dark blue during ripening. In this cultivar, the skin becomes blue relatively early during fruit development, well before the optimal harvesting maturity has been reached. However, the changes of a* and b* indicated that plum colour was slightly improved and reached a complete blue through further maturation from the 1st to the 3rd harvest date (Fig. 25. A, B).The fact that colour only changed further during storage in early-harvested fruit but not in mid-late or late-picked plums may indicate that the latter had already reached the final stage of maturation at harvest and, hence, an 'optimal' dark blue skin colour.

Soluble solids content and titratable acidity

Soluble solids content and titratable acidity are assumed to be good indicators for acceptance of plums by consumers (Crisosto et al., 2004; Manganaris et al., 2008). For most consumers, plums with a SSC below 12.5 °Brix were not acceptable (Vangdal, 1980). In the present investigation, SSC significantly increased with later harvesting, as also previously reported for fruit of other European plum cultivars (Taylor et al., 1995; Guerra and Casquero, 2008; Usenik et al., 2008). In the present study, SSC of fruit was always higher than 12.5 °Brix, irrespective of date of harvest. Nevertheless, titratable acidity was also high in early-harvested plums; consequently, these fruit did not seem ready for consumption.

Titratable acidity of plums decreased with fruit maturation; hence, acidity strongly depended on harvesting date and, thus, the ripening stage of plums (Crisosto et al., 2004; Crisosto and Crisosto, 2005). This decrease in titratable acidity during the harvesting period was also reported for plums of several other cultivars (Westercamp, 1996; Crisosto et al., 2004; Guerra and Casquero, 2008; Usenik et al., 2008).

In this study, the lack of change in SSC during cold storage and shelf life (Fig. 25. D) can mainly be explained by a low production of CO_2 after the harvest of 'Jojo' plums (Kožiškova and Goliaš, 2012). In addition, according to Kluge et al. (1996), sugar losses due to respiration could compensate the increases in sugar content due to the concentrating effects of water losses in plum fruit. In studies reported by Casquero and Guerra (2009) and Guerra and Casquero (2008), the SSC in 'Green Gage' plums was not changed during cold storage. In contrast, Vangdal (1981) and Westercamp (1996) observed that SSC increased in both 'Mallard' and 'Green Gage' plums during cold storage.

In the present study, the titratable acidity of plums decreased during cold storage. Although, this was statistically irrespective of harvest date, a decline in acidity seemed to be slightly smaller in fruit harvested early. In 'Oullins Gage' plums TA reportedly (Casquero and Guerra, 2009) decreased during storage in fruit of all harvest dates as well, except in those of the earliest maturity. Moreover, Santos and

Ribeiro (1998) found that TA decreased after three weeks of storage in unripe and almost ripe 'Rainha claudia' plums.

The sugar to acidity ratio (SSC:TA) increased during cold storage in fruit of all cultivars (Kluge et al., 1996). Crisosto (1994a) indicated that the SSC:TA ratio might be better suited to differentiate between harvest date-related quality differences of plums than TA or SSC alone. Therefore, the increase in the SSC:TA ratio with fruit maturation, as observed in the present study, may be generally favourable, as it improves both fruit flavour and consumer acceptability. However, Crisosto et al. (2004) reported that consumer acceptance only depended on SSC:TA when SSC was ≤ 12.0% in 'Blackamber' plums; on the contrary, when SSC was ≥ 12.0%, SSC had the greater influence on consumer responses.

Transpiration rate

After harvest, during cold storage and shelf life, fresh fruits and vegetables continue to transpire. As a diffusion process, transpiration is directly related to the driving force, i.e. the water vapour partial pressure gradient between produce skins and the surrounding air (Von Willert et al., 1995; Yehoshua and Rodov, 2003). In the present investigation, early-harvested and thus, less-mature, fruit had higher transpiration rates than those harvested at later dates; both at harvest, and during cold storage and shelf life (Fig. 25. G; Tab. A.3). Hence, these findings confirm the results of Kluge et al. (1996) showing that mass losses were lower in ripe 'Green Gage' plums than in unripe fruit. In contrast, in ripe 'Green Gage' plums, mass losses during storage (40 days) were greater than in unripe fruit (Guerra and Casquero, 2008). In the present study, transpiration rates of 'Jojo' plums decreased during cold storage and shelf life, irrespective of harvest date. Variations in rates of mass loss during storage have also been previously reported (Guerra and Casquero, 2008; Eum et al., 2009; Bal, 2013; Valero et al., 2013). In general, harvesting plums at an optimum stage of maturity could minimize water losses during cold storage.

5.3.2. Edible coating

Fruit transpiration rate and flesh firmness

Fresh fruits and vegetables continue transpiration after harvest and during storage (Yehoshua and Rodov, 2003). Edible coatings act as an extra layer, which reduces transpiration and, consequently mass losses (Valero et al., 2013). The positive effect of various edible coatings on the reduction of mass losses has been demonstrated in plums of various cultivars (Reinoso et al., 2008; Eum et al., 2009; Navarro-Tarazaga et al., 2011; Sohail et al., 2014). As shown in the present study, coating fruit with Versasheen and sorbitol successfully reduced the transpiration of 'Jojo' and 'Tophit plus' plums, during both cold storage and simulated shelf life (Fig. 26).

Similarly, in a previous study by Eum et al. (2009), treatment with Versasheen (5%) and sorbitol (0.2%), as well as Versasheen alone, reduced mass losses in coated Sapphire plums when compared to untreated controls. In this investigation, the authors found that the mass loss in uncoated plums during storage was caused by higher respirational CO_2 losses.

Plasticizers such as sorbitol are generally small molecules that intersperse and intercalate among and between polymer chains, disrupting hydrogen bonding and spreading the chains apart, which not only increases the flexibility of the coating, but also water vapour and gas permeability (Gontard et al., 1993; Sobral et al., 2001).

The differences between the transpiration rates of 'Jojo' and 'Tophit plus' plums during storage may indicate different fruit epidermal and cuticle structures in the fruit of these cultivars (Valero et al., 2013).

Among other factors, fruit softening is caused by a conversion of insoluble proto-pectins into soluble pectin (Krishna and Rao, 2014). The application of coating materials may reduce or delay texture changes during storage not only by decreasing water losses but also by inhibiting pectin solubilisation. This was reported in peaches and plums treated with methyl cellulose or alginate (Maftoonazad et al., 2008; Valero et al., 2013). In the present investigation, Versasheen coatings with sorbitol significantly slowed softening over 21 days of cold storage for 'Jojo' plums and over the whole period of cold storage and simulated shelf life for 'Tophit plus' fruit (Fig. 27). The coating is assumed to reduce cell wall degradation which in turn protects cell wall structure (Bal, 2013). In 'Sapphire' plums, the retardation of fruit softening through the application of a Versasheen (5%) and sorbitol (0.2%) coating during 4 days of room temperature storage has been shown by Eum et al. (2009).

Soluble solids content and titratable acidity

In the present study, SSC did not significantly change during cold storage and simulated shelf life, and was also not affected by the Versasheen coating of plums of both cultivars. This also reflects the data obtained for 'Sapphire' plums (Eum et al., 2009); in that study, SSC remained unaffected by Versasheen coating both with and without sorbitol. The lack of any effects of coatings on the SSC of stored plums may be due to the low CO_2 and ethylene production in these suppressed climacteric fruit (Kožiškova and Goliaš, 2012). In these plums, ethylene production increases only during the later stage of ripening and at low rates, in comparison to fruit of truly climacteric cultivars (Abdi et al., 1997).

Coating with Versasheen did not reduce the decline of TA in 'Jojo' and 'Tophit plus' plums during cold storage. In contrast to this finding, coating 'Sapphire' plums with Versasheen plus sorbitol effectively delayed the reduction of TA during room temperature storage (Eum et al., 2009).

Skin colour

The absence of any significant differences between coated and control fruit during cold storage and shelf life may result from the fact that the blue dark colour had been reached well before harvest. The minor colour changes during storage might be due to the beginning of fruit senescence that leads to a darker colour. The a* and b* values indicated that the blue skin colour of 'Tophit plus' plums was deeper than that of 'Jojo' fruit. Hence, colour is a cultivar-specific property and does not necessarily reflect the stage of maturation.

5.4. Changes in optical fruit properties

5.4.1. Optical properties of plums during fruit development on the tree and during storage

LLBI readings in the green wavelength range

In this study, $FWHM_{532}$ value had noticeably decreased by 33% and 46% by the time of harvest for both 'Jojo' and 'Tophit plus' plums (Fig. 29), and moved closer to the light incident point with increasing levels of ripeness. As the fruit ripened and maturity level increased, anthocyanin and carotenoid pigments appeared. The reduction of $FWHM_{532}$ was related to an increase of anthocyanin (as indicated by NAI) during fruit development. According to the literature, differences at lower wavelengths in the range of 475-560 nm can be the result of typical absorption in anthocyanin (Hopkins, 1995). The highest correlation coefficient has been found for NAI with r = 0.76 and r = 0.85 in 'Jojo' and 'Tophit plus' plums, respectively. Therefore, reduction of FWHM at 532 nm during fruit development could be explained by increases in the content of anthocyanin as indicated by NAI in both cultivars.

Moreover, the more pronounced reduction of $FWHM_{532}$ in 'Tophit plus' plums than in 'Jojo' fruit could be explained by higher changes of NAI value in 'Tophit plus' than 'Jojo' plums. This occurred because the 1st sampling was performed at different physiological stages for the 'Jojo' and 'Tophit plus' plums. At the 1st sampling, the NAI of 'Jojo' fruit was approx. four times larger than that of 'Tophit plus' plums in 2013 (Fig. 17).

The constant $FWHM_{532}$ during storage is in agreement with colour (Fig. 16) and NAI changes (Fig. 17), since the full colour which corresponded to the highest NAI was attained at some approximate point before harvest and was not changed during storage in both cultivars.

LLBI readings in the red and near infrared wavelength range

The results of the backscattering in this study showed that the $FWHM_{660}$ increased in the beginning of the experiment (only in 2013) and then decreased in both cultivars

(Fig. 30). As 660 nm is sensitive to chlorophyll content (Abbott, 1999), the increase of FWHM at 660 nm could be related to fruit chlorophyll content. When the fruit ripened and the chlorophyll pigment disappeared, the light absorption decreased and more photons were backscattered (Romano et al., 2012).

In 2011, there was no increase in $FWHM_{660}$, because the chlorophyll was already decreased and the skin colour had already become almost dark blue before the sampling period. Hashim et al. (2014) showed that the values of the backscattering parameters at 660 nm, such as inflection point (IP) and FWHM, increased with decreasing chlorophyll content during the fruit ripening of bananas.

It is not easy to interpret the reduction of $FWHM_{660}$ during experimental time. But it can be explained by interaction changes between molecules and the light caused by change in fruit components, as we found a correlation between some fruit components and $FWHM_{660}$, especially in 'Tophit plus' plums (Tab. 11). Therefore, reduction of $FWHM_{660}$ as a scatter profile might be explained by increases in SSC and dry matter content during the preharvest period. Romano et al. (2011) reported that the backscattering area at 635 nm decreased with a reduction in moisture content while increasing SSC and hardness in fruit tissue during fruit drying. They explained that this can happen due to an increase in light absorption by the fruit solid material including saccharides, resulting in less scattered light by the end of fruit drying. The different behaviour of $FWHM_{660}$ between years and cultivars can also be explained with their component values.

In this study, contrary to 660 nm, it was observed that the $FWHM_{785}$ values increased during the pre- and postharvest periods in both 'Jojo' and 'Tophit plus' plums. This phenomenon might be related to the changes in the textural properties of the plums during storage. As a result, wavelengths around 770 and 2500 nm are sensitive to textural properties and the laser light around 780 and 880 nm provides information mainly on the light scattering in the fruit tissue (Qing et al., 2007b).

On one hand, the increase in $FWHM_{785}$ during the preharvest period could be due to a slight reduction in the water content of the fruit (Fig.13). With the reduction of moisture, air can replace water in some inter-cellular spaces, causing an increase in near-infrared light refraction (785 nm) and thus a higher scattering coefficient can be measured (Romano et al., 2010).

On the other hand, the increase of FWHM calculated at 785 nm during the duration of the experiment was parallel with the softening of the plum (Fig. 15). This suggests that fruit flesh firmness is related to fruit texture properties, thus, influencing the light scattering in the fruit tissue. The difference in the behaviour of $FWHM_{785}$ between years and cultivars can be explained with the different values of their fruit firmness (Fig. 15).

Basically, soft fruits have more intercellular spaces compared to firmer ones (Harker et al., 1997) and as a consequence, differences in reflectance from the tissue can be expected (Peng and Lu, 2007). As reported by Hashim et al. (2014), the backscattering parameters of bananas obtained at 785 nm (e.g. FWHM and inflection point) decreased with increasing fruit hardness during storage at chilling temperatures. Moreover, they explained that light penetration into the tissues of firm fruit is more difficult, and hence the photons took a straight trajectory and a more direct reflection occurred, instead of backscattering.

The relationship between $FWHM_{785}$ and quality parameters of both cultivars during the experiments of 2011 and 2013 showed that the $FWHM_{785}$ was positively correlated with fruit firmness ($r > 0.50$; Tab. 12). The highest correlation was reached in plums of 'Tophit plus' in 2013 ($r = 0.79$). Although, the relationship between $FWHM_{785}$ and flesh firmness in 'Tophit plus' plums ($r = 0.60$) was lower than that in 'Jojo' ($r = 0.72$), considering the total duration of the experiment in 2011 (Tab. 12), when the regressions were broken down into two time periods - preharvest and postharvest - the correlations obtained from 'Tophit plus' plums were higher than those from 'Jojo' plums during the postharvest period (data not shown).

Previous studies (Lu, 2004; Qing et al., 2007a) have shown that light backscattering profiles from apple fruit can be used to predict fruit firmness with $r = 0.87$ and $r = 0.90$, respectively. Additionally, Mollazade et al. (2013) have studied the potential of texture-based image analysis features for laser light backscattering to predict the mechanical properties of mushrooms, tomatos, apples, and plums. They found the highest correlation coefficient for prediction in tomato ($r = 0.92$) followed by mushroom ($r = 0.90$), apple ($r = 0.89$), and plum ($r = 0.79$).

5.4.2. Effects of pre- and postharvest factors on change in optical properties of plums

Both crop load and MDS affected $FWHM_{532}$ during fruit development on the tree. The reduction of $FWHM_{532}$ in plums of low crop load (LCL) and high maximum daily shrinkage (HMDS) was higher than in those obtained from high crop load (HCL) and low maximum daily shrinkage (LMDS). Such a finding can be interpreted with NAI changes during fruit development since there was a high correlation between NAI and $FWHM_{532}$ (Fig. 31). Therefore, the higher value of NAI in fruits of LCL and HMDS caused a higher light absorption at 532 nm through the level of anthocyanin pigments in this fruit, resulting in a lower scatter profile of $FWHM_{532.}$

In this study, contrary to the light at 532 nm, the optical values of $FWHM_{660}$ and $FWHM_{785}$ were not affected by preharvest (Soil ECa, Crop load and MDS) factors. This may have occurred because the $FWHM_{785}$ is related to fruit texture, while preharvest factors mostly affected fruit chemical properties such as SSC and dry matter in both plum fruit.

Regarding the optical profile of FWHM during harvest period, $FWHM_{660}$ and $FWHM_{785}$ declined from the 1st to the 3rd harvest date (Tab. A. 4). Irrespective of the date of harvest, these profiles further decreased and increased, respectively, during cold storage and shelf life. These changes may have occurred due to changes in the physicochemical properties of the fruit, as explained in detail in 5.4.1.

The edible coating affected the $FWHM_{785}$ during storage (Tab. 10). In 'Jojo' plums, the increase of $FWHM_{785}$ in coated fruit was significantly lower than in the controls. These findings can be explained by the changes in fruit texture during fruit development, since there was a high negative correlation between flesh firmness and $FWHM_{785}$. Therefore, the coated fruit with a high firmness caused a lower scatter profile of $FWHM_{785}$. Further details are explained in 5.4.1. (LLBI readings in the red and near infrared wavelength range).

Conclusion

Crop load had a strong effect on the physicochemical properties of fruit of both cultivars in 2012 and 2013 but not in 2011. Plums grown on low crop load trees had generally higher fresh mass, dry matter content, SSC, NAI and advanced colour (CIE b* values) than those grown on high crop load trees. In contrast, the effect of soil ECa was significant only in 2013. Here, the low soil ECa caused lower fresh mass in fruit of both cultivars and higher SSC, dry matter content and NAI (during preharvest) in 'Jojo' fruit. These differences between effects of LECa and HECa zones suggest the need for specific management strategies for each zone in order to reach optimum fruit yield and quality. Crop load and soil ECa did not have any considerable interactive effect on fruit quality, except in 'Tophit plus' in 2013. Here, the effects of crop load on SSC and dry matter content were statistically significant, however only under a LECa. In general, fruit from low crop load trees grown under a low ECa had the highest SSC and dry matter content, while those from low crop load trees under a high ECa showed the highest level of fresh mass in 2013.

A clear relationship between MDS as a water deficit indicator and fruit quality could be obtained in both cultivars. Trees characterised by a low MDS had a lower fruit yield. In addition, their fruit showed higher rates of transpiration than those grown on trees with high MDS in both cultivars. In contrast, preharvest colour development and accumulation of anthocyanins in 'Jojo' was advanced in fruit grown on trees with high MDS. The HMDS plums also developed a higher SSC and dry matter content than those grown on trees with low MDS. This effect, however, was most prominent in 'Jojo' plums. This was probably because of the water deficit in high MDS trees. Nevertheless, it was not shown that high MDS trees suffered from a soil water deficit. In this context, a clear correlation between soil ECa and variations in MDS could not be found. Moreover, several other factors such as the growth stage and crop load of trees may also cause variations in MDS. It is especially important to note that MDS and crop load were correlated in both cultivars in this study.

To summarize, tree crop load, MDS of tree trunks and soil ECa had, respectively, the most significant effects on the physical and chemical properties of developing plums that determine fruit quality.

In 'Jojo', the evaluation of the quality of fruit harvested at different dates clearly indicated that a late harvest of fully ripe plums yielded the best quality by far. These fruit showed the highest fresh mass, lowest transpiration and a fully developed colour. Even though early harvesting has been proposed as a solution to allow for a longer storage period and extended marketability regarding fruit firmness, in this experiment no quality advantage was noted. Cold storage (2°C) of 'Jojo' plums slowed down ripening, thus resulting in a poor taste due to low SSC and SSC:TA, particularly in early harvested fruit. In the present study, flesh firmness and SSC or SSC:TA could be used to distinguish the true stages of maturity at harvest. The results suggested that the best post-storage quality of 'Jojo' plums could be obtained when fruit were harvested with a SSC higher than 15.5, SSC:TA higher than 10.5, and flesh firmness higher than 4.3 N in order to ensure a long storage as well as shelf life. The determination of fruit maturity on the basis of fruit colour is not suitable for plums of this cultivar and needs to involve some other additional parameters to precisely determine fruit maturity.

Additionally, using Versasheen plus sorbitol effectively reduced fruit transpiration and, thus, delayed changes in firmness, especially for 'Tophit plus' plums, during cold storage and shelf life. The application of this edible coating did not show any effect on fruit SSC and skin colour in plums of both cultivars. According to these results, Versasheen-based edible coatings could be used as postharvest treatments to extend both the storage quality and shelf life of 'Jojo' and 'Tophit plus' plums.

Moreover, the results obtained by laser light backscattering imaging profiles indicated that the reduction in full width half maximum measured at 532 nm was always strongly correlated with an increase in anthocyanin content as indicated by NAI during fruit maturation. In contrast, the variation of $FWHM_{660}$ during fruit development may be related to the combined effects of the degradation of fruit chlorophyll content and changes in other fruit properties. Furthermore, the increase in $FWHM_{785}$ was strongly correlated with a decrease in fruit firmness during pre- and postharvest periods. Except for a minor effect of MDS on $FWHM_{532}$, the profiles were not influenced by preharvest factors. In general, the laser-induced backscattering technique using 532 nm and 785 nm lasers could be feasible for non-destructive prediction of NAI and firmness in plum fruit. However a replacement of conventional methods with non-destructive optical methods for the prediction of fruit quality such as firmness in plums needs further research.

Summary

In Europe, plum is an economically important fruit with high consumer acceptance. Despite this, plum consumption has not increased in most European countries, most probably because of a non-uniform fruit quality and a lack of fully-mature fruit. Thus, it is necessary to manage preharvest conditions such as crop load and soil properties optimally in order to obtain high quality plums and to harvest the fruit ripe state. In this study, the effects of (i) soil properties as indicated by the apparent electrical conductivity (ECa), (ii) crop load, and (iii) tree water status as indicated by the maximum daily trunk shrinkage (MDS) on various fruit quality parameters of two European plum cultivars 'Jojo' and 'Tophit plus') were evaluated. Harvest maturity is also important for plums' consumer acceptance due to the detrimental effects that both too early and too late harvests may have on fruit quality. Furthermore, plums are perishable and cannot be stored for long period. Thus, the application of postharvest treatments such as edible coatings can be an effective method for the preservation of plum quality. Hence, additionally to the effects of (1) ECa, crop load and MDS (2) the internal and external fruit quality as it relates to different picking times throughout the harvest period in 'Jojo' plums (2013); (3) the application of a Versasheen and sorbitol-based edible coating on various fruit parameters and, finally, (4) the potential of laser backscattering imaging as an additional optical technique to non-destructively evaluate variations in the quality properties of plum tissues were investigated.

The investigation of plums was carried out in an experimental orchard in 2011, 2012 and 2013. For evaluation of the effects of the preharvest factors, fruit of selected trees were sampled and subjected to laboratory measurements three times before and at the commercial harvest. At the commercial harvest, plums were stored at 2 °C and 90% RH for up to 28 days plus 2 days at 20 °C, after initial analyses. During storage, fruit of each treatment group were removed after 7, 14, 21, 28 and 30 days and analysed. Furthermore, the effects of edible coatings (Versasheen plus sorbitol) on changes in fruit quality during storage were analysed. Various physicochemical quality parameters were recorded using destructive methods. In addition, the optical properties of samples were non-destructively evaluated through laser light backscattering imaging (LLBI).

The results showed that the plums grown on low crop load trees had generally higher fresh mass, dry matter content, total soluble solids content, normalised anthocyanin index (NAI) and advanced colour (CIE b*) than those from high crop load trees in 2012 and 2013. In contrast, soil ECa did not affect fruit quality, except in 2013. Here, the low soil ECa only caused higher total soluble solids content (SSC), dry matter content and anthocyanin content, in 'Jojo' plums while it caused a lower fresh mass in the fruit of both cultivars. In general, fruit from low crop load trees grown under low ECa had the highest SSC and dry matter content, while those from low crop load trees under high ECa showed the highest fresh mass in 2013. Moreover, low MDS trees had lower total fruit yield and their fruit showed higher transpiration than those grown on trees with high MDS. Furthermore, in 'Jojo', fruit grown on high MDS trees had advanced colour and NAI during fruit development on the tree. Additionally, they had a higher fruit SSC and dry matter content when compared to those grown on low MDS trees. This effect, however, was most prominent in 'Jojo' plums.

The evaluation of different harvest maturities for determining the optimal harvest time of 'Jojo' plums indicated that fruit quality was best when plums had been harvested late, preferably at the 3rd harvest date (137 DAFB) in this study. These fruit had the highest fresh mass and lowest transpiration. In contrast, early-harvested fruit were still immature and had low quality; i.e. the SSC was less than 14 °Brix and titratable acidity was higher than 1.7 g per 100 ml juice.

The results of the third part indicated that the coating the plums by Versasheen plus sorbitol reduced their transpiration rate, and thus resulted in lower mass losses when compared to uncoated controls during storage. Moreover, the coating considerably delayed the decrease in flesh firmness by about 7 days in comparison to controls.

Finally, the results of laser light backscattering imaging profiles showed that the decrease and increase of full width half maximum (FWHM) measured at 532 nm and 785 nm, respectively, were correlated with an increase in anthocyanin content and reduction of fruit firmness. However, the variation of FWHM obtained at 660 nm was not easy to interpret.

In conclusion, this study demonstrates that the preharvest factors with high effect on fruit quality considering physicochemical properties of developing plums were

exerted by tree crop load, MDS of tree trunks, and soil ECa, respectively. 'Jojo' plums should be harvested when SSC is higher than 15.5, the SSC:TA ratio is higher than 10.5, and flesh firmness is higher than 4.3 N in order to ensure both a long storage and shelf life. Moreover, Versasheen and sorbitol -based coatings could be effective tools to improve the storability and shelf life of 'Jojo' and 'Tophit plus' plums with regard to losses of fruit mass and firmness. Finally, the LLBI measured at 532 nm and 785 nm has a great potential either to predict some quality parameters of plums such as anthocyanin content and fruit firmness or as a new method for measuring the optical fruit properties itself.

Zusammenfassung

Pflaumen sind eine in Europa wirtschaftlich wichtig Frucht. Das drückt sich in einer hohen Verbraucherakzeptanz aus. Wegen der häufig unbefriedigenden Fruchtqualität, nicht zuletzt aufgrund von oft unreif geernteter Früchte, hat der Verbrauch in den letzten Jahren jedoch nicht weiter zugenommen. Aus diesem Grund ist es notwendig, sowohl die Vorerntebedingungen wie Fruchtbehang und Bodeneigenschaften optimal zu gestalten, um Pflaumen in hoher Qualität zu erzeugen als auch die Früchte im richtigen Reifestadium zu ernten.

Im Rahmen der vorliegenden Untersuchung wurde der Einfluss verschiedener Vorerntefaktoren auf unterschiedliche Fruchtqualitätseigenschaften bei zwei Europäischen Pflaumenarten, 'Jojo' und 'Tophit plus', analysiert. Diese Faktoren waren (i) die Bodeneigenschaften, gemessen über die elektrische Leitfähigkeit des Bodens, (ii) der Fruchtbehang, und (iii) der Baumwasserzustand, erfasst über die maximale tägliche Schrumpfung des Stammes.

Die optimale Reife zur Ernte ist ebenso wichtig für die Akzeptanz der Pflaumen. Sowohl unreife als auch überreife Früchte sind beim Konsumenten unerwünscht. Desweitern sind Pflaumen leicht verderblich und können nicht für lange Zeit gelagert werden. Aus diesem Grund kann eine Nacherntebehandlung mit essbaren Überzügen, sogenannte coatings, eine effektive Methode sein, um die Pflaumenqualität länger zu erhalten.

Die Forschungsziele dieses Projektes waren daher

- 1. den Einfluss und die interaktiven Effekte der Bodeneigenschaften (ECa), des Fruchtbehangs (crop load) und des Baumwasserzustand (MDS) auf die Änderungen der Fruchtqualität während der Vor- und Nachernteperiode von Pflaumen zu untersuchen,
- 2. den Effekt von unterschiedlichen Pflückterminen während der gesamten Ernteperiode auf die innere und äußere Fruchtqualität von 'Jojo'-Pflaumen zu bewerten,
- 3. die Wirksamkeit von Versasheen und Sorbitol-basierten essbaren Überzügen (coating) auf verschiedene Fruchtparameter zu bewerten und abschließend,

- 4. das Potenzial von Laserlichtrückstreubildanalyse (laser backscattering imaging, LLBI) als ein neuartiges optisches Verfahren zur zerstörungsfreien Bewertung von Qualitätseigenschaften des Pflaumengewebes abzuschätzen.

Die Untersuchungen wurden in einem Forschungsobstgarten nahe Potsdam, Deutschland, in den Jahren 2011 bis 2013 durchgeführt. Um die Einflüsse der Vorerntefaktoren zu bewerten, wurden Früchte dreimal vor und einmal zum kommerziellen Erntetermin geerntet und im Labor untersucht. Anschließend wurden die Pflaumen bei 2°C und 90% relativer Luftfeuchte für bis zu 28 Tage plus 2 Tage bei 20°C gelagert. Während der Lagerzeit wurden Früchte von jeder Behandlungsgruppe nach 7, 14, 21, 28 und 30 Tagen entnommen und analysiert. Weiterhin wurden die Effekte der essbaren Überzüge auf Veränderungen in der Fruchtqualität während der Lagerung analysiert. Verschiedene physikalisch-chemische Qualitätsparameter wurden mit destruktiven Untersuchungsmethoden erfasst. Zusätzlich wurden die optischen Eigenschaften von Proben zerstörungsfrei mit Hilfe von Laserlichtrückstreubildverarbeitung bestimmt.

In den Jahren 2012 und 2013 hatten Pflaumen von Bäumen mit geringem Fruchtbehang grundsätzlich höhere Frisch- und Trockenmasse, höhere Gesamtgehalte an löslichen Feststoffen (SSC), einen höheren normalisierten Anthocyanindex (NAI) und eine bessere Entwicklung der Farbe (CIE b*) als Früchte von Bäumen mit hohem Fruchtbehang. Außer im Jahr 2013 beeinflusste die Bodenqualität (ECa) im Gegensatz dazu die Fruchtqualität nicht. In diesem Jahr führte eine geringere Bodenqualität zu höheren SSC, Trockenmassegehalt und Anthocyangehalt in den 'Jojo' Pflaumen während die Fruchtfrischmasse bei beiden Pflaumensorten geringer ausfiel. Grundsätzlich hatten Früchte von Bäumen mit geringerem Fruchtbehang von Böden mit geringen ECa Werten die höchsten SSC und Trockenmassegehalte während solche von Bäumen mit geringem Fruchtbehang aber hohem ECA 2013 die höchste Frischmasse aufwiesen. Zusätzlich zeigten Bäume ohne Wassermangel also mit geringer maximaler täglicher Schrumpfung niedriger Fruchterträge und ihre Früchte zeigten höhere Transpiration als jene von Bäumen mit starker täglicher Schrumpfung. Weiterhin zeigten 'Jojo' Früchte, die an Bäumen mit ungenügender Wasserversorgung (MDS) gewachsen waren, während des Fruchtwachstums eine beschleunigte Farb- und NAI-Entwicklung. Zusätzlich hatten diese Früchte höhere Zucker- und Trockenmassegehalte im Vergleich mit den Pflaumen von Bäumen mit guter Wasserversorgung (geringes tägliches maximales Schrumpfen). Dieser Effekt war bei der Sorte 'Jojo' stärker ausgeprägt als bei 'Tophit plus'. Die Bewertung verschiedener Erntetermine für 'Jojo' Pflaumen ergab, dass die beste Fruchtqualität bei den späten Ernteterminen, vorzugsweise beim dritten (ca. 137 Tage nach der Vollblüte), zu erzielen war. Diese Früchte hatten die höchste Frischmasse und zeigten die geringste Transpiration. Im Gegensatz dazu waren früh geerntete Früchte noch zu unreif. Beispielsweise lag der Zuckergehalt unter 14 °Brix und die titrierbare Säure lag über 1,7 g je 100 ml Saft.

Die Versuche im dritten Teil der Arbeit zeigten, dass mit Versasheen und Sorbitol überzogene Früchte deutlich weniger transpirierten, was zu geringerem Frischmasseverlust im Vergleich zu den unbehandelten Früchten während der Lagerung führte. Zusätzlich verzögerte das Coating die Abnahme der Fruchtfleischfestigkeit um etwa 7 Tage im Vergleich zu den Kontrollen.

Abschließend zeigten die Ergebnisse der Untersuchungen mit der Laserlichtrückstreuungsbildanalyse, dass die Ab- und Zunahme des „full width half maximum" – Verlaufs (FWHM), gemessen bei 532 nm bzw. 785 nm, eng mit der Zunahme der Anthocyankonzentration bzw. der Abnahme der Fruchtfleischfestigkeit korrelierten. Jedoch war die Veränderung des bei 660 nm gemessenen FWHM–Verlaufs kaum zu interpretieren.

Zusammenfassend zeigt diese Studie, dass die Vorerntefaktoren einen hohen Einfluss auf die Fruchtqualität bezüglich physikalischer und chemischer Eigenschaften der sich entwickelten Pflaumen haben und diese besonders vom Ertrag, vom Baumwasserzustand und von der Bodenleitfähigkeit beeinflusst werden. 'Jojo' Pflaumen sollten geerntet werden, wenn der Zuckergehalt höher als 15,5°Brix, das Zucker / Säureverhältnis höher als 10,5 liegt und die Fruchtfleischfestigkeit mehr als 4,3 Newton beträgt, um eine lange Lagerfähigkeit und Haltbarkeit zu gewährleisten. Versasheen und Sorbitol-basierte Überzüge können wirkungsvoll die Lagerfähigkeit und Haltbarkeit von 'Jojo' und 'Tophit plus' Pflaumen bezüglich Fruchtmasse und Fruchtfleischfestigkeitsabnahme beeinflussen. Abschließend zeigten die Rückstreumessungen bei 532 und 785 nm, dass dieses zerstörungsfreie optische

Verfahren großes Potenzial für die Analyse verschiedener Qualitätsparameter (z.B. von Anthocyangehalt und Fruchtfleischfestigkeit) von Pflaumen besitzt.

References

Abbott, J.A. (1999). Quality Measurement of Fruits and Vegetables. *Postharvest Biol Tec* **15 (3),** 207-225.

Abdi, N., Holford, P., and McGlasson, W.B. (1997). Effects of Harvest Maturity on the Storage Life of Japanese Type Plums. *Aust J Exp Agr* **37 (3),** 391-397.

Abdi, N., McGlasson, W.B., Holford, P., Williams, M., and Mizrahi, Y. (1998). Responses of Climacteric and Suppressed-Climacteric Plums to Treatment with Propylene and 1-Methylcyclopropene. *Postharvest Biol Tec* **14 (1),** 29-39.

Alcobendas, R., Miras-Avalos, J.M., Alarcon, J.J., Pedrero, F., and Nicolas, E. (2012). Combined Effects of Irrigation, Crop Load and Fruit Position on Size, Color and Firmness of Fruits in an Extra-Early Cultivar of Peach. *Sci Hortic-Amsterdam* **142,** 128-135.

Bal, E. (2013). Postharvest Application of Chitosan and Low Temperature Storage Affect Respiration Rate and Quality of Plum Fruits. *J Agr Sci Tech-Iran* **15 (6),** 1219-1230.

Baranyai, L., and Zude, M. (2009). Analysis of Laser Light Propagation in Kiwifruit Using Backscattering Imaging and Monte Carlo Simulation. *Comput Electron Agr* **69 (1),** 33-39.

Barbosa, R.N., and Overstreet, C. (2012). What Is Soil Electrical Conductivity? Lsu Agcenter Publication No. 3185. Online (Access: 13.07.2015): Https://Www.Lsuagcenter.Com/Nr/Rdonlyres/E57e82a0-3b99-4dee-99b5-Cf2ad7c43aef/77101/Pub3185whatissoilelectricalconductivityhighres.Pdf.

Berman, M.E., and DeJong, T.M. (1996). Water Stress and Crop Load Effects on Fruit Fresh and Dry Weights in Peach (Prunus Persica). *Tree Physiology* **16 (10),** 859-864.

Birth, G.S. (1976). How Light Interacts with Foods. *In: Gaffney, J. J. (Ed.), Quality detection in foods. St. Joseph: American society for Agricultural Engineering, 6-11.*

Blanco, A., Pequerul, A., Val, J., Monge, E., and Aparisi, J.G. (1995). Crop-Load Effects on Vegetative Growth, Mineral Nutrient Concentration and Leaf Water Potential in (Catherine) Peach. *J Hortic Sci* **70 (4),** 623-629.

Blankenship, S.M., and Dole, J.M. (2003). 1-Methylcyclopropene: A Review. *Postharvest Biol Tec* **28 (1),** 1-25.

Boland, A.M., Mitchell, P.D., Jerie, P.H., and Goodwin, I. (1993). The Effect of Regulated Deficit Irrigation on Tree Water-Use and Growth of Peach. *J Hortic Sci* **68 (2),** 261-274.

Bourtoom, T. (2008). Edible Films and Coatings: Characteristics and Properties. *International Food Research Journal* **15 (3)**.

Bramley, R.G.V., and Hamilton, R.P. (2004). Understanding Variability in Winegrape Production Systems 1. Within Vineyard Variation in Yield over Several Vintages. *Aust J Grape Wine R* **10 (1),** 32-45.

Buendia, B., Allende, A., Nicolas, E., Alarcon, J.J., and Gil, M.I. (2008). Effect of Regulated Deficit Irrigation and Crop Load on the Antioxidant Compounds of Peaches. *J Agr Food Chem* **56 (10),** 3601-3608.

Buwalda, J.G., and Lenz, F. (1992). Effects of Cropping, Nutrition and Water-Supply on Accumulation and Distribution of Biomass and Nutrients for Apple-Trees on M9 Root Systems. *Physiol Plantarum* **84 (1),** 21-28.

Campos, C.A., Gerschenson, L.N., and Flores, S.K. (2011). Development of Edible Films and Coatings with Antimicrobial Activity. *Food Bioprocess Tech* **4 (6),** 849-875.

Candan, A.P., Graell, J., and Larrigaudiere, C. (2008). Roles of Climacteric Ethylene in the Development of Chilling Injury in Plums. *Postharvest Biol Tec* **47 (1),** 107-112.

Casquero, P.A., and Guerra, M. (2009). Harvest Parameters to Optimise Storage Life of European Plum 'Oullins Gage'. *Int J Food Sci Tech* **44 (10),** 2049-2054.

Chapman, G.W., Horvat, R.J., and Forbus, W.R. (1991). Physical and Chemical-Changes During the Maturation of Peaches (Cv Majestic). *J Agr Food Chem* **39 (5),** 867-870.

Cohen, M., Goldhamer, D.A., Fereres, E., Girona, J., and Mata, M. (2001). Assessment of Peach Tree Responses to Irrigation Water Deficits by Continuous Monitoring of Trunk Diameter Changes. *J Hortic Sci Biotech* **76 (1),** 55-60.

Cohen, M., Ameglio, T., Cruiziat, P., Archer, P., Valancogne, C., and Dayau, S. (1997). Yield and Physiological Responses of Walnut Trees in Semiarid Conditions: Application to Irrigation Scheduling. *Chania, Greece. Acta Horticulturae* **449,** 273-280.

Conejero, W., Alarcon, J.J., Garcia-Orellana, Y., Abrisqueta, J.M., and Torrecillas, A. (2007). Daily Sap Flow and Maximum Daily Trunk Shrinkage Measurements for Diagnosing Water Stress in Early Maturing Peach Trees During the Post-Harvest Period. *Tree Physiology* **27 (1),** 81-88.

Corwin, D.L., and Lesch, S.M. (2005). Apparent Soil Electrical Conductivity Measurements in Agriculture. *Comput Electron Agr* **46 (1-3),** 11-43.

Corwin, D.L., Lesch, S.M., Shouse, P.J., Soppe, R., and Ayars, J.E. (2003). Identifying Soil Properties That Influence Cotton Yield Using Soil Sampling Directed by Apparent Soil Electrical Conductivity. *Agron J* **95 (2),** 352-364.

Costa, G., and Vizzotto, G. (2000). Fruit Thinning of Peach Trees. *Plant Growth Regul* **31 (1-2),** 113-119.

Crisosto, C.H. (1994a). Stone Fruit Maturity Indices: A Descriptive Review. *Postharvest News and Information* **5,** 65-68.

Crisosto, C.H., and Kader, A.A. (2000). Plum and Fresh Prune Postharvest Quality Maintenance Guidelines. Pomology Department University of California Davis, Ca 95616. Online (Access: 13.07.2015): Http://Kare.Ucanr.Edu/Files/123829.Pdf.

Crisosto, C.H., and Crisosto, G.M. (2005). Relationship between Ripe Soluble Solids Concentration (Rssc) and Consumer Acceptance of High and Low Acid Melting Flesh Peach and Nectarine (Prunus Persica (L.) Batsch) Cultivars. *Postharvest Biol Tec* **38 (3),** 239-246.

Crisosto, C.H., and Costa, G. (2008). Preharvest Factors Affecting Peach Quality. *CAB International. The Peach: Botany, Production and Uses (eds D.R. Layne and D. Bassi)* **20,** 536-549.

Crisosto, C.H., Mitchell, F.G., and Johnson, R.S. (1995). Factors in Fresh Market Stone Fruit Quality *Postharvest News and Information* **6,** 17-21.

Crisosto, C.H., Mitchell, F.G., and Ju, Z.G. (1999). Susceptibility to Chilling Injury of Peach, Nectarine, and Plum Cultivars Grown in California. *Hortscience* **34 (6),** 1116-1118.

Crisosto, C.H., Johnson, R.S., Luza, J.G., and Crisosto, G.M. (1994b). Irrigation Regimes Affect Fruit Soluble Solids Concentration and Rate of Water-Loss of O Henry Peaches. *Hortscience* **29 (10),** 1169-1171.

Crisosto, C.H., Johnson, R.S., DeJong, T., and Day, K.R. (1997). Orchard Factors Affecting Postharvest Stone Fruit Quality. *Hortscience* **32 (5),** 820-823.

Crisosto, C.H., Garner, D., Crisosto, G.M., and Bowerman, E. (2004). Increasing 'Blackamber' Plum (Prunus Salicina Lindell) Consumer Acceptance. *Postharvest Biol Tec* **34 (3),** 237-244.

Crisosto, C.H., Crisosto, G.M., Echeverria, G., and Puy, J. (2007). Segregation of Plum and Pluot Cultivars According to Their Organoleptic Characteristics. *Postharvest Biol Tec* **44 (3),** 271-276.

Cuquel, F.L., Motta, A.C.V., Tutida, I., and De Mio, L.L.M. (2011). Nitrogen and Potassium Fertilization Affecting the Plum Postharvest Quality. *Rev Bras Frutic* **33 (1),** 328-336.

Daane, K., Johnson, R., Michailides, T., Crisosto, C., Dlott, J., Ramirez , H., Yokota, G., and Morgan, D. (1995). Excess Nitrogen Raises Nectarine Susceptibility to Disease and Insects. *Cal Ag* **49 (4),** 13-18.

Daza, A., Garcia-Galavis, P.A., Grande, M.J., and Santamaria, C. (2008). Fruit Quality Parameters of 'Pioneer' Japanese Plums Produced on Eight Different Rootstocks. *Sci Hortic-Amsterdam* **118 (3),** 206-211.

De Belie, N., Tu, K., Jancsok, P., and De Baerdemaeker, J. (1999). Preliminary Study on the Influence of Turgor Pressure on Body Reflectance of Red Laser Light as a Ripeness Indicator for Apples. *Postharvest Biol Tec* **16 (3),** 279-284.

De Clercq, W.P., and Van Meirvenne, M. (2005). Effect of Long-Term Irrigation Application on the Variation of Soil Electrical Conductivity in Vineyards. *Geoderma* **128 (3-4),** 221-233.

De Swaef, T., Mellisho, C.D., Baert, A., De Schepper, V., Torrecillas, A., Conejero, W., and Steppe, K. (2014). Model-Assisted Evaluation of Crop Load Effects on Stem Diameter Variations and Fruit Growth in Peach. *Trees-Struct Funct* **28 (6),** 1607-1622.

Diaz-Mula, H.M., Serrano, M., and Valero, D. (2012). Alginate Coatings Preserve Fruit Quality and Bioactive Compounds During Storage of Sweet Cherry Fruit. *Food Bioprocess Tech* **5 (8),** 2990-2997.

Diaz-Mula, H.M., Zapata, P.J., Guillen, F., Castillo, S., Martinez-Romero, D., Valero, D., and Serrano, M. (2008). Changes in Physicochemical and Nutritive Parameters and Bioactive Compounds During Development and on-Tree Ripening of Eight Plum Cultivars: A Comparative Study. *J Sci Food Agr* **88 (14),** 2499-2507.

Diaz-Mula, H.M., Zapata, P.J., Guillen, F., Martinez-Romero, D., Castillo, S., Serrano, M., and Valero, D. (2009). Changes in Hydrophilic and Lipophilic Antioxidant Activity and Related Bioactive Compounds During Postharvest Storage of Yellow and Purple Plum Cultivars. *Postharvest Biol Tec* **51 (3),** 354-363.

DiazSobac, R., Luna, A.V., Beristain, C.I., DeLaCruz, J., and Garcia, H.S. (1996). Emulsion Coating to Extend Postharvest Life of Mango (Mangifera Indica Cv Manila). *J Food Process Pres* **20 (3),** 191-202.

Dodd, M.C. (1984). Internal Breakdown in Plums. *Deciduous Fruit Grower* **34,** 355-356.

Doerge, T. (2001). Fitting Soil Electrical Conductivity Measurements into the Precision Farming Toolbox. *In Wisconsin Fertilizer, Aglime and Pest Management Conference, Madison, Wisconsin,USA.*

Domsch, H., and Giebel, A. (2004). Estimation of Soil Textural Features from Soil Electrical Conductivity Recorded Using the Em38. *Precis Agric* **5 (4),** 389-409.

Dong, L., Zhou, H.W., Sonego, L., Lers, A., and Lurie, S. (2001). Ripening of 'Red Rosa' Plums: Effect of Ethylene and 1-Methylcyclopropene. *Aust J Plant Physiol* **28 (10),** 1039-1045.

Donhowe, I.G., and Fennema, O. (1993). The Effects of Plasticizers on Crystallinity, Permeability, and Mechanical-Properties of Methylcellulose Films. *J Food Process Pres* **17 (4),** 247-257.

Ehlers, W., and Goss, M.J. (2003). Water Dinamics in Plant Production *CABA Publishing***,** 26-29.

Eum, H.L., Hwang, D.K., Linke, M., Lee, S.K., and Zude, M. (2009). Influence of Edible Coating on Quality of Plum (Prunus Salicina Lindl. Cv. 'Sapphire'). *Eur Food Res Technol* **229 (3),** 427-434.

FAOSTAT. (2014). Statistical Data. Http://Faostat.Fao.Org/Site/567/Desktopdefault.Aspx#Ancor.

Fereres, E., and Goldhamer, D.A. (2003a). Suitability of Stem Diameter Variations and Water Potential as Indicators for Irrigation Scheduling of Almond Trees. *J Hortic Sci Biotech* **78 (2),** 139-144.

Fereres, E., and Soriano, M.A. (2007). Deficit Irrigation for Reducing Agricultural Water Use. *J Exp Bot* **58 (2),** 147-159.

Fereres, E., Goldhamer, D.A., and Parsons, L.R. (2003b). Irrigation Water Management of Horticultural Crops. *Hortscience* **38 (5),** 1036-1042.

Fernandez, J.E. (2014). Plant-Based Sensing to Monitor Water Stress: Applicability to Commercial Orchards. *Agr Water Manage* **142,** 99-109.

Flore, J.A., and Layne, D.R. (1997). Prunus. In: Zamski E, Scheffler H (Eds.), Photoassimilates Distribution in Plants and Crops: Sink-Source Relationship. Marcel Dekker, New York, 825-849.

Gebbers, R., and Zude, M. (2008). Spatial Distribution of Drought Stress and Quality Related Apple Fruit Monitoring on Tree. *In Proceedings CIGR - International Conference of Agricultural Engineering XXXVII Congresso Brasileiro de Engenharia Agrícola, Brazil*.

Girona, J., Marsal, J., Mata, M., Arbones, A., and Dejong, T.M. (2004). A Comparison of the Combined Effect of Water Stress and Crop Load on Fruit Growth During Different Phenological Stages in Young Peach Trees. *J Hortic Sci Biotech* **79 (2),** 308-315.

Goldhamer, D.A., and Fereres, E. (2001). Irrigation Scheduling Protocols Using Continuously Recorded Trunk Diameter Measurements. *Irrigation Sci* **20 (3),** 115-125.

Goldhamer, D.A., Fereres, E., and Salinas, M. (2003). Can Almond Trees Directly Dictate Their Irrigations Needs? *Calif. Agric* **57 (4),** 138-144.

Goldhamer, D.A., Fereres, E., Mata, M., Girona, J., and Cohen, M. (1999). Sensitivity of Continuous and Discrete Plant and Soil Water Status Monitoring in Peach Trees Subjected to Deficit Irrigation. *J Am Soc Hortic Sci* **124 (4),** 437-444.

Gontard, N., S., G., and Cuq, J.L. (1993). Water and Glycerol as Plasticizer Affect Mechanical and Water Vapour Barriers Properties of an Edible Wheat Gluten Film. *J. food Sci.* **58,** 206-211.

Guerra, M., and Casquero, P.A. (2008). Effect of Harvest Date on Cold Storage and Postharvest Quality of Plum Cv. Green Gage. *Postharvest Biol Tec* **47 (3),** 325-332.

Guerra, M., and Casquero, P.A. (2009). Site and Fruit Maturity Influence on the Quality of European Plum in Organic Production. *Sci Hortic-Amsterdam* **122 (4),** 540-544.

Guerra, M., and Casquero, P.A. (2010). Post-Harvest Quality of 'Green Gage' European Plum in Integrated Production: Effects of Year and Fruit Maturity. *J Hortic Sci Biotech* **85 (1),** 66-70.

Gutzler, C., Helming, K., Balla, D., Dannowski, R., Deumlich, D., Glemnitz, M., Knierim, A., Mirschel, W., Nendel, C., Paul, C., Sieber, S., Stachow, U., Starick, A., Wieland, R., Wurbs, A., and Zander, P. (2015). Agricultural Land Use Changes - a Scenario-Based Sustainability Impact Assessment for Brandenburg, Germany. *Ecol Indic* **48,** 505-517.

Harker, F.R., Redgwell, R.J., Hallett, I.C., and Murray, S.H. (1997). Texture of Fresh Fruit. *Horticultural Reviews* **20,** 121-224.

Hashim, N., Janius, R.B., R.A., R., Osman, A., Shitan, M., and Zude, M. (2014). Changes of Backscattering Parameters During Chilling Injury in Bananas. *Engineering Science and Technology* **9 (3),** 314 - 325.

Hewett, E.W. (2006). An Overview of Preharvest Factors Influencing Postharvest Quality of Horticultural Products. *International Journal of Postharvest Technology and Innovation* **1,** 4-15.

Hopkins, W.G. (1995). Light and Pigments: An Introduction to Photobiology. In: Introduction to Plant Physiology.1st Ed. John Wiley & Sons Inc., New York, USA,125-144. .

Huguet, J.G., Li, S.H., Lorendeau, J.Y., and Pelloux, G. (1992). Specific Micromorphometric Reactions of Fruit-Trees to Water-Stress and Irrigation Scheduling Automation. *J Hortic Sci* **67 (5),** 631-640.

HunterLab. (1996). Insight on Colour, Cie L*a*B* Colour Scale. *Applications Note* **8 (7),** 1-4.

Intrigliolo, D.S., and Castel, J.R. (2004). Continuous Measurement of Plant and Soil Water Status for Irrigation Scheduling in Plum. *Irrigation Sci* **23 (2),** 93-102.

Intrigliolo, D.S., and Castel, J.R. (2006a). Usefulness of Diurnal Trunk Shrinkage as a Water Stress Indicator in Plum Trees. *Tree Physiology* **26 (3),** 303-311.

Intrigliolo, D.S., and Castel, J.R. (2006b). Performance of Various Water Stress Indicators for Prediction of Fruit Size Response to Deficit Irrigation in Plum. *Agr Water Manage* **83 (1-2),** 173-180.

Intrigliolo, D.S., and Castel, J.R. (2007). Crop Load Affects Maximum Daily Trunk Shrinkage of Plum Trees. *Tree Physiology* **27 (1),** 89-96.

Intrigliolo, D.S., and Castel, J.R. (2010). Response of Plum Trees to Deficit Irrigation under Two Crop Levels: Tree Growth, Yield and Fruit Quality. *Irrigation Sci* **28 (6),** 525-534.

Intrigliolo, D.S., Ballester, C., and Castel, J.R. (2014). Crop Load Regulation and Irrigation Strategies to Accelerate the Recovery of Previously Water-Stressed Japanese Plum Trees. *Agr Water Manage* **132,** 23-29.

Ionica, M.E., Nour, V., and Trandafir, I. (2012). The Influence of Aero-Ionized Stream on the Storage Capacity of Plums. *Acta Horticulturae* **968,** 205-210.

Ionica, M.E., Nour, V., Trandafir, I., Cosmulescu, S., and Botu, M. (2013). Physical and Chemical Properties of Some European Plum Cultivars (Prunus Domestica L.). *Not Bot Horti Agrobo* **41 (2),** 499-503.

Irvine, J., and Grace, J. (1997). Continuous Measurements of Water Tensions in the Xylem of Trees Based on the Elastic Properties of Wood. *Planta* **202 (4),** 455-461.

Johnson, R.S., and Handley, D.F. (1989). Thinning Response of Early, Mid-Season, and Late-Season Peaches. *J Am Soc Hortic Sci* **114 (6),** 852-855.

Jones, H.G. (1990). Physiological-Aspects of the Control of Water Status in Horticultural Crops. *Hortscience* **25 (1),** 19-26.

Jones, H.G. (2004). Irrigation Scheduling: Advantages and Pitfalls of Plant-Based Methods. *J Exp Bot* **55 (407),** 2427-2436.

Kader, A.A. (2002). Pre- and Postharvest Factors Affecting Fresh Produce Quality, Nutritional Values and Implications for Human Health. In Proceeding of the Internation Congress Food Production and Quality of Life 1, Sassary, Italy, 1, 109-119.

Kader, A.A., and Mitchell, F.G. (1989). Maturity and Quality. *In: LaRue, J.H., Johnson, R.S. (Eds.), Peaches, Plums and Nectarines: Growing and Handling for Fresh Market. Univ. Calif. Dept. of Agric. and Nat. Res., Publication No. 3331, 191-196.*

Kadir, S.A. (2004). Fruit Quality at Harvest of "Jonathan" Apple Treated with Foliarly-Applied Calcium Chloride. *J Plant Nutr* **27 (11),** 1991-2006.

Kathner, J., and Zude-Sasse, M. (2015). Interaction of 3d Soil Electrical Conductivity and Generative Growth in Prunus Domestica. *Eur J Hortic Sci* **80 (5),** 231-239.

Käthner, J., Alchanatis, V., Selbeck, J., Peeters, A., Ben-Gal, A., Blumenstein, O., and Zude, M. (2014). Influence of Small Scale Variability of Soil Eca on the Crop Water Stress Index, Leaf Area Ratio, and Yield in Prunus Domestica Orchard. *In: Proceedings. International Conference of Agricultural Engineering AgEng 2014, Zürich, switzerland, p.1.*

Kays, S.J. (1999). Preharvest Factors Affecting Appearance. *Postharvest Biol Tec* **15 (3),** 233-247.

Khan, A.S., and Singh, Z. (2007). 1-Mcp Regulates Ethylene Biosynthesis and Fruit Softening During Ripening of 'Tegan Blue' Plum. *Postharvest Biol Tec* **43 (3),** 298-306.

Khan, A.S., Singh, Z., Abbasi, N.A., and Swinny, E.E. (2008). Pre- or Post-Harvest Applications of Putrescine and Low Temperature Storage Affect Fruit Ripening and Quality of 'Angelino' Plum. *J Sci Food Agr* **88 (10),** 1686-1695.

King, J., Dampney, P., Lark, R., Wheeler, H., Bradley, R., and & Mayr, T. (2005). Mapping Potential Crop Management Zones within Fields: Use of Yield-Map Series and Patterns of Soil Physical Properties Identified by Electromagnetic Induction Sensing. *Precis Agric* **6,** 167-181.

Klages, K., Donnison, H., #252, nsche, J., and Boldingh, H. (2001). Diurnal Changes in Non-Structural Carbohydrates in Leaves, Phloem Exudate and Fruit in 'Braeburn' Apple *Functional Plant Biology* **28 (2),** 131-139.

Kluge, R.A., Bilhalva, A.B., and Cantillano, R.F.F. (1996). Cold Storage of 'Reubennel' Plums (Prunus Salicina Lindl.): Effects of Ripening Stages and Polyethylene Packing. . *Scientia Agricola* **53,** 226-231.

Kožiškova, J., and Goliaš, J. (2012). Influence of Ripening on the Ethylene and Carbon Dioxide Production During Storage of Plum Fruits. *Acta univ. agric. et silvic. Mendel. Brun* **LX (8),** 133-140.

Krishna, K.R., and Rao, D.V.S. (2014). Effect of Chitosan Coating on the Physiochemical Characteristics of Guava (Psidium Guajava L.) Fruits During Storage at Room Temperature *Indian Journal of Science and Technology* **7 (5),** 554-558.

Krochta, J.M., and DeMulderJohnston, C. (1997). Edible and Biodegradable Polymer Films: Challenges and Opportunities. *Food Technol-Chicago* **51 (2),** 61-74.

Lakso, A.N., Grappadelli, L.C., Barnard, J., and Goffinet, M.C. (1995). An Expolinear Model of the Growth-Pattern of the Apple Fruit. *J Hortic Sci* **70 (3),** 389-394.

Larrigaudiere, C., Candan, A.P., Ubach, D., and Graell, J. (2009). Physiological Response of 'Larry Ann' Plums to Cold Storage and 1-Mcp Treatment. *Postharvest Biol Tec* **51 (1),** 56-61.

Lee, J.H., Bae, R., and Lee, S.K. (2011). Effect of 1-Methylcyclopropene on Postharvest Quality in 'Formosa' Plums (Prunus Salicina L.) Harvested at Various Stages of Maturity. *Korean J Hortic Sci* **29 (6),** 583-591.

Li, H.S., Huguet, J.G., and Bussi, C. (1989b). Irrigation Scheduling in a Mature Peach Orchard Using Tensiometers and Dendrometers. *Irrigation and Drainage Systems* **3,** 1-12.

Li, H.Y., and Yu, T. (2001). Effect of Chitosan on Incidence of Brown Rot, Quality and Physiological Attributes of Postharvest Peach Fruit. *J Sci Food Agr* **81 (2),** 269-274.

Li, S.H., Huguet, J.G., Schoch, P.G., and Orlando, P. (1989a). Response of Peach-Tree Growth and Cropping to Soil-Water Deficit at Various Phenological Stages of Fruit-Development. *J Hortic Sci* **64 (5),** 541-552.

Limandri, S.P., Bonetto, R.D., Di Rocco, H.O., and Trincavelli, J.C. (2008). Fast and Accurate Expression for the Voigt Function. Application to the Determination of Uranium M Linewidths. *Spectrochim Acta B* **63 (9),** 962-967.

Linke, M. (1997). Modelling and Predicting the Postharvest Behaviour of Fresh Vegetables. In: Munack, A.Tantau, H.J. (Eds.), Mathematical and Control Applications in Agriculture and Horticulture, Pergamon Press: Oxford, Uk, 283-288.

Lopez, G., Mata, M., Arbones, A., Solans, J.R., Girona, J., and Marsal, J. (2006). Mitigation of Effects of Extreme Drought During Stage Iii of Peach Fruit Development by Summer Pruning and Fruit Thinning. *Tree Physiol* **26 (4),** 469-477.

Lopez, G., Behboudian, M.H., Vallverdu, X., Mata, M., Girona, J., and Marsal, J. (2010). Mitigation of Severe Water Stress by Fruit Thinning in 'O'henry' Peach: Implications for Fruit Quality. *Sci Hortic-Amsterdam* **125 (3),** 294-300.

Lorente, D., Zude, M., Idler, C., Gomez-Sanchis, J., and Blasco, J. (2015). Laser-Light Backscattering Imaging for Early Decay Detection in Citrus Fruit Using Both a Statistical and a Physical Model. *J Food Eng* **154,** 76-85.

Lu, R. (2001). Predicting Firmness and Sugar Content of Sweet Cherries Using near-Infrared Diffuse Reflectance Spectroscopy. *T Asae* **44 (5),** 1265-1271.

Lu, R.F. (2004). Multispectral Imaging for Predicting Firmness and Soluble Solids Content of Apple Fruit. *Postharvest Biol Tec* **31 (2),** 147-157.

Lück, E., Gebbers, R., Ruehlmann, J., and Spangenberg, U. (2009). Electrical Conductivity Mapping for Precision Farming. *Near Surf Geophys* **7,** 17-25.

Lund, E., Christy, C., and Drummond, P. (2000). Using Yield and Soil Electrical Conductivity (Ec) Maps to Derive Crop Production Performance Information. *In Proceedings of the 5th International Conference on Precision Agriculture, Bloomington, Minnesota, USA*.

Maftoonazad, N., Ramaswamy, H.S., and Marcotte, M. (2008). Shelf-Life Extension of Peaches through Sodium Alginate and Methyl Cellulose Edible Coatings. *Int J Food Sci Tech* **43 (6),** 951-957.

Mancuso, S. (2012). Measuring Roots, Springer. (Edition). **Land,** 151-168.

Manganaris, G.A., Vicente, A.R., and Crisosto, C.H. (2008). Effect of Pre-Harvest and Post-Harvest Conditions and Treatments on Plum Fruit Quality. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 3 (9), 1-10.*

Mann, K.K., Schumann, A.W., and Obreza, T.A. (2011). Delineating Productivity Zones in a Citrus Grove Using Citrus Production, Tree Growth and Temporally Stable Soil Data. *Precis Agric* **12 (4),** 457-472.

Marini, R.P., Sowers, D., and Marini, M.C. (1991). Peach Fruit-Quality Is Affected by Shade During Final Swell of Fruit-Growth. *J Am Soc Hortic Sci* **116 (3),** 383-389.

Marsal, J., Basile, B., Solari, L., and DeJong, T.M. (2003). Influence of Branch Autonomy on Fruit, Scaffold, Trunk and Root Growth During Stage Iii of Peach Fruit Development. *Tree Physiology* **23 (5),** 313-323.

Marsal, J., Lopez, G., Mata, M., and Girona, J. (2006). Branch Removal and Defruiting for the Amelioration of Water Stress Effects on Fruit Growth During Stage Iii of Peach Fruit Development. *Sci Hortic-Amsterdam* **108 (1),** 55-60.

Martinez-Romero, D., Dupille, E., Guillen, F., Valverde, J.M., Serrano, M., and Valero, D. (2003). 1-Methylcyclopropene Increases Storability and Shelf Life in Climacteric and Nonclimacteric Plums. *J Agr Food Chem* **51 (16),** 4680-4686.

Mata, A.P., Val, J., and Blanco, A. (2006). Prohexadione-Calcium Effects on the Quality of 'Royal Gala' Apple Fruits. *J Hortic Sci Biotech* **81 (6),** 965-970.

McGlone, V.A., and Kawano, S. (1998). Firmness, Dry-Matter and Soluble-Solids Assessment of Postharvest Kiwifruit by Nir Spectroscopy. *Postharvest Biol Tec* **13 (2),** 131-141.

McNeill, J.D. (1992). Rapid, Accurate Mapping of Soil Salinity by Electromagnetic Ground Conductivity Meters. In: G.C. Topp, W.D. Reynolds, and R.E. Green, (Eds.), Advances in Measurement of Soil Physical Properties: Bringing Theory into Practice Madison, Wi: Soil Science Society of America, 209-229.

Menniti, A.M., Gregori, R., and Donati, I. (2004). 1-Methylcyclopropene Retards Postharvest Softening of Plums. *Postharvest Biol Tec* **31 (3),** 269-275.

Menniti, A.M., Donati, I., and Gregori, R. (2006). Responses of 1-Mcp Application in Plums Stored under Air and Controlled Atmospheres. *Postharvest Biol Tec* **39 (3),** 243-246.

Miletic´, N., Popovic´, B., Mitrovic´, O., and Kandic´, M. (2012). Phenolic Content and Antioxidant Capacity of Fruits of Plum Cv. "Stanley" (Prunus Domestica L.) as Influenced by Maturity Stage and on-Tree Ripening. *Aust. J. Crop Sci* **6,** 681-687.

Mollazade, K., Omid, M., Tab, F.A., Kalaj, Y.R., and Mohtasebi, S.S. (2015). Data Mining-Based Wavelength Selection for Monitoring Quality of Tomato Fruit by Backscattering and Multispectral Imaging. *Int J Food Prop* **18 (4),** 880-896.

Mollazade, K., Omid, M., Tab, F.A., Kalaj, Y.R., Mohtasebi, S.S., and Zude, M. (2013). Analysis of Texture-Based Features for Predicting Mechanical Properties of Horticultural Products by Laser Light Backscattering Imaging. *Comput Electron Agr* **98,** 34-45.

Muleo, R., Masetti, C., Tellini, A., Loreti, F., and Morini, S. (1994). Modifications of Some Characteristics in Nectarine Fruit Induced by Light Deprival at Different Times of Fruit Growth. *Advanced Horticutural Science* **8,** 75-79.

Murray, X.J., Holcroft, D.M., Cook, N.C., and Wand, S.J.E. (2005). Postharvest Quality of 'Laetitia' and 'Songold' (Prunus Salicina Lindell) Plums as Affected by Preharvest Shading Treatments. *Postharvest Biol Tec* **37 (1),** 81-92.

Nadler, A. (2004). Relations between Soil and Tree Stem Water Content and Bulk Electrical Conductivity under Salinizing Irrigation. *Soil Sci Soc Am J* **68 (3),** 779-783.

Nagy, V., Milics, G., Smuk, N., Kovacs, A.J., Balla, I., Jolankai, M., Deakvari, J., Szalay, K.D., Fenyvesi, L., Stekauerova, V., Wilhelm, Z., Rajkai, K., Nemeth, T., and Nemenyi, M. (2013). Continuous Field Soil Moisture Content Mapping by Means of Apparent Electrical Conductivity (Eca) Measurement. *J Hydrol Hydromech* **61 (4),** 305-312.

Naor, A. (2000). Midday Stern Water Potential as a Plant Water Stress Indicator for Irrigation Scheduling in Fruit Trees. *Acta Horticulturae* **537,** 447-454.

Naor, A. (2006). Irrigation Scheduling and Evaluation of Tree Water Status in Deciduous Orchards. *Hortic. Rev* **32,** 111-166.

Naor, A., Klein, I., Hupert, H., Grinblat, Y., Peres, M., and Kaufman, A. (1999). Water Stress and Crop Level Interactions in Relation to Nectarine Yield, Fruit Size Distribution, and Water Potentials. *J Am Soc Hortic Sci* **124 (2),** 189-193.

Naor, A., Hupert, H., Greenblat, Y., Peres, M., Kaufman, A., and Klein, I. (2001). The Response of Nectarine Fruit Size and Midday Stem Water Potential to Irrigation Level in Stage Iii and Crop Load. *J Am Soc Hortic Sci* **126 (1),** 140-143.

Navarro-Tarazaga, M.L., Massa, A., and Perez-Gago, M.B. (2011). Effect of Beeswax Content on Hydroxypropyl Methylcellulose-Based Edible Film Properties and Postharvest Quality of Coated Plums (Cv. Angeleno). *Lwt-Food Sci Technol* **44 (10),** 2328-2334.

Olivas, G.I., and Barbosa-Canovas, G.V. (2005). Edible Coatings for Fresh-Cut Fruits. *Crit Rev Food Sci* **45 (7-8),** 657-670.

Ortuno, M.F., Alarcon, J.J., Nicolas, E., and Torrecillas, A. (2004). Interpreting Trunk Diameter Changes in Young Lemon Trees under Deficit Irrigation. *Plant Sci* **167 (2),** 275-280.

Ortuno, M.F., Garcia-Orellana, Y., Conejero, W., Ruiz-Sanchez, M.C., Mounzer, O., Alarcon, J.J., and Torrecillas, A. (2006). Relationships between Climatic Variables and Sap Flow, Stem Water Potential and Maximum Daily Trunk Shrinkage in Lemon Trees. *Plant Soil* **279 (1-2),** 229-242.

Ortuno, M.F., Conejero, W., Moreno, F., Moriana, A., Intrigliolo, D.S., Biel, C., Mellisho, C.D., Perez-Pastor, A., Domingo, R., Ruiz-Sanchez, M.C., Casadesus, J., Bonany, J., and Torrecillas, A. (2010). Could Trunk Diameter Sensors Be Used in Woody Crops for Irrigation Scheduling? A Review of Current Knowledge and Future Perspectives. *Agr Water Manage* **97 (1),** 1-11.

Palmer, J.W. (1992). Effects of Varying Crop Load on Photosynthesis, Dry Matter Production and Partitioning of Crispin/M.27 Apple Trees. *Tree Physiol* **11 (1),** 19-33.

Parlange, J.Y., Turner, N.C., and Waggoner, P.E. (1975). Water Uptake, Diameter Change, and Nonlinear Diffusion in Tree Stems. *Plant Physiol* **55 (2),** 247-250.

Pavel, E.W., and Dejong, T.M. (1993). Source-Limited and Sink-Limited Growth Periods of Developing Peach Fruits Indicated by Relative Growth-Rate Analysis. *J Am Soc Hortic Sci* **118 (6),** 820-824.

Peng, Y.K., and Lu, R.F. (2007). Prediction of Apple Fruit Firmness and Soluble Solids Content Using Characteristics of Multispectral Scattering Images. *J Food Eng* **82 (2),** 142-152.

Perez-Gago, M.B., Rojas, C., and Del Rio, M.A. (2003). Effect of Hydroxypropyl Methylcellulose-Lipid Edible Composite Coatings on Plum (Cv. Autumn Giant) Quality During Storage. *J Food Sci* **68 (3),** 879-883.

Pérez-Pastor, A., Ruiz-Sánchez, M.C., Martínez, J.A., Nortes, P.A., Artés, F., and Domingo, R. (2007). Effect of Deficit Irrigation on Apricot Fruit Quality at Harvest and During Storage. *J Sci Food Agr* **87 (13),** 2409-2415.

Perez-Sarmiento, F., Alcobendas, R., Mounzer, O., Alarcon, J., and Nicolas, E. (2010). Effects of Regulated Deficit Irrigation on Physiology and Fruit Quality in Apricot Trees. *Span J Agric Res* **8,** S86-S94.

Ping, J.L., Green, C.J., Bronson, K.F., Zartman, R.E., and Doermann, A. (2005). Delineating Potential Management Zones for Cotton Based on Yields and Soil Properties. *Soil Sci* **170 (5),** 371-385.

Qin, J.W., and Lu, R.F. (2009). Monte Carlo Simulation for Quantification of Light Transport Features in Apples. *Comput Electron Agr* **68 (1),** 44-51.

Qing, Z., Ji, B., and Zude, M. (2007b). Wavelength Selection for Predicting Physicochemical Properties of Apple Fruit Based on near-Infrared Spectroscopy. *J Food Quality* **30 (4),** 511-526.

Qing, Z.S., Ji, B.P., and Zude, M. (2007a). Predicting Soluble Solid Content and Firmness in Apple Fruit by Means of Laser Light Backscattering Image Analysis. *J Food Eng* **82 (1),** 58-67.

Qing, Z.S., Ji, B.P., and Zude, M. (2008). Non-Destructive Analyses of Apple Quality Parameters by Means of Laser-Induced Light Backscattering Imaging. *Postharvest Biol Tec* **48 (2),** 215-222.

Rab, A., Rahman, J., Abdiani, S., Qadim, A., Khattak, M.K., and Nawab, K. (2012). Thinning Intensity Affects the Yield and Fruit Quality of Apricot Cv. Trevett. *Pak J Bot* **44 (3),** 887-890.

Rahmati, M., Vercambre, G., Davarynejad, G., Bannayan, M., Azizi, M., and Genard, M. (2015). Water Scarcity Conditions Affect Peach Fruit Size and Polyphenol Contents More Severely Than Other Fruit Quality Traits. *J Sci Food Agr* **95 (5),** 1055-1065.

Ratliff, L.F., Ritchie, J.J., and Cassel, D.K. (1983). Field Measured Limits on Soil Water Availability as Related to Laboratory-Measured Properties. *Soil Science Society of American* **47,** 770-775.

Rato, A.E., Agulheiro, A.C., Barroso, J.M., and Riquelme, F. (2008). Soil and Rootstock Influence on Fruit Quality of Plums (Prunus Domestica L.). *Sci Hortic-Amsterdam* **118 (3),** 218-222.

Reedy, R.C., and Scanlon, B.R. (2003). Soil Water Content Monitoring Using Electromagnetic Induction. *J Geotech Geoenviron* **129 (11),** 1028-1039.

Reinoso, E., Mittal, G.S., and Lim, L.T. (2008). Influence of Whey Protein Composite Coatings on Plum (Prunus Domestica L.) Fruit Quality. *Food Bioprocess Tech* **1 (4),** 314-325.

Remorini, D., and Massai, R. (2003). Comparison of Water Status Indicators for Young Peach Trees. *Irrigation Sci* **22 (1),** 39-46.

Rettke, M.A., and Dahlenburg, A.P. (1999). Effect of Timing of Hand Thinning on Productivity of Moorpark Apricots Destined for Drying. *Aust J Exp Agr* **39 (7),** 885-889.

Rindlav-Westling, A., Stading, M., Hermansson, A.M., and Gatenholm, P. (1998). Structure, Mechanical and Barrier Properties of Amylose and Amylopectin Films. *Carbohyd Polym* **36 (2-3),** 217-224.

Robertson, J.A., Meredith, F.I., Lyon, B.G., and Norton, J.D. (1991). Effect of Cold-Storage on the Quality Characteristics of Au-Rubrum Plums. *J Food Quality* **14 (2),** 107-117.

Romano, G., Baranyai, L., Gottschalk, K., and Zude, M. (2008). An Approach for Monitoring the Moisture Content Changes of Drying Banana Slices with Laser Light Backscattering Imaging. *Food Bioprocess Tech* **1 (4),** 410-414.

Romano, G., Nagle, M., Argyropoulos, D., and Muller, J. (2011). Laser Light Backscattering to Monitor Moisture Content, Soluble Solid Content and Hardness of Apple Tissue During Drying. *J Food Eng* **104 (4),** 657-662.

Romano, G., Argyropoulos, D., Gottschalk, K., Cerruto, E., and Müller, J. (2010). Influence of Colour Changes and Moisture Content During Banana Drying on Laser Backscattering. *International Journal of Agricultural and Biological Engineering* **3,** 46-51.

Romano, G., Argyropoulos, D., Nagle, M., Khan, M.T., and Muller, J. (2012). Combination of Digital Images and Laser Light to Predict Moisture Content and Color of Bell Pepper Simultaneously During Drying. *J Food Eng* **109 (3),** 438-448.

Roussos, P.A., Sefferou, V., Denaxa, N.K., Tsantili, E., and Stathis, V. (2011). Apricot (Prunus Armeniaca L.) Fruit Quality Attributes and Phytochemicals under Different Crop Load. *Sci Hortic-Amsterdam* **129 (3),** 472-478.

Rutkowski, K., B., M., and P., K. (2008). Nondestructive Determination of 'Golden Delicious' Apple Quality and Harvest Maturity. . *Plant Res* **16,** 39-52.

Sablani, S.S., Kasapis, S., Al-Tarqe, Z.H., Al-Marhubi, I., Al-Khuseibi, M., and Al-Khabori, T. (2007). Isobaric and Isothermal Kinetics of Gelatinization of Waxy Maize Starch. *J Food Eng* **82 (4),** 443-449.

Santos, A.C.A., and Ribeiro, G.P. (1998). Evolution During Cold Storage of Plum 'Rainha Claudia' for Two Different Ripeness Stages at Harvest. *In Physiological and technological aspects of gaseous and thermal treatments of fresh fruit and vegetables Conference COST915, Madrid, Spain*.

Schumann, A.W., and Zaman, Q.U. (2003). Mapping Water Table Depth by Electromagnetic Induction. *Appl Eng Agric* **19 (6),** 675-688.

Seehuber, C., Damerow, L., and Blanke, M. (2011). Regulation of Source: Sink Relationship, Fruit Set, Fruit Growth and Fruit Quality in European Plum (Prunus Domestica L.)-Using Thinning for Crop Load Management. *Plant Growth Regul* **65 (2),** 335-341.

Sekse, L., Simčič, M., and Vidrih, R. (2013). Fruit Surface Colour as Related to Quality Attributes in Two Plum (Prunus Domestica L.) Cultivars at Different Maturity Stages. *Europ.J.Hort.Sci* **78 (1),** 13-21.

Serrano, M., Martinez-Romero, D., Castillo, S., Guillen, F., and Valero, D. (2004). Role of Calcium and Heat Treatments in Alleviating Physiological Changes Induced by Mechanical Damage in Plum. *Postharvest Biol Tec* **34 (2),** 155-167.

Shackel, K.A., Ahmadi, H., Biasi, W., Buchner, R., Goldhamer, D., Gurusinghe, S., Hasey, J., Kester, D., Krueger, B., Lampinen, B., Mcgourty, G., Micke, W., Mrrcham, E., Olson, B., Pelletrau, K., Philips, H., Ramos, D., Schwankl, L., Sibbeti, S., Snyder, R., Southwick, S., Stevenson, M., Thorpe, M., Weinbaum, S. and Yeager, J. (1997). Plant Water Status as an Index of Irrigation Need in Deciduous Fruit Trees. *Horttechnology* **7,** 23-29.

Smith, D.M., and Allen, S.J. (1996). Measurement of Sap Flow in Plant Stems. *J Exp Bot* **47 (305),** 1833-1844.

Sobral, P.J.A., Menegalli, F.C., Hubinger, M.D., and Roques, M.A. (2001). Mechanical, Water Vapor Barrier and Thermal Properties of Gelatin Based Edible Films. *Food Hydrocolloid* **15 (4-6),** 423-432.

Sohail, M., Afridi, S.R., Khan, R.U., Ullah, F., and Mehreen, B. (2014). Combined Effect of Edible Coating and Packaging Materials on Post Harvest Storage Life of Plum Fruits. *ARPN Journal of Agricultural and Biological Science* **9 (4),** 134-138.

Solornakhin, A.A., and Blanke, M.M. (2007). Overcoming Adverse Effects of Hailnets on Fruit Quality and Microclimate in an Apple Orchard. *J Sci Food Agr* **87 (14),** 2625-2637.

Son, L. (2004). Effects of Hand and Chemical Thinning on Fruit Size and Quality of 'Priana' and 'Beliana' Apricot (Prunus Armeniaca) Cultivars. *New Zeal J Crop Hort* **32 (3),** 331-335.

Steppe, K., De Pauw, D.J.W., and Lemeur, R. (2008). A Step Towards New Irrigation Scheduling Strategies Using Plant-Based Measurements and Mathematical Modelling. *Irrigation Sci* **26 (6),** 505-517.

Stopar, M., Bolcina, U., Vanzo, A., and Vrhovsek, U. (2002). Lower Crop Load for Cv. Jonagold Apples (Malus X Domestica Borkh.) Increases Polyphenol Content and Fruit Quality. *J Agr Food Chem* **50 (6),** 1643-1646.

Sudduth, K.A., Drummond, S.T., and Kitchen, N.R. (2001). Accuracy Issues in Electromagnetic Induction Sensing of Soil Electrical Conductivity for Precision Agriculture. *Comput Electron Agr* **31 (3),** 239-264.

Sudduth, K.A., Kitchen, N.R., Bollero, G.A., Bullock, D.G., and Wiebold, W.J. (2003). Comparison of Electromagnetic Induction and Direct Sensing of Soil Electrical Conductivity. *Agron J* **95 (3),** 472-482.

Taylor, M.A., Rabe, E., Dodd, M.C., and Jacobs, G. (1993a). Influence of Sampling Date and Position in the Tree on Mineral Nutrients, Maturity and Gel Breakdown in Cold Stored Songold Plums. *Sci Hortic-Amsterdam* **54 (2),** 131-141.

Taylor, M.A., Rabe, E., Jacobs, G., and Dodd, M.C. (1993b). Physiological and Anatomical Changes Associated with Ripening in the Inner and Outer Mesocarp of Cold-Stored Songold Plums and Concomitant Development of Internal Disorders. *J Hortic Sci* **68 (6),** 911-918.

Taylor, M.A., Rabe, E., Jacobs, G., and Dodd, M.C. (1995). Effect of Harvest Maturity on Pectic Substances, Internal Conductivity, Soluble Solids and Gel Breakdown in Cold-Stored Songold Plums. *Postharvest Biol Tec* **5 (4),** 285-294.

Telford, W.M., L.P., G., and R.E., S. (1990). Applied Geophysics (Chapter.4). Cambridge Univ. Press, New York.

Terron, J.M., da Silva, J.R.M., Moral, F.J., and Garcia-Ferrer, A. (2011). Soil Apparent Electrical Conductivity and Geographically Weighted Regression for Mapping Soil. *Precis Agric* **12 (5),** 750-761.

Thakur, A., and Singh, Z. (2013). Deficit Irrigation in Nectarine: Fruit Quality, Return Bloom and Incidence of Double Fruits. *Europ.J.Hort.Sci* **78 (2),** 67-75.

Topp, B.L., Russell, D.M., Neumüller, M., Dalbó, M.A., and W., L. (2012). Plum (Handbook of Plant Breeding) **8 (3),** 571-621.

Turhan, K.N. (2009). Is Edible Coating Alternative to Map for Fresh and Minimally Processed Fruits. *In 10th International Controlled and Modified Atmosphere Research Conference, Antalya, Turkey, 80-85.*

Udomkun, P., Nagle, M., Mahayothee, B., and Muller, J. (2014). Laser-Based Imaging System for Non-Invasive Monitoring of Quality Changes of Papaya During Drying. *Food Control* **42,** 225-233.

Usenik, V., Orazem, P., and Stampar, F. (2010). Low Leaf to Fruit Ratio Delays Fruit Maturity of 'Lapins' Sweet Cherry on Gisela 5. *Sci Hortic-Amsterdam* **126 (1),** 33-36.

Usenik, V., Kastelec, D., Veberic, R., and Stampar, F. (2008). Quality Changes During Ripening of Plums (Prunus Domestica L.). *Food Chem* **111 (4),** 830-836.

Valero, D., Martinez-Romero, D., Valverde, J.M., Guillen, F., and Serrano, M. (2003). Quality Improvement of Shelf Life by 1-Methylcyclopropene in Plum as Aff Ected by Ripening Stage at Harvest. *Innovative Food Science & Emerging Technologies* **4,** 339-348.

Valero, D., Diaz-Mula, H.M., Zapata, P.J., Guillen, F., Martinez-Romero, D., Castillo, S., and Serrano, M. (2013). Effects of Alginate Edible Coating on Preserving Fruit Quality in Four Plum Cultivars During Postharvest Storage. *Postharvest Biol Tec* **77,** 1-6.

Vangdal, E. (1980). Threshold Values of Soluble Solids in Fruit Determined for the Fresh Fruit Market. *Acta Agr Scand* **30 (4),** 445-448.

Vangdal, E. (1981). Postharvest Ripening of Plums. *Forsking og Forsøk i Landbruket* **32,** 13-20.

Vargas, M., Pastor, C., Chiralt, A., McClements, D.J., and Gonzalez-Martinez, C. (2008). Recent Advances in Edible Coatings for Fresh and Minimally Processed Fruits. *Crit Rev Food Sci* **48 (6),** 496-511.

Von Willert, D.J., Matyssek, R., and Herppich, W.B. (1995). Experimentelle Pflanzenökologie,Grundlagen Und Anwendungen. *In Georg Thieme Verlag, Stuttgart, Germany, pp. 344.*

Vu, K.D., Hollingsworth, R.G., Leroux, E., Salmieri, S., and Lacroix, M. (2011). Development of Edible Bioactive Coating Based on Modified Chitosan for Increasing the Shelf Life of Strawberries. *Food Res Int* **44 (1),** 198-203.

Wareing, P.F., and Patrick, J. (1975). Source-Sink Relations and the Partitioning of Assimilates in the Plant. *In: Cooper, J. P.,(Ed.), Photosynthesis and Productivity in Different Environments. Cambridge University Press,Cambridge, UK, 481-499.*

Webster, A.D., and Spencer, J.E. (2000). Fruit Thinning Plums and Apricots. *Plant Growth Regul* **31 (1-2),** 101-112.

Westercamp, P. (1996). Greengage Plums Infel (R) 1119: Ripeness and Storage.Infos (Paris) **123,** 36-39.

Williamson, J.G., and Coston, D.C. (1989). The Relationship among Root-Growth, Shoot Growth, and Fruit-Growth of Peach. *J Am Soc Hortic Sci* **114 (2),** 180-183.

Wünsche, J.N., Greer, D.H., Laing, W.A., and Palmer, J.W. (2005). Physiological and Biochemical Leaf and Tree Responses to Crop Load in Apple. *Tree Physiol* **25 (10),** 1253-1263.

Yehoshua, S.B. (1969). Gas Exchange, Transportation, and the Commercial Deterioration in Storage of Orange Fruits. J. Am. Soc. *horticult. Sci* **94,** 524-528.

Yehoshua, S.B., and Rodov, V. (2003). Transpiration and Water Stress. *In: Bartz, J.A., Brecht, J.K. In Postharvest Physiology and Pathology of Vegetables, 2nd revised and expanded edition. Marcel Dekker Inc, New York, 111-159.*

Zaman, Q.U., and Schumann, A.W. (2006). Nutrient Management Zones for Citrus Based on Variation in Soil Properties and Tree Performance. *Precis Agric* **7 (1),** 45-63.

Zude, M. (2003). Non-Destructive Prediction of Banana Fruit Quality Using Vis/Nir Spectroscopy. *Fruits* **58 (3),** 135-142.

Zude, M., Truppel, I., and Herold, B. (2002). An Approach to Non-Destructive Apple Fruit Chlorophyll Determination. *Postharvest Biol Tec* **25 (2),** 123-133.

Zuzunaga, M., Serrano, M., Martinez-Romero, D., Valero, D., and Riquelme, F. (2001). Comparative Study of Two Plum (Prunus Salicina Lindl.) Cultivars During Growth and Ripening. *Food Sci Technol Int* **7 (2),** 123-130.

Appendices

Tab. A.2. Statistical analysis of the effects of soil ECa and crop load on flesh firmness, TA and transpiration rate of 'Jojo' and 'Tophit plus' plums during preharvest, at harvest and during 28 days at 2°C plus 2 days at 20°C in 2011, 2012 and 2013.

Quality parameters	Cultivar	Year	Treatment				Factor					
			LECa		HECa		ECa	CL	T	ECa × CL	CL × T	ECa × T
			LCL	HCL	LCL	HCL						
During preharvest												
Flesh firmness (N)	**Jojo**	**2011**	8.2	9.5	9.3	8.2	NS	NS	**	NS	NS	*
		2012	16.0	16.4	16.3	18.0	NS	*	**	NS	**	NS
		2013	17,2	18,8	17.0	17.8	NS	NS	**	NS	NS	NS
	Tophit plus	**2011**	13.7	13.1	14.2	15.3	NS	NS	**	NS	NS	NS
		2013	17.0	18.4	18.0	17.5	NS	NS	**	NS	NS	**
TA (g/100ml)	**Jojo**	**2011**	1.35	1.31	1.37	1.31	NS	NS	**	NS	NS	NS
		2012	1.86	1.96	1.89	1.84	NS	NS	**	NS	**	NS
		2013	2.30	2.24	2.36	2.21	NS	NS	**	NS	**	**
	Tophit plus	**2011**	1.21	1.13	1.20	1.26	NS	NS	**	NS	**	NS
		2013	1.87	1.73	1.73	1.70	NS	NS	**	NS	NS	NS
At harvest												
Flesh firmness (N)	**Jojo**	**2011**	5.4 b	6.8 ab	7.5 a	5.6 ab	NS	NS	-	**	-	-
		2012	4.1	5.4	4.3	4.9	NS	*	-	NS	-	-
		2013	4.9	5.2	4.0	4.2	NS	NS	-	NS	-	-
	Tophit plus	**2011**	5.2	6.8	6.1	5.8	NS	NS	-	NS	-	-
		2013	5.5 b	7.5 ab	8.4 a	7.0 ab	*	NS	-	**	-	-
TA (g/100ml)	**Jojo**	**2011**	1.38	1.15	1.38	1.17	NS	**	-	NS	-	-
		2012	1.11	1.09	0.99	0.92	*	NS	-	NS	-	-
		2013	1.31	1.29	1.25	1.20	NS	NS	-	NS	-	-
	Tophit plus	**2011**	0.81	0.75	0.93	0.65	NS	**	-	NS	-	-
		2013	0.95	0.93	0.99	0.92	NS	NS	-	NS	-	-
During storage												
Flesh firmness (N)	**Jojo**	**2011**	2.6 b	3,0 ab	3.6 a	2.9ab	NS	NS	**	*	NS	NS
		2012	1.3	2.2	1.8	2.3	NS	**	**	NS	**	*
		2013	3.0	3.5	2.8	2.7	NS	NS	**	NS	NS	NS
	Tophit plus	**2011**	4.3	4.8	5.0	4.6	NS	NS	**	NS	NS	NS
		2013	4.5 c	5.5 b	6.5 a	5.5 b	*	NS	**	**	NS	NS
TA (g/100ml)	**Jojo**	**2011**	1.00	0.98	1.03	0.99	NS	NS	**	NS	NS	NS
		2012	0.76	0.72	0.68	0.74	NS	NS	**	NS	NS	NS
		2013	1.11	1.06	1.07	1.01	NS	NS	**	NS	NS	NS
	Tophit plus	**2011**	0.75 a	0.72 ab	0.75 a	0.68 b	NS	**	**	*	NS	NS
		2013	0.81	0.80	0.79	0.75	NS	NS	**	NS	NS	NS
Transpiration rate (g/cm^2h)	**Jojo**	**2011**	0.84	0.76	0.87	0.88	NS	NS	**	NS	NS	NS
		2012	0.78	0.75	0.84	0.73	NS	NS	**	NS	NS	NS
		2013	0.71	0.72	0.76	0.77	*	NS	**	NS	NS	*
	Tophit plus	**2011**	0.96	0.98	0.95	1.15	NS	NS	**	NS	NS	NS
		2013	1.11	1.07	1.17	1.08	NS	*	**	NS	NS	NS

Values are means of each treatment. Statistical significant (LSD test, $p<0.05$) differences between means are indicated by different letter. Significance of effects of treatments (ECa, soil ECa; LECa, low soil ECa; HECa, high soil ECa; CL, crop load; LC, low crop load; HC, high crop load; T, time of measurements) and their interactions on the various parameter are also indicated (*: $p<0.05$; **: $p< 0.01$; ns: not significant).

Tab. A.3. Statistical analysis of the effects of soil ECa and crop load on skin colour (a* and b*) of 'Jojo' and 'Tophit plus' plums during fruit development and at harvest and during 28 days at 2°C plus 2 days at 20°C in 2011, 2012 and 2013.

Quality parameters	Cultivar	Year	Treatment				Factor					
			LECa		HECa		ECa	CL	T	ECa × CL	CL × T	ECa × T
			LCL	HCL	LCL	HCL						
During preharvest												
a* value	Jojo	2011	4.7	5.0	4.6	6.3	NS	*	**	NS	NS	NS
		2012	3.6	3.1	3.8	3.8	NS	NS	**	NS	NS	NS
		2013	0.6	-0.3	0.2	0.9	NS	NS	**	NS	**	NS
	Tophit plus	2011	2.2	4.2	2.8	1.9	NS	NS	**	NS	NS	NS
		2013	-0.7	-0.4	-0.4	1.0	NS	NS	**	NS	NS	NS
b* value	Jojo	2011	-1.4	-0.7	-1.4	0.0	NS	*	**	NS	NS	NS
		2012	6.1	7.4	7.9	8.9	**	*	**	NS	NS	NS
		2013	8.2	11.9	9.2	12.0	NS	**	**	NS	*	NS
	Tophit plus	2011	2.3	0.6	0.1	3.0	NS	NS	**	NS	NS	NS
		2013	3.0	5.9	5.3	6.2	NS	*	**	NS	NS	NS
At harvest												
a* value	Jojo	2011	2.8	3.3	2.6	2.3	NS	NS	-	NS	-	-
		2012	3.5	4.3	4.0	4.2	NS	NS	-	NS	-	-
		2013	2.5	2.3	1.9	3.1	NS	NS	-	NS	-	-
	Tophit plus	2011	0.0	0.4	0.4	0.3	NS	NS	-	NS	-	-
		2013	-0.3	0.8	0.5	0.4	NS	NS	-	NS	-	-
b* value	Jojo	2011	-2.9	-1.2	-2.1	-0.4	NS	*	-	NS	-	-
		2012	-0.6	-0.5	-0.6	-0.5	NS	NS	-	NS	-	-
		2013	-2.4	-1.9	-2.2	-1.8	NS	NS	-	NS	-	-
	Tophit plus	2011	-4.2	-2.1	-3.1	-2.9	NS	NS	-	NS	-	-
		2013	-6.0	-5.6	-5.6	-5.2	NS	NS	-	NS	-	-
During storage												
a* value	Jojo	2011	2.5	2.3	2.4	2.5	NS	NS	NS	NS	NS	**
		2012	2.5	3.1	2.1	3.9	**	**	*	NS	NS	NS
		2013	1.9	2.2	2.3	2.4	NS	NS	NS	NS	NS	NS
	Tophit plus	2011	-0.1	0.1	-0.1	0.2	NS	NS	NS	NS	NS	NS
		2013	0.0	0.1	0.2	0.1	NS	NS	NS	NS	NS	**
b* value	Jojo	2011	-1.4	-1.2	-1.4	-0.9	NS	NS	NS	NS	NS	NS
		2012	-1.8	-0.9	-0.8	-0.6	NS	NS	NS	NS	NS	**
		2013	-1.9	-1.7	-1.8	-1.7	NS	NS	NS	NS	NS	NS
	Tophit plus	2011	-3.8	-3.8	-3.3	-3.8	NS	NS	NS	NS	**	NS
		2013	-5.5	-5.6	-5.9	-5.5	NS	NS	NS	NS	NS	NS

Values are means of each treatment. Significance of effects of treatments (ECa, soil ECa; LECa, low soil ECa; HECa, high soil ECa; CL, crop load; LC, low crop load; HC, high crop load; T, time of measurements) and their interactions on the various parameter are also indicated (*: $p<0.05$; **: $p<0.01$; ns: not significant).

Tab. A.4. Statistical analysis of effects of maximum daily shrinkage (MDS), as well as the interactions between MDS and soil ECa, crop load and time of measurement on fruit quality parameters of 'Jojo' and 'Tophit plus' plums during fruit development, at harvest and during 28 days at 2°C plus 2 days at 20°C) in 2013.

Quality parameters	Treatment				Factor							
	Jojo		Tophit plus		Jojo				Tophit plus			
	LMDS	HMDS	LMDS	HMDS	MDS	MDS × ECa	MDS × T	MDS × CL	MDS	MDS × ECa	MDS × T	MDS × CL
During preharvest												
Fresh mass (g)	30.1	28.7	44.2	43.3	NS	**	NS	NS	NS	NS	NS	NS
NAI (0;1)	0.63	0.72	0.49	0.53	**	*	**	**	NS	**	*	**
DMC (%)	13.4	14.8	16.3	17.3	**	NS	NS	NS	*	**	NS	NS
SSC (°Brix)	12.8	14.1	13.6	14.3	**	NS	NS	**	**	**	NS	NS
a* value	-0.3	1.1	-0.6	1.8	NS	NS	**	NS	NS	NS	**	**
b* value	11.6	9	5.5	5.6	**	NS	**	NS	NS	NS	**	NS
Flesh firmness (N)	17.3	18.0	18.5	20	NS	NS	NS	NS	**	**	NS	NS
TA (g/100ml)	2.27	2.25	1.74	1.65	NS	NS	*	NS	NS	NS	NS	**
At harvest												
Yield (kg/tree)	23	28.1	4.9	5.6	**	NS	-	*	*	*	-	NS
Fresh mass (g)	40.3	38.2	57.8	55.8	NS	*	-	NS	NS	NS	-	NS
DMC (%)	16.7	17.9	19.6	20.3	*	NS	-	NS	NS	NS	-	NS
SSC (°Brix)	16.3	18.2	18.1	19.3	**	NS	-	NS	*	NS	-	NS
a* value	3.2	2.1	0.0	0.8	NS	NS	-	NS	NS	NS	-	*
b* value	-1.5	-2.5	-6.1	-5.2	NS	NS	-	NS	NS	NS	-	NS
Flesh firmness (N)	3.9	4.9	7.8	7.0	NS	NS	-	NS	NS	NS	-	**
TA (g/100ml)	1.22	1.30	0.97	0.92	NS	NS	-	NS	NS	NS	-	NS
During storage												
Transpiration rate ($mg/cm^2 h$)	0.83	0.71	1.11	0.93	**	NS	*	NS	**	**	NS	NS
DMC (%)	17.0	18.2	20.1	21.2	**	NS	NS	*	NS	**	NS	NS
SSC (°Brix)	16.8	18.0	18.0	19.4	**	NS	NS	*	*	**	NS	NS
a* value	2.6	2.0	0.0	0.0	NS	NS	NS	NS	NS	NS	NS	NS
b* value	-1.7	-2.2	-5.9	-4.5	NS	NS	NS	NS	NS	NS	NS	NS
Flesh firmness (N)	2.8	2.9	5.8	5	NS	NS	NS	**	NS	NS	NS	**
TA (g/100ml)	1.02	1.09	0.80	0.75	NS	NS	NS	NS	NS	NS	NS	NS

Values are means of each treatment. Significance of effects of treatments (MDS, maximum daily shrinkage; LMDS, low maximum daily shrinkage; HMDS, high maximum daily shrinkage; ECa, soil ECa; CL, crop load; T, time of measurement) and their interactions on the various parameters are also indicated (*: $p < 0.05$; **: $p < 0.01$; ns: not significant).

Tab. A.5. The effects of harvest dates and storage time on fruit physical and chemical quality parameters and LLBI-derived optical properties of 'Jojo' plum at harvest and during 28 days at 2°C plus 2 days at 20°C in 2013.

	Parameters	Treatment (Harvest date)			Factor		
		1[st]	2[nd]	3[rd]	HD	T	HD × T
At harvest							
physicochemical parameters	**Fresh mass (g)**	34.9 b	37.9 a	39.0 a	**	-	-
	a* value	7.9 a	4.2 b	2.6 c	**	-	-
	b* value	1.9 a	-1.4 b	-2.0 c	**	-	-
	Flesh firmness (N)	9.0 a	7.0 b	4.3 c	**	-	-
	SSC (°Brix)	13.2 c	15,5 b	17.0 a	**	-	-
	TA (g/100ml)	1.76 a	1.51 b	1.26 c	**	-	-
	SSC:TA ratio	7.5 c	9.7 b	14.0 a	**	-	-
	DMC (%)	13.8 c	14.8 b	17.1 a	**	-	-
	Transpiration rate (mg/cm^{2}h)	0.99 a	0.89 b	0.91 b	*	-	-
Optical properties	**$FWHM_{660}$ (%)**	16.6 a	10.7 b	4.7 c	**	-	-
	$FWHM_{785}$ (%)	38.7 c	43.7 b	50.8 a	**	-	-
During storage							
physicochemical parameters	**a* value**	5.8 a	3.9 b	2.4 c	*	NS	*
	b* value	0.1 a	-0.9 b	-1.9 c	*	NS	*
	Flesh firmness (N)	7.2 a	5.0 b	2.8 c	**	**	**
	SSC (°Brix)	13.7 c	15.4 b	17.4 a	**	NS	NS
	TA (g/100ml)	1.61 a	1.31 b	1.05 c	**	**	**
	SSC:TA ratio	8.8 c	12.1 b	17.5 a	**	**	**
	DMC (%)	14.0 c	15.5 b	17.4 a	**	*	NS
	Transpiration rate (mg/cm^{2}h)	0.86 a	0.75 b	0.76 b	**	**	**
Optical properties	**$FWHM_{660}$ (%)**	13.4 a	5.8 b	2.1 c	**	**	NS
	$FWHM_{785}$ (%)	40.5 c	47.4 b	54.2 a	**	**	NS

Values are means of each harvest date. Statistical significant (LSD test, $p<0.05$) differences between means are indicated by different letter. Significance of effects of treatments (HD, harvest date; T, storage time) and their interactions on the various parameter are also indicated (*: $p<0.05$; **: $p<0.01$; ns: not significant).

Tab. A.6. Monthly mean of daily temperature, relative humidity and total precipitation in 2011, 2012 and 2013 (weather station near the orchard).

Month	Relative humidity (%)			Temperature (°C)			Total precipitation (mm)		
	2011	2012	2013	2011	2012	2013	2011	2012	2013
J	93.9	88.1	91.5	2.2	2.7	1.1	18	29	42
F	77.3	85.1	91.6	0.9	-1.0	0.9	10	13	16
M	74.2	75.5	78.5	5.8	8.4	0.3	13	3	14
A	66.3	69.3	70.6	13.7	10.3	10.0	19	17	15
M	62.1	64.3	76.1	16.2	16.6	14.9	22	30	95
J	68.6	74.1	71.1	18.9	17.0	18.6	52	55	72
J	77.2	76.4	67.9	18.6	19.5	21.7	168	121	28
A	76.8	75.0	70.8	19.6	19.8	20.1	58	72	36
S	79.1	76.2	83.5	17.0	15.7	14.3	41	26	35
O	85.5	84.8	84.2	11.1	10.3	12.1	25	22	54
N	91.7	92.4	91.7	5.5	6.3	6.2	0	25	33
D	88.2	92.6	89.8	5.4	1.7	5.0	33	18	26

Tab. A.7. Climatic conditions during transpiration measurements

Year	Air temperature (°C)		Relative humidity (%)	
	Jojo	Tophit plus	Jojo	Tophit plus
2011	21.7 ± 0.5	20.5 ± 0.7	63 ± 3	62 ± 2
2012	21.0 ± 0.5	-	61 ± 3	-
2013	21.0 ± 0.5	21.0 ± 0.5	57 ± 3	56 ± 3

Fig. A.1. Some pictures from experimental orchard and storage room

Publication and conference attendance

Publication

1. **Rezaei kalaj, Y.,** Mollazade, K., Herppich, W., Regen, C., and Geyer, M. (2016). Changes of Backscattering Imaging Parameter during Plum Fruit Development on the Tree and during Storage, *Scientia Horticulturae Journal* 202, 63-69.
2. **Rezaei kalaj, Y.,** Herppich, W., Geyer, M,. and Zude, M. (2016). Relationships Between Maximum Daily Trunk Shrinkage and Fruit Quality Indices in 'Jojo' and 'Tophit plus' Plums, *Fruits Journal* (submited).
3. Mollazade, K., Omid, M., Tab, F. A.**, Kalaj, Y.** R., and Mohtasebi, S. S. (2015). Data Mining-Based Wavelength Selection for Monitoring Quality of Tomato Fruit by Optical Techniques, *International Journal of Food Properties* 18 (4), 880-896.
4. Mollazade, K., Omid, M., Tab, F. A., **Kalaj, Y. R.,** Mohtasebi, S. S. and and Zude, M. (2013). Analysis of Texture-Based Features for Predicting Mechanical Properties of Horticultural Products by Laser Light Backscattering Imaging, *Computers and Electronics in Agriculture* 98, 34-45.

Conference attendance

1. **Rezaei kalaj, Y.,** Herppich, W., and Geyer, M. (2014). Effect of Edible Coating on Postharvest Quality of Plum. 3rd International Conference on "Effects of Pre- and Post-harvest Factors on Health Promoting Components and Quality of Horticultural Commodities", 24-25 March 2014, Skierniewice, Poland.
2. **Rezaei kalaj, Y.,** Regen, C., Mollazade, K., and Geyer, M. (2014). Evaluation of Quality Parameters of Plum Fruit in Postharvest by Laser Induced Backscattering. International Conference of Agricultural Engineering (Ag Eng), 6-10 July 2014, Zürich, Switzerland.
3. **Rezaei kalaj, Y.,** Regen, C., Mollazade, K., and Geyer, M. (2013). Evaluation of Optical Properties of Plum Fruit by Laser Light Backscattering Imaging (LLBI), 1st National Postharvest Symposium (NPS), 30-31 January 2013, Shiraz, Iran. (in Persian).

4. Käthner, J., Gebbers, R., Herppich, W., **Rezaei kalaj, Y.,** and Manuela Zude. (2012). A Sensor Based Approach to Understand Spatial Variability of Plant Parameter in Orchards. 2nd International Conference on Hydrology, 22-27 July 2012, Leipzig, Germany

5. Käthner, J., Jörn Selbeck, J., Gebbers, R., Herppich, W., **Rezaei kalaj, Y.,** and Manuela Zude. (2012). A Sensor Based Approach to Understand Spatial Variability of Plant Parameter in Orchards. 32. GIL Jahrestagung Informationstechnologie für eine nachhaltige Landbewirtschaftung-Freising, Jan 2012, Germany.

Declaration

I hereby declare that the present thesis has not been submitted as a part of any other examination procedure and has been independently written. All passages, including those from the internet, which were used directly or in modified form, especially those sources using text, graphs, charts or pictures, are indicated as such. I realize that an infringement of these principles which would amount to either an attempt of deception or deceit will lead to the institution of proceedings against myself.

Yousef Rezaei Kalaj

Berlin - August 2015

Acknowledgments

There are many people who supported me during my time as a PhD student and to whom I would like to express my gratitude.

First of all, I would like to express **my** deep gratitude to my supervisors Prof. Dr. Uwe Schmidt and Dr. Martin Geyer for accepting me as a PhD student and for their scientific support, valuable advice, comments and encouragement.

In addition, I would like to offer my sincere gratitude to Dr. Martin Geyer for giving me the opportunity to work in and to use the facilities of the horticulture engineering department at the Leibniz-Institut für Agrartechnik Potsdam-Bornim (ATB), and for his exceptional support, assistance and guidance above and beyond the regular duties of a supervisor.

I am particularly grateful to Dr. Werner Herppich and Prof. Manuela Zude for their valuable comments on, their contributions to the proofreading of and their suggestions for improvements to this thesis. I would also like to mention Namrata Pathak's excellent assistance in correcting my thesis.

I also truly appreciate the guidance and helpful comments from Dr. Christian Ammon with regard to the statistical analyses in this work.

I would like to acknowledge Jana Käthner for conducting the soil ECa measurements and for the superb collaboration.

Advice given by Christian Regen was a great help for optical sensors and IT service and that by David Sakowsky for technical support. Thanks are also due to our laboratory colleagues, Corinna Rolleczek and Gabriele Wegner for their assistance and support.

I would like to thank all of my kind colleagues at ATB. You made my time here very enjoyable and I look forward to our future interactions. In particular, I would like to express my appreciation to my friends and fellow colloquium members, Manfred Linke, Jelena Surdilovic, Guido Rux, Theresa Kabakeris, Birgit Seifert, Michael

Pflanz, Dr. Ulrike Praeger, and all members of the horticultural engineering department at ATB for many interesting discussions and productive collaborations.

I would also like to thank the secretary of the Horticultural Engineering Dept Andrea Gabbert. She is always smiling, willing to help and answer questions.

A special thanks goes to my best friend Amin Ghadiri Khozroughi. Thank you for your help and encouragement in my many, many moment of crisis. Your unconditional support helped me a lot during all these years.

I would also like to thank my family-my parents, my sisters and brothers, who have always supported me with their love and care. A huge thank you goes to my Mom and Dad for their unconditional love and support during my whole life.

I would like to dedicate this thesis to my sweet small daughter 'Rosa' who was born 10 months ago.

Last but not least, I would like to express my very great appreciation to my wife, who has supported and accompanied me always, especially during my studies. I could not have finished my studies without her encouragement, patience, sacrifice and sympathy.