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The Effect of Low Temperature Blanching on the Texture of Whole Processed New Potatoes

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The Effect of Low Temperature Blanching on the Texture of Whole Processed New Potatoes

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A thesis presented to the Dublin Institute of Technology for the award
of Master of Philosophy

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Declaration

I certify that this thesis which I now submit for examination for the award of Master of Philosophy, is entirely my own work and has not been taken from the work of others save and to the extent that such work has been sited and acknowledged within the text of my work.

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Signature Helen Crowley Date 1/12/01

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List of Abbreviations

°C	degrees Celcius
ANOVA	Analysis Of Variance
AOAC	Association of Official Analytical Chemists
ATP	Adenosine triphosphate
cm	centimetres
E	Optical density
E_a	activation energy (J K mol$^{-1)}$
E_{max}	maximum slope before fracture (N/mm)
f	dilution factor
F	force
F_R	maximum load force in the raw product after processing (N)
F_{R0}	maxim load force in the raw product before processing (N)
F_T	maximum load force in the blanched product after processing (N)
F_{T0}	maximum load force in the raw product after blanching (N)
K	degrees Kelvin
k	rate constant
k_0	initial rate constant
Kg	kilograms
KN	KiloNewtons
K_T	constant
L	litre
m	metre
min	minute
ml	millilitre
mm	millimetres
N	Newtons
N	nitrogen
n	order of reaction
NADP	β - Nicotinamide adenine dinucleotide phosphate
nm	nanometre
P	property used to characterise softening

PGU	Polygalacturonase
PIT	Pre-processing effect on Initial Texture
PME	Pectinmethylesterase
PVP	Pre-processing effect on texture Variation due to Processing
R	universal gas constant (J K mol^{-1})
R^2	coefficient of determination
s	seconds
T	temperature (K)
t	time
TPA	Texture Profile Analysis
TPT	Total effect on Product Texture
TSE	Time Step Effect
TTE	Time Temperature Effect
v/v	volume per volume
W_f	work to fracture (J)

Abstract

This study was undertaken to investigate 1) the effect of low temperature blanching on the firmness of processed whole new potatoes and 2) to determine the extent to which the activity of pectin methyl esterase (PME), a naturally occurring enzyme in fruits and vegetables (proposed to play a role in firming using low blanching temperatures), contributes to improved firmness in processed pre-blanched potatoes.

Whole new potatoes (var. Maris peer from Portugal and Nicola from England) were blanched at temperatures of 60, 65, 70, 75, 80, 90 and 100°C for times of 5 up to 60 minutes to investigate texture changes with time and temperature. Texture was measured by puncture testing using a probe attached to an Instron Universal Testing Machine. Results showed that blanching temperatures could be grouped according to the rate of texture degradation: 1) 60 - 75°C minimal texture degradation 2) 80°C intermediate degradation and 3) 90 and 100°C rapid degradation. Degradation at temperatures of 90 and 100°C consisted of two phases – an initial rapid phase followed by a slower phase where there was minimal change in texture. The process of texture changes at 80, 90 and 100°C was found to be temperature dependent on application of the Arrhenius equation, which is used to show the temperature dependence of a reaction.

PME activity was studied by blanching whole new potatoes at temperatures of 65, 75, 80 and 90°C for times of 5 up to 30 minutes. Optimum activity was recorded after blanching at 65°C for 15 minutes. The enzyme was rapidly inactivated after 15 minutes at 75°C and after 5 minutes at both 80 and 90°C.

The effect on potato texture of using a low temperature pre-treatment before processing was investigated at processing temperatures of 95 and 100°C for 5 up to 25 minutes with pre-processing temperatures of 65 and 75°C for 5 up to 30 minutes. Texture was measured by shearing the whole potato with a single blade. It was found that using a low temperature pre-treatment at 65°C before processing improved the firmness of the processed potatoes at both 95 and 100°C. However, although the

firmest overall product was achieved with a pre-treatment at 65°C followed by processing at 95°C (highest shear force values) the best result in terms of texture retention when using a low temperature pre-treatment before processing compared to when no pre-treatment was used, was for potatoes pre-processed at 65°C then processed at 100°C. This improved firmness may be related to PME activity at 65°C since blanching at 75°C did not significantly improve the firmness of the processed potatoes ($P > 0.05$).

Calculated instrumental parameters of work to fracture (J) and maximum slope before fracture (N/mm) showed that using a low temperature pre-treatment in combination with a high processing temperature increases the energy required to fracture the product and makes it more elastic thereby strengthening the potato and making it less breakable and more suitable for further processing.

Sensory analysis of a selection of blanching and processing treatments was carried out to see if there was a noticable difference after processing between the texture of potatoes that had received a pre-processing treatment and those that had not. Panellists tested for hardness, denseness, chewiness, moistness, fibres and palatability and were asked to comment on each sample and give their preference. Overall, potatoes that were processed without a pre-treatment were preferred. However, although potatoes that had received a pre-treatment prior to processing were considered to be inedible and undercooked they would be ideal for further processing. Instrumental parameters were found to be good indicators of the hardness and denseness of potatoes.

1. Introduction

The potato (*Solanum tuberosum L.*) is the main staple, not only of the Irish diet but also of the diet of many other nationalities throughout the world. Over the past three decades, potato production according to the FAO (United Nations Food and Agriculture Organization) has grown faster than that of any other crop except wheat (Glennon, 2000). Growing potatoes is the world's most efficient way of converting land, water and labour into an edible product (Barker and Mansfield, 1999). Agriculturally, no other crop in the eyes of developing countries has more production potential. Over a billion people, half of who live in the developing world now eat potato (Glennon, 2000). Ireland is credited with the highest consumption of potatoes in Europe at 140 Kg per capita. No one knows precisely how the potato came to be introduced into Ireland though it is thought to have been introduced at Youghal, Co.Cork by Sir Walter Raleigh (Glennon 2000).

Potato processors in developed countries have been aware of the *production potential* of the potato for a long time. However, with the rise in demand for convenience foods that are tasty, nutritious, economical and low in fat, manufacturers of processed potato products are constantly seeking new and innovative ways of using the potato. There is also increasing pressure from consumers for products that have a texture similar to that of home cooked products. As a result, there is increasingly more interest in ways of minimising or reducing texture degradation during processing.

The overall aim of this work is to study the effects of low temperature blanching on the final texture of cooked whole new potatoes. 'New potatoes' can be defined as potatoes that are harvested as early as three months after being sown. Little research had been undertaken on 'new potatoes' in relation to their texture during and after heat treatment. Only one reference was found to research on measuring the texture of *whole* potatoes. Bourne and Mondy (1967) carried out this study to develop an objective method for determining whether potatoes were considered 'hard' or 'soft and springy', as a measure of the quality of the potato.

New potatoes are an ideal raw material for processing. They have many advantages for the potato processor. They are small and generally uniform in shape and can be processed whole doing away with the need for slicing, chopping and peeling. This would cut down considerably on time and expenses at the preparation stage and reduces waste. Today, new potatoes are available all year round from a variety of different countries and this is a further advantage to the processor. They have the potential to be used in a variety of ways. For example, new potatoes would be ideal for inclusion in ready meals as a substitute for meat, to give mouthfeel satisfaction. They could be included in Mediterranean style dishes, salads or simply presented by themselves with butter and herbs. It was felt by this author that new potatoes were not being sufficiently exploited by potato processors and communications with newly established potato processing plants at the start of this study revealed that information on the effect of processing on potato texture would be beneficial to these processors. By providing information on how new potatoes respond to typical processing conditions used in industry, this study could be particularly beneficial to those processors who are considering using new potatoes.

Generally, when the texture of potatoes is being investigated, regular shaped samples are removed from the potato for heat treatments and subsequent texture measurement. The behaviour of the texture of the whole potato has not been well researched. As a result, this study considers the changes in texture that take place during processing, in particular during blanching and cooking, using whole new potatoes.

Blanching is traditionally carried out at temperatures of 80 to 100°C for short times ranging between 20 s and 15 min (Andersson *et al*, 1994). However, using such high temperatures leads to structural damage and loss of firmness in the fruit or vegetable tissue. This is undesirable, particularly in today's market where the emphasis is on fresh or 'like fresh' foods. Soggy or soft processed vegetables and fruits are no longer acceptable and manufacturers of processed vegetables must find ways of preserving the structural integrity of the fruit or vegetable.

Low temperature blanching, in the range of 55 - 75°C, has been shown to improve the firmness of cooked vegetables and fruits, reducing physical breakdown and sloughing during further processing (Verlinden *et al.*, 2000) and provides an excellent and safe way of preserving texture. It has been proposed that the enzyme pectin methyl esterase (PME), native to many fruits and vegetables including potatoes, plays a role in this firming effect at low blanching temperatures (Andersson *et al.*, 1994). Both blanching and PME activity will be investigated in this study in relation to their effect on the processed texture of whole new potatoes.

1.1 The history of the potato

The history of the potato is an interesting one going back more than thirteen thousand years to the Chilean coast, where potatoes grew wild in a time before human agriculture (Glennon, 2000). The potato was discovered by pre-Inca Indians in the foothills of the Andes Mountains in South America. The original potatoes, ranging from the size of a nut to a small apple, and ranging in colour from red and gold to blue and black, flourished in these temperate mountain plateaux. The first recorded information on the potato was written in 1553 by the Spanish conquistador Pedro Cieza de Leon and soon potatoes joined the treasures carried away by the Spanish invaders (Barker and Mansfield, 1999).

However, although considered a treasure by the Spanish, the potato did not immediately become popular as a food in Europe. There were several reasons for this. Firstly, in 1596, the Swiss botanist Gaspond Baukin named the plant *Solanum tuberosum*. Unfortunately, this linked the potato to the family Solanaceae i.e. the nightshades, whose members include deadly nightshade, tobacco and henbane (as well as aubergine, tomato and sweet pepper). Furthermore, the potato was a root vegetable, a group viewed with strong suspicion in 16th and 17th Century Europe. Herbalists at the time believed that root vegetables provoked 'lust' and among the general population such food was said to cause headaches and dull the senses. They were also said to increase 'evil blood'. This corrupted blood was believed to be the cause of infectious diseases so it was assumed that by eating potato, infectious diseases could be spread. To make matters worse, a rumour in France that potatoes caused leprosy meant that the potato was fast becoming a leper itself. The popularity of the potato did not grow until an army pharmacist in France, having been taken prisoner by the Prussians in the Seven Years War (1756-63), survived on potatoes and became convinced of their worth as a food (Glennon, 2000).

The potato began to gain popularity as a food and by the end of the 18th Century the potato was becoming a major crop, particularly in Germany and Britain. The potato was especially important to the Irish peasants who not only depended on it for their main food source, but also used it to feed their animals who provided their milk, meat and eggs. In the years leading up to the famine (1840's) these peasants were eating an average of ten potatoes per person per day, 80 per cent of their diet (Barker and Mansfield, 1999).

1.2 Potato production, anatomy and composition

1.2.1 Growth of the potato

There are thousands of varieties of potato available today. A recently published handbook (1998) by the USDA (United States Department of Agriculture) Agricultural Research Service listed, for the first time, more than 4000 pedigrees of North American and European potato varieties. This book provides information on the origin of the potato variety, the year of release, countries in which it is cultivated and extensive references. According to statistics from the USDA's Economic Research Service more than 280,000 million tonnes of potatoes are produced throughout the world annually.

Varieties differ in terms of maturity, yield, appearance, disease resistance, market and cooking quality (Thompson, 1967). Generally, each country will have a few varieties that are most popular depending on these characteristics.

Potatoes are a cool season crop, which is why they grow so well in Ireland. They will grow in most types of soil except sandy and alkaline and require adequate moisture to achieve steady growth and maximum yield (Jadhav and Kadam, 1998). Potatoes can be classified according to harvest time, as seen in Table (1.1).

*Table 1.1: Classification of potato according to harvest time**

Classification	**Description**
First early	Sown in Jan/Feb and harvested in June. Referred to as scrapers i.e. skin peels off (not set skin)
Second early	Sown in Feb/March and harvested late June/July
Early main crop	Sown late March/April and harvested from August onwards

* *Teagasc, 1999*

Another classification based on harvest time of potatoes is shown in Table (1.2).

*Table 1.2: Classification of potatoes according to harvest time in Eastern and Central Europe and in Anglo-Saxon Countries**

	Classification	
Growth period	***Central and Eastern Europe***	***Anglo-Saxon Countries***
60-95 days	Early	(First early)
95-125 days	Medium early	(Second early)
125-135 days	Medium late	(Early main crop)
135-145 days	Late	(Late main crop)

* *Lisinska and Leszczynski, 1989*

When a young potato is dug up it has a fragile, flaky skin. This is what is seen with earlies. Early varieties are referred to as new potatoes. They tend to have low dry matter and low starch content and tend to be used in salads or served cooked in their skins. As the potato matures the skin sets and the dry matter and starch content increases. These older varieties are suitable for boiling, frying and roasting. They are used for processing more than new potatoes, particularly for fried products. In general, main-crop potatoes go into long-term storage for sale the next season whilst earlies go straight into the shops (Barker and Mansfield, 1999).

Each year the FAO produces a list of total potato production for the potato producing countries of the world. Table (1.3) gives the production totals for the year 1999.

Table 1.3: *Total potato production for top ten potato producing countries for 1999 (FAO)**

Country	***Potato production 1999 (Million tonnes)***
China	55
EU	48
Russia	31
India	23
U.S.A	22
Poland	20
Belarus	8
Ukraine	7
Turkey	5
Canada	4

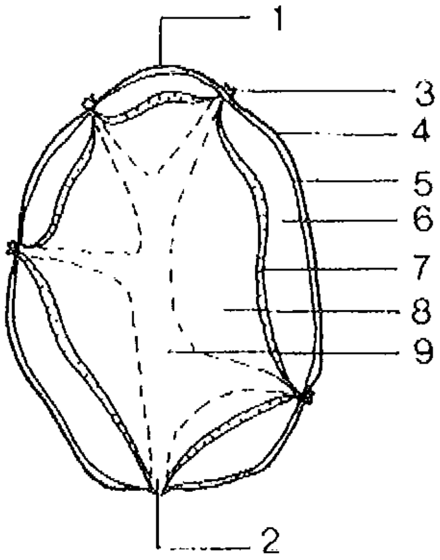
* From the FAOSTAT Database

1.2.2 Structure of the potato tuber

One of the first considerations when dealing with the study of the texture of a food is its structure. Texture is essentially a function of structure. Therefore, processing conditions, such as heat in the case of this study, which bring about a change in the structure of the vegetable tissue, will affect the texture of the end product so a study of texture changes must take into account the structure of the vegetable being used. In the case of the potato the principal areas in the tuber are the *periderm* (skin), the *cortex*, the *vascular cylinder perimedullary zone* and the central *pith* (Figure 1.1). The periderm, or skin, acts as a protective layer over the surface of the potato. Directly underneath the periderm lies a thin layer of parenchyma tissue (soft plant tissue composed of thin walled, relatively undifferentiated cells). Vascular storage parenchyma, which is high in starch, is found in the cortex area. The pith, also called the water core, contains less starch and is located at the centre of the tuber (Jadhav and Kadam, 1998).

In new or immature potatoes, the cortex makes up a very small part of the potato. When the potatoes used in this study were cut in half longitudinally, the cortex could be clearly seen as an area running around the edge, no more than 2mm in

***Figure 1.1** Longitudinal section of the potato tuber showing principal structural features. 1 – bud end; 2 – stem end; 3 – eye; 4 – periderm (skin); 5 – cortex; 6 – parenchyma; 7 – vascular ring; 8 – parenchyma; 9 - pith*
(Lisinska and Leszczynski, 1989)



thickness. This area develops as the potato matures. Although the volume of the tuber occupied by the cortex may appear insubstantial when compared to the pith, it actually comprises a large fraction of the volume and in the case of more mature potatoes can exceed the pith (Anzaldua-Morales, 1992). It is therefore important not to dismiss the cortex and its contribution to potato texture, when measuring texture.

The measurement of potato texture has been approached in many ways but in very few cases has the relationship between structure and texture been considered (Anzaldua-Morales and Bourne, 1992). In many studies the part of the potato used for the texture measurements is not specified despite the importance of specifying such information, since measurements taken in one area of the potato are not the same as those taken in another area. Many reports have shown differences in the texture of cooked potatoes, between measurements taken in the pith area and those in the cortex. So, if one or other of these areas is disregarded, then the results for texture will be inaccurate or misleading. Anzaldua-Morales and Bourne (1992) found that in raw potatoes puncture force in the cortex tissue of eleven potato cultivars was 10 to 90% higher than for pith tissue. In cooked tissue the difference in puncture force was still found to be significant. They also reported that cortex tissue had 3 to 9% higher dry matter than the pith tissue. Ereifej *et al.* (1997) analysed ten potato cultivars grown in Jordan and found there to be significant differences in the composition of the bud end, stem end, vascular area and pith. Taguchi *et al.* (1991) excluded the bud and stem ends and the pith in their experiments to investigate the influence of cultivar and pre-warming on the texture retention of processed potatoes, because of the compositional differences in these areas.

From these observations the importance of being aware of these differences when measuring texture of potatoes seems obvious. Unfortunately, these differences are not always taken into account and many reports give no indication of the area of the tuber used for texture measurements.

1.2.3 Potato Composition

Potato composition is another important consideration when investigating textural changes. Potatoes are made up mostly of water, with starch as the second major component. They also contain protein, sugars, trace amounts of fat and vitamins B and C. Their composition varies greatly depending on variety, storage, growing season, soil type and storage conditions. The average composition is shown in Table (1.4).

*Table 1.4 Average chemical composition of potato tubers (dry matter basis)**

Constituent	**Average range (%)**
Starch	70
Reducing sugars	0.5-2.0
Protein	0.5-0.1
Fat	0.3-0.5
Dietary fibre	6-8

** Jadhav and Kadam, 1998*

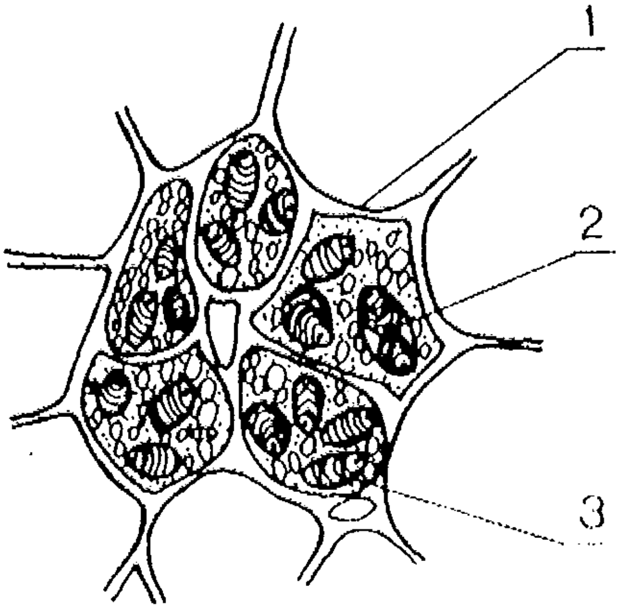
1.2.3.1 Starch

Many convenience potato products are heat treated, which brings demands in terms of the functional properties of different potato cultivars and their starches, required for different products (Hopkins and Gormley, 2000). In the raw tuber starch is stored in microscopic *granules* in the cells of the parenchyma tissue (Figure 1.2). The granules are *ellipsoidal in shape* and about 100 microns by 60 microns on average in size (Talburt and Smith, 1967). Each starch granule contains two polymers of glucose: *amylose*, which is essentially linear, and *amylopectin*, which is branched.

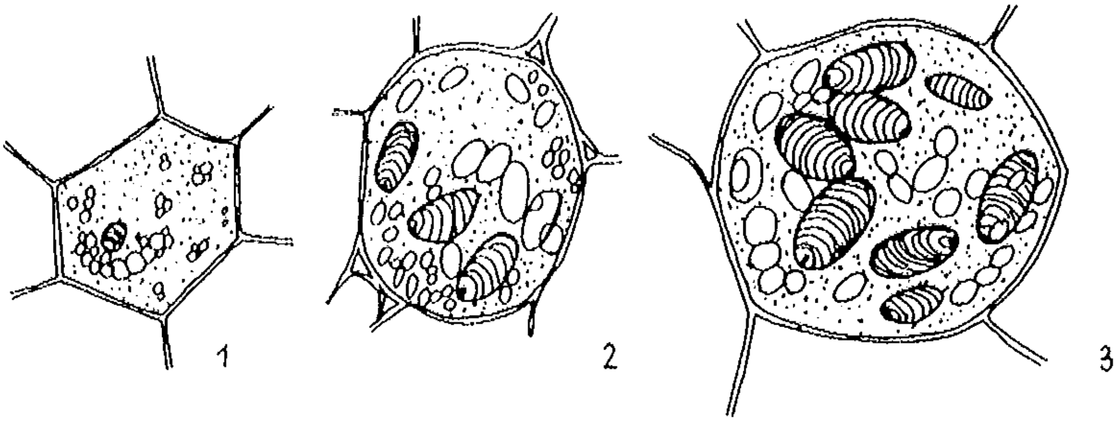
In the plant starch granules represent the plants reserve food store, and from a nutritional point of view, starch is the most important component, providing a valuable source of energy. During potato growth starch content increases with the most intense increase occurring at the initial stage of the tuber growth. It reaches its maximum at different stages of the growing season depending on the variety. The maximum is usually achieved just prior to the maximum yield of potato tubers (Lisinska and Leszczynski, 1989). Starch, making up such a large part of the potato, would be expected to play some sort of role in texture changes during heat treatment. The effect of starch on texture during heat treatment is discussed in Sections 1.3.4 and 1.4.2.1.

Figure 1.2: *Potato tuber cell (a) showing starch granules – 1. cell wall; 2. complex granule; 3. single granule, and (b) during potato growth – 1. a tuber 0.5 cm in diameter; 2. a tuber 2 cm in diameter; 3. mature tuber*
(Lisinska and Leszczynski, 1989)

(a)



(b)



1.2.3.2 Reducing sugars

The reducing sugar (glucose and fructose) content of potatoes is significant when fried potato products are being produced. A high level of reducing sugars leads to a fried product that is dark brown in colour and has an 'off-flavour' due to a reaction between the sugars and amino acids during heating (Maillard reaction) (Coultate, 1996). This, of course, is undesirable and reducing sugar levels are controlled during storage by reconditioning[1] and during blanching where sugars are leached out of the potato. For our study reducing sugar content is not of much interest since these sugars do not have a significant effect on the texture of cooked potatoes.

1.2.3.3 Protein

The essential nitrogen fraction in a potato tuber is protein nitrogen and its contribution to the total content of nitrogen ranges from 27 to 73% (Lisinska and Leszczynski, 1989). Proteins in potatoes are important constituents of cellular membranes, as well as various cytoplasmic structures, and enzymes present in potatoes are also made up of proteins. The major potato tuber protein is tuberine which is in fact made up of albumin and globulin (Lisinska and Leszczynski, 1989). Potatoes contain a higher concentration of lysine than cereals and can supplement a cereal-based diet. Overall the potato is a well-balanced food in terms of protein and energy content (Jadhav and Kadam, 1998).

1.2.3.4 Lipids and other nutrients

Potatoes contain a very small amount of lipids, approximately 0.1% based on fresh weight (Jadhav and Kadam, 1998). The lipid content consists mainly of fatty acids, fats and phospholipids. The predominance of unsaturated fatty acids in potatoes results in easy oxidation, an important consideration in manufacture and storage, especially for dehydrated potato products (Lisinska and Leszczynski, 1989).

Potatoes are an excellent source of ascorbic acid, thiamin, niacin and pyridoxine. Of all the vitamins, vitamin C is present in the greatest amounts, although

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[1] Reconditioning is a process whereby sugar, produced by breakdown of starch during storage, is converted back to starch.

the levels of this vitamin decline with ageing, storage and processing. The potato is also a good source of iron, magnesium, phosphorus and potassium (Jadhav and Kadam, 1998).

1.2.3.5 Specific Gravity

Specific gravity is a parameter generally used by potato processors as an indication of the dry matter content of the potato. Potatoes must lie within a certain specific gravity range (depending on the potato product being produced) in order to be considered suitable for processing. Much research has been carried out in an attempt to correlate specific gravity with the texture of heat-treated potatoes. It would be of great benefit to potato processors if the specific gravity gave an indication of the texture of the finished potato product. However, the results obtained from these studies are conflicting. Some reports show a correlation between specific gravity and texture (Keilbets *et al.*, 1974 and O'Beirne and Cassidy, 1990) but others have found no correlation (Barrios *et al.*, 1963 and McComber *et al.*, 1988). These conflicting results may be explained by the fact that potatoes vary greatly from one season to the next even within the same variety and that different methods of measuring texture were used and different aspects of texture were measured.

1.3 Texture of potatoes

1.3.1 Introduction to the concept of texture

Since the aim of this study is to investigate the effect of low temperature blanching on the texture of processed potatoes it is necessary to have an understanding of what is meant by texture, particularly in relation to potatoes.

Bourne (1982) *classified textural characteristics* into three groups:

1. *Critical:* those foods for which texture is the dominant quality characteristic e.g. potatoes, celery and meat
2. *Important:* foods in which texture makes a significant, but not dominant contribution in comparison to flavour and appearance e.g. bread, sugary confectionary

3. *Minor:* foods in which texture makes a negligible contribution to overall quality e.g. beverages and thin soups

Texture is essentially a function of structure and composition and the changes in texture that take place during heat treatments are brought about by changes in structure and chemical composition. The rigid structure of the raw potato, as with other raw vegetables is mainly due to the *pectic substances*, *celluloses* and *hemicelluloses*, collectively referred to as the cell wall components. It is changes in these cell wall components, as well as changes in starch, that take place during heating that leads to the changes in texture (or texture degradation) observed during and after cooking of potatoes (Van Buren, 1979).

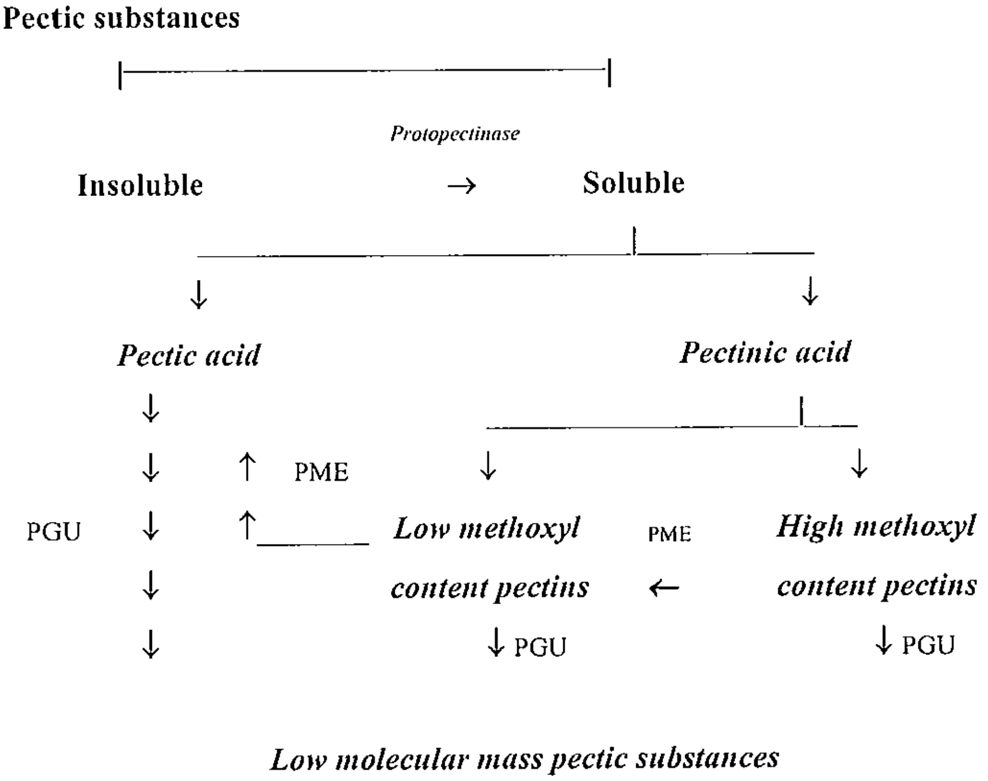
1.3.2 Cell wall components

The function of the cell wall components is to hold the plant tissue together, that is, to give it a structure. Simply put, *cellulose* gives rigidity and resistance to tearing, while the *hemicelluloses* confer plasticity and the ability to stretch. The middle lamella, which may be considered an extension of the primary cell wall lacking the cellulose fibrils, plays the primary role in intercellular adhesion (Van Buren, 1979). The pectic substances, which are the main constituents of the middle lamella, are the components of most interest to this study.

1.3.3 Pectic substances

As well as playing a role in intercellular adhesion, pectic substances also contribute to the mechanical strength of the cell wall. They are brought more easily into solution than other cell wall polymers and are more chemically active. It is for this reason that processes that result in changes in texture, such as ripening, storage and cooking, are accompanied by changes in the characteristics of the pectic substances (Van Buren, 1979). Pectic substances are essentially made up of protopectin (insoluble in water), pectinic acid (soluble in water, high methoxyl pectin) and pectic acids (soluble in water, low methoxyl pectin). Figure (1.3) shows a classification scheme of the pectic substances. It is the calcium and magnesium salts of these pectic acids that are the main components of the intercellular substances cementing the cells and tissues of the potato tuber (Lisinska and Leszczynski, 1989). Softening of vegetables during cooking is considered to be affected by the properties of the pectic substances (Fuchigami, 1987). In simple terms, solubilisation of these pectic substances during heating leads to loss of strength in the middle lamella and consequently loss of structure so that the tissue falls apart.

Figure 1.3: *A classification scheme of the pectic substances showing the enzymatic reactions between the various types**



PME = pectin methyl esterase

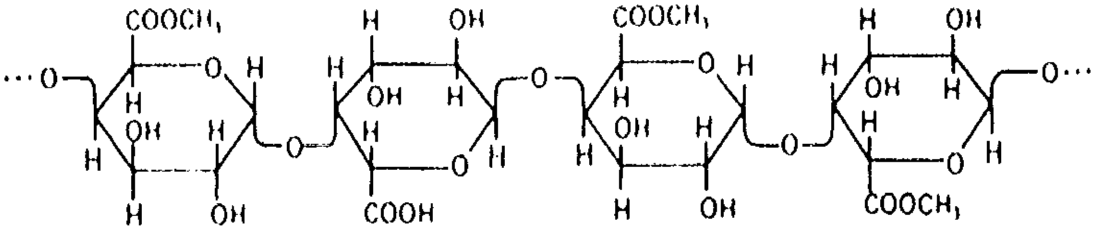
PGU = polygalacturonase

Protopectinase – its existence is only speculative

**Andersson* et al., *1994*

The basic structure of the pectic substances consists of chains of galacturonic residues linked by α (1→4) glycosidic bonds (Figure 1.4). The carboxyl groups of the galacturonic residues are extensively esterified with methyl alcohol (CH_3OH). The degree of such esterification differs among fruits and vegetables but is normally between 50 and 90% (Van Buren, 1979) with the degree of esterification for potatoes found to vary between 34 and 64% (Andersson *et al.*, 1994). Low methoxyl pectins refer to those pectins that have a low level of methoxylation of the galacturonic residue (few $-COOCH_3$ groups) and high methoxyl pectins are extensively esterified. The physiological role of the enzyme, pectin methyl esterase, is thought to be the de-esterification of high methoxyl pectins making them more susceptible to breakdown by the enzyme polygalacturonase, leading to a break down of structure (Andersson *et al*, 1994).

*Figure 1.4: Basic structure of the pectic substances**



* Coultate, 1996

1.3.4 Texture of cooked potatoes

Over the years there have been many attempts to classify the texture of foodstuffs. A *classification system*, proposed by Szczesniak (1963), recognised the following basic textural elements: *hardness, cohesiveness, viscosity, elasticity and adhesiveness*. In this paper it was suggested that the overall texture of a foodstuff was the result of an interaction between a number of these parameters. Classification of the texture of the potato itself has also been attempted, with the earliest suggested classification proposed by Salaman in 1926 (Linehan and Hughes, 1969). The behaviour of cooked potato tissue, when mashed with a fork, was classified by Salaman into four types:

Floury – The tubers often burst spontaneously during cooking and, on the application of a fork, crumble into pieces.

Close – The tubers do not burst on cooking but are readily broken with a fork without crumbling.

Waxy – The flesh is firm and consistent and only breaks down on definite kneading with a fork.

Soapy – The flesh is somewhat similar to that of waxy but is watery and somewhat translucent.

A relatively recent system for the classification of potato texture proposed by the Utilisation and Quality Research Working Group of the European Association for Potato Research gave the following parameters: *disintegration, consistency, firmness, mealiness, dryness and structure* (Rose *et al.*, 1989).

The texture of potatoes can be described in terms of *mealiness* (referred to as flouriness in Ireland), *waxiness*, *sloughing* (disintegration) and *firmness*. Mealiness and sloughing are related to the separation of intact cells. Firmness is often related to starch swelling and gelatinisation as well as to the stability of the pectic substances in the cell wall and middle lamellae (Andersson *et al.*, 1994).

Mealiness is generally agreed to be the most important aspect of cooked potato texture (Unrau and Nylind, 1957; Smith and Davis, 1963 and Warren and Woodman, 1974) although the causes and physical basis of mealiness are still unclear (Warren and Woodman, 1974). Mealiness is highly correlated with cell separation so a high level of cell separation generally means a mealy potato. It is, however, the cause of cell separation during cooking that has researchers divided.

Some studies (Bettleheim and Sterling, 1955; Linehan and Hughes, 1969 and Jarvis *et al.*, 1992) found that 'rounding off' of starch cells during heating due to *starch swelling pressure* caused by gelatinisation[2] of starch, brings about cell separation. However, there is evidence to contradict these findings. Personius and Sharpe (1938) measured the tensile strength (the minimum longitudinal stress required to pull a section of potato tuber asunder) of both raw and heat-treated potato tissue. They found that the rate of tensile reduction increased with increasing temperature. Since the weakening of cell cohesiveness started at temperatures lower than those necessary for starch gelatinisation to take place, they concluded that cell separation and starch gelatinisation were independent of each other.

Other authors have concluded that it is the breakdown of the pectic substances during cooking which allows the cells to separate (Hughes *et al.*, 1975; Moledina *et al.*, 1978; Speiss *et al.* (1987) and Wu and Chang, 1990). Heating causes some of the pectic materials of the cell wall and the middle lamella to change and become more soluble. This is particularly important with regard to the middle lamella. The role of pectic substances here, as already stated, is in intercellular cohesion. If the pectic material is brought into solution, the middle lamella is weakened and the cells separate leading to a softening in texture. A decrease in the pectic content of vegetables including potatoes after cooking has been reported (Hughes *et al.*, 1975; Moledina *et al.*, 1978 and Wu and Chang, 1990). Speiss *et al.* (1987), in a study of the rheological behaviour of potatoes during cooking at temperatures of 70 - 100°C, concluded from their findings that the distinct reduction in shear strength of potatoes initially during heating is due to splitting of the pectin of the middle lamellae. This altered pectin is water-soluble and loses its cementing function. Loosening of the cell contents and a decrease in shear strength are the result.

Some authors (Barrios *et al.*, 1963; Reeve, 1977 and Harada and Paulus, 1986) have found that cell size increases slightly after cooking, possibly due to some swelling pressure exerted by starch and that this may help in bringing about cell separation because the pectic substances and other cell wall and middle lamellae polyuronides have been broken down during cooking.

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[2] Gelatinisation is the process by which starch granules within the cell absorb water during heating and swell to form a gel.

It seems from the various studies carried out (Warren and Woodman, 1974; McComber *et al.*, 1988; Leung *et al.*, 1983, Speiss *et al.*, 1987 and Jarvis and Duncan, 1992) that there is not one particular element that contributes to the texture of cooked potatoes, but rather a combination of different elements, in particular starch and pectic substances. Harada and Paulus (1986) recognised the role of many factors in texture such as specific gravity, total solids, starch content, cell size and surface area, soluble amylose, pectin and polyvalent cation content (calcium and magnesium).

In conclusion, it is likely that the texture of cooked potatoes cannot be simply explained by the action of one component or another, but rather by a complex interaction of many different components of the potato tuber.

1.3.5 Measurement of food texture

The 'texture' of food is difficult to define since our perception of the texture of a food is not just a matter of chewing and tasting but also involves other senses: touch, sight, smell and hearing (such as tapping a fruit to test its readiness to eat). Various attempts to *define food texture* have culminated in some international agreement with the development of the international standard ISO 5492 (International Organisation for Standardisation [1992]). This defines texture as "All the mechanical, geometrical and surface attributes of a product perceptible by means of mechanical, tactile and, where appropriate, visual and auditory receptors" (Rosenthal, 1999).

To fully understand how the texture of a food can be measured it is important to look first at the rheology of foods. *Rheology* can be defined as the study of the relationship between forces exerted on a material and the ensuing deformation as a function of time (Van Vliet, 1999). The choice of instrument for measuring texture depends on the rheological properties of a particular food. These properties can vary from liquids such as water or wine to hard, solid products such as toffee or sweets.

There are two ideal types of rheological behaviour (Van Vliet, 1999):

(1) *Ideal liquid or viscous behaviour* – viscous materials start to flow at a certain rate when a stress is applied to the material, and after the removal

of the stress they keep the shape they had at the moment the stress was taken away.

(2) *Ideal solid or liquid behaviour* – elastic materials deform instantaneously to a certain extent when a stress is applied and regain their original shape after the stress has been removed.

However, the reaction of many foods to a stress and strain consists partly of a viscous contribution and partly of an elastic one: they are *viscoelastic*. Therefore, problems arise in that the elasticity or viscosity of the food alone cannot be measured as an indication of texture.

There are two ways of measuring the texture of a food: *subjective testing* (taste panel) and *objective testing* (using a texture-measuring machine or instrument). Food by its very nature is complex and the process of tasting and eating food is also complex. As a result, objective testing of food is a difficult process. The traditional method of evaluating the texture of a food was carried out using a taste panel. However, over the years food scientists and technologists have investigated the use of machines for testing texture. There are many machines available for testing mechanical properties such as hardness, firmness, strength, toughness, strain, elasticity, work and many others for a wide range of materials. The properties of interest to the current study are hardness/firmness, elasticity and work or energy. These texture-testing instruments would originally have been used for testing materials such as metals, concrete, wood and other building materials. Over the years they have been adapted to measure the texture of foods.

Most food technologists prefer to use instruments because they are objective, require much less labour and results are obtained more quickly than with sensory methods (Bourne, 1983). However, food texture is essentially a human experience that arises from our interaction with food. Therefore, when using a machine for the purpose of measuring the texture of a food it is important to give careful consideration to the method of measurement to avoid obtaining meaningless results. Data can be collected by subjecting any material to any procedure, but results from the test do not necessarily mean anything in terms of texture (Rosenthal, 1999).

1.3.6 Instrumental techniques for measuring texture

When attempting to measure texture it is important to be aware of what is involved in the human perception of texture. "Texture" is governed by a combination of mechanical and fracture properties and the changes they undergo in the mouth during chewing (Dobraszczyk and Vincent, 1999). If one thinks about the chewing, tasting and swallowing process, involving interaction of food with the teeth, tongue, cheeks, auditory signals and saliva, under complex states of deformation (Dobraszczyk and Vincent, 1999), that are partly responsible for our perception of the texture of a food, it seems impossible that any machine could come near to evaluating its texture. However, although it is probably impossible to measure "texture" on a machine, it is probably possible to identify the main factors that govern the texture of a food material and to measure them, thus accounting for a large part of texture (Dobraszczyk and Vincent, 1999). This is what food technologists attempt to do, with varying degrees of success.

For objective measurements of food texture the texture-measuring machine used will usually apply some form of deforming stress to the food sample. This stress may be applied in the form of uniaxial compression, shearing, extrusion or puncture testing.

(1) Uniaxial compression – the food is generally pressed between two metal plates. The sample sits on one of the plates and force is then applied at a constant rate, via the upper plate until the sample fractures.

(2) Shearing – there are two types of shearing:

   (a) Kramer-Shear Press (Brown *et al.*, 1970 and Ng *et al.*, 1997) which actually involves compression and extrusion, as well as shear. It consists of a multi-blade attachment that travels through a sample holder fitted with slots through which the blades can pass. It compresses the sample as it shears through. The sample extrudes from the slots of the sample holder as it is compressed.

   (b) Single blade shearing – which gives a true shear, consisting simply of a single blade that passes through the sample which rests on a platform.

(3) Extrusion – the sample is extruded through an opening. This can also be combined with compression where it is called back extrusion

(4) Puncture test - uses a probe or punch of a certain diameter to punch a hole in the sample to a specified depth.

The choice of test depends to a large extent on the type of food to be tested. Not all foods can be tested with one particular method and often many trials will be required to decide which method is most suitable. Compression appears to be one of the most commonly used methods for measuring the texture of foods. Uniaxial compression for potatoes has been used by Leung *et al.* (1983), Canet and Hill (1987), Taguchi *et al.* (1991), Jankowski (1992), Thybo *et al.* (1998), and Thybo and Nielsen (2000). Speiss *et al.* (1987) and Lin and Schyvens (1995) used shear for carrots and a variety of vegetables respectively. Brown (1970) and Ng (1997) used the Kramer-Shear Press for carrots. Back extrusion was used by Quintero-Ramos *et al.* (1992) for carrots and Stanley *et al.* (1995) for testing the texture of canned carrots and green beans. Moledina *et al.* (1981), Anzaldua-Morales *et al.* (1992), Mittal (1994) and Fuchighami *et al.* (1995) all used puncture testing for carrots and potatoes. Both puncture and shear tests are used in this study.

Scott-Blair, in 1958, categorised the instrumental techniques used to measure food texture into three groups:

1. *Empirical tests:* measure something physical under well-defined conditions
2. *Imitative tests:* attempt to simulate the conditions to which the material is subjected in the mouth
3. *Fundamental tests:* measure well-defined physical properties such as viscosity or elastic modulus

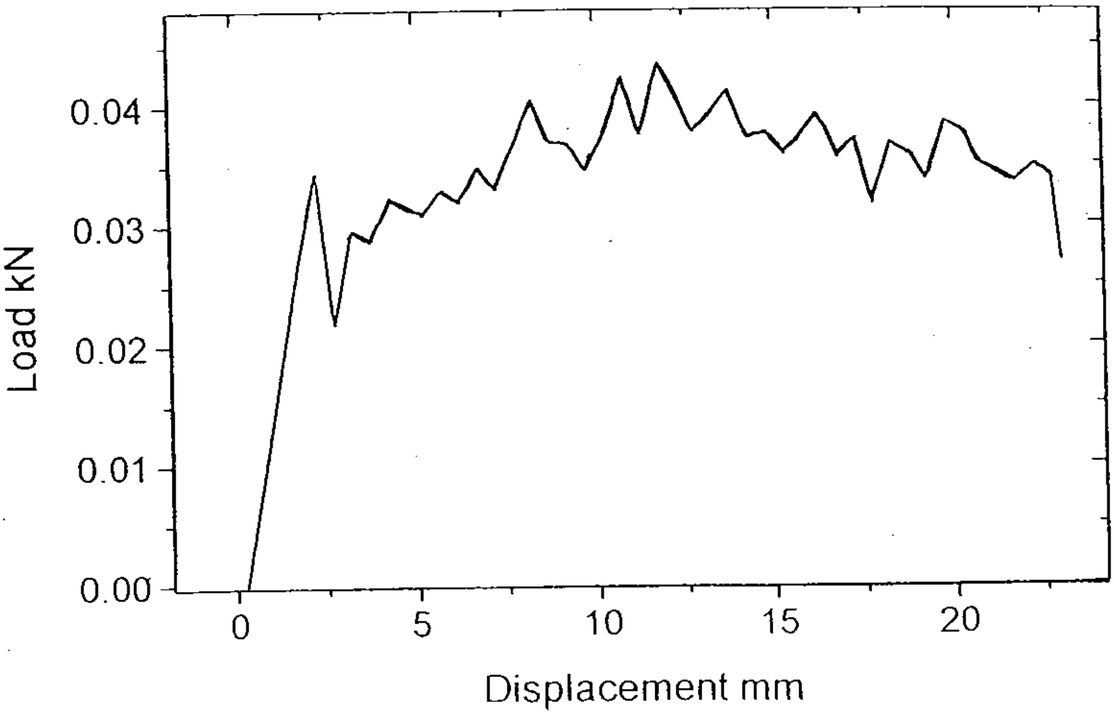
Empirical tests are developed by experimentation and observation and as a result they may lack a rigorous scientific basis. Fundamental tests measure innate physical properties of materials. They are scientifically rigorous and data are expressed in well-defined scientific units.

Imitative tests are those that attempt to mimic in some way the chewing action of the mouth. The most popular of these tests is *Texture Profile Analysis (TPA).* A force-time profile is obtained after the instrumental test has been performed, and this gives information on the following parameters: hardness, elasticity, adhesiveness, cohesiveness, brittleness, chewiness and gumminess, which are related to a particular sensorial definition. For example, hardness is defined sensorially as the force required to compress a food between the molars (Rosenthal, 1999).

As already mentioned, puncture and shear testing, both examples of fundamental tests, were used in this study. The tests were carried out using an *Instron Universal Testing Machine*. This consists of a moving bar (cross-head), which holds the load cell and a metal base or platform upon which the sample sits. Various accessories can be attached to the crosshead allowing for different types of measurements to be made. For example, a blade would be attached for shear testing or a probe for puncture testing. Following the pioneering work of Bourne *et al.* (1966) the use of the Instron Universal Testing Machine has become widespread in evaluation of textural properties of solid foods (Shama and Sherman, 1973). In particular the Instron has the advantage of offering a wide range of test conditions. Different load cells can be used depending on the material to be tested and the speed at which the cross-head travels (deformation rate) can be adjusted to suit the test. Software packages used in conjunction with the Instron allow for data collection and analysis, and for various parameters to be calculated both during and after the test. When the test is completed the software produces a graph plotting force against displacement (Figure 1.5). The fracture point for the material being tested can then be identified from this graph. *Fracture* is considered to occur when all bonds between structural elements in a certain macroscopic plane break, resulting in a breakdown of the structure of the material over distances much larger than the size of the structural elements and ultimately leading to a falling apart of the material (Van Vliet, 1999).

Various parameters can be calculated from the force vs. displacement curve. The instrumental parameters calculated by the Instron software for this study were hardness/firmness, elasticity and work or energy. Firmness is usually measured in Newtons (N) and is defined as the force required to fracture a food product. Elasticity is measured in N/m and is usually calculated from the slope of the curve before fracture. Work or energy is expressed in Joules and is calculated from the area under the curve.

Figure 1.5: A typical curve produced by the Instron software plotting force against displacement for puncturing a raw potato.



1.3.7 Correlating instrumental methods with sensory analysis

Initially, instrumental methods of measuring texture were considered to be completely separate from, and more reliable than, sensory methods, being 'objective' in their analysis. However, a study by Bourne (1983) correlating instrumental measurements with sensory evaluation of texture suggested that, after the move from calibration of texture measuring machines with an arbitrary standard, to calibration in fundamental internationally recognised standards based on units of mass, length and time, the next move should be towards calibration of the machine against the human senses.

Since then, more and more studies are including correlations of instrumental textural evaluations with sensory analysis. Collinson *et al.* (1980) investigated the relationship between subjective and objective texture measurements of potatoes cooked by different methods: boiling, steaming and microwaving. They found that for each heating method the taste panel score was related to instrumental measurements of rupture energy and load. This was despite the fact that rupture energy and rupture load are not fundamental rheological properties and can only be defined in terms of the instrumental conditions under which they were measured. There is the further complication that the mechanical action of the Instron texture-measuring machine on food is different to that of eating (Collinson *et al.*, 1980). Despite these difficulties a degree of correlation was found and this would indicate that it is not necessary to exactly simulate the chewing action of the mouth in order to obtain information on the texture of food.

Truong *et al.* (1997) found a high correlation between mouthfeel attributes (moistness, ease of swallow, chalkiness) and mechanical type notes (cohesiveness, hardness, denseness, chewiness and adhesiveness) with shear stress of uniaxial compression, as well as fracturability, hardness and gumminess of TPA (Texture Profile Analysis) for cooked sweet potatoes. The two sets of instrumental parameters (uniaxial compression and TPA) were found to be linearly related and could be converted from one to another with a high degree of reliability. Having found that regression equations based on shear stress significantly explained eight of the sensory notes they concluded that these instrumental parameters could be good predictors of cooked sweet potato texture.

Thybo and Martens (1999) investigated the relationship between instrumental and sensory analysis of cooked potato. Uniaxial compression (Instron), TPA and chemical measurements were related to sensory texture evaluation. From their results these authors were able to differentiate between mealy, grainy and easy to chew potatoes and moist springy and firm potatoes by specific gravity, uniaxial compression data, and size and structure of raw starch grains. They found that specific gravity, stress, strain, modulus of deformability, roundness and aspect of raw starch grains, and activity of PME to be important variables in texture prediction of cooked potatoes.

Again these studies show that it is possible to relate instrumental measurements to sensory parameters with a good degree of correlation. However, a lot more research is necessary before a stage can be reached where all instrumental measurements can be defined sensorially.

1.4 Blanching

1.4.1 Introduction to blanching

Having discussed the concept of texture, its relationship with the structure of a food, and how it can be measured, the next step is to look at those heat processes that are applied to potatoes in this study and how they affect texture. Blanching or pre-cooking is one of the most important unit operations in food processing. Blanching usually involves immersion of the food, usually a fruit or vegetable, in water at temperatures between 80 and 100°C for times ranging from a few seconds up to 15 minutes. Blanching before processing has many functions and the reasons for blanching depend on the type of food being processed. It is generally carried out to inactivate enzymes, prevent lipid oxidation and other degenerative reactions, eliminate included air and reduce bacterial load (Moreno-Perez *et al.*, 1996). For potato processing, the *main objectives* of traditional blanching i.e. using high temperatures (80 - 100°C) are:

(1) *inactivation* of enzymes, namely peroxidase, which causes blackening after cooking if not destroyed, and pectin methyl esterase, which can cause structural degradation if not destroyed.

(2) *regulation* of the reducing sugar content of the superficial layers of the potato tissue. These sugars are leached out over time during blanching. High levels of reducing sugars are undesirable if the potato is to be fried, as they lead to the development of a dark brown colour and 'off-flavours' (Andersson *et al.*, 1994).

Disadvantages of blanching at such high temperatures (80 - 100°C) include vitamin loss, nutrient leaching and most importantly in this study, undesirable textural changes (Andersson *et al.*, 1994). A problem with blanching in potato processing is that it is hard to fulfil all the objectives of blanching using traditional blanching methods i.e. a one step high temperature blanch. Many of these objectives are contradictory and it is difficult for a single step blanching treatment to meet all the requirements. On the one hand, leaching of sugar requires time during blanching, and low temperatures are required to avoid overcooking and structural degradation, but conversely a high temperature is required for a short time for enzyme inactivation (Andersson *et al.*, 1994). A solution to this problem is a blanching treatment that combines low temperatures for relatively long times followed by a higher temperature for a short time.

This two-step blanching approach has been found to be effective in both minimising softening of the fruits or vegetables and destroying the undesirable enzymes. Canet and Hill (1987) showed that stepwise or two step blanching by pre-treatment at 70°C for 10 min followed by cooling and conventional blanching at 97°C for 2 min improved the texture of frozen potatoes, compared to one step conventional blanching (97°C, 2 min), and completely destroyed the peroxidase enzyme. Canet *et al.* (1982) found improved texture of potatoes blanched at 60°C for 10 min then 97°C for 2 min. Brown and Morales (1970) reported improved texture after blanching at 80°C for 15 min followed by 95°C for 1 min.

1.4.2 Low temperature blanching

The first step in the stepwise blanching treatments above usually involves an initial blanch at low temperatures. The use of *lower temperatures*, in the range of *50-75°C*, for blanching has been investigated over many years and has been found to have a beneficial effect on the texture of the processed product, actually improving the firmness. Some of the earliest work in this area was carried out in the early 60's and 70's. Van Buren *et al.* (1960, 1962) carried out low temperature blanching of snap peas prior to canning and found a firming effect (the 'firming effect' refers to the higher firmness of the fully processed product) on the texture of the final product. Hoogzand and Doesburg (1961) subjected cauliflower to long blanching times at low temperatures, and an increase in firmness of the canned product was reported. Brown and Morales (1970) investigated a range of blanching temperatures for par-fried frozen potatoes and achieved optimum firmness with lower blanching temperatures. This improved firmness has been observed in other vegetables; sweet potatoes (Moreno-Perez *et al.*, 1996 and Truong *et al.*, 1998); carrots (Lee *et al.*, 1979; Quintero-Ramos *et al.*, 1992; Fuchigami *et al.*, 1995 and Stanley *et al.*, 1995); Jalapeno pepper (Quintero-Ramos, 1998); cauliflower (Garcia-Reverter *et al.*, 1994) and potatoes (Brown *et al.*, 1970; Taguchi *et al.*, 1991; Aguilar *et al.*, 1997; Canet and Hill, 1987 and Aguilera-Carbo *et al.*, 1999). This firming effect as a result of low temperature blanching reduces physical breakdown and sloughing during further processing and therefore affects the final texture (Verlinden *et al.*, 2000)

Optimum blanching temperatures vary according to the type of food, the sample size and the method of texture measurement (Table 1.5). However, in all cases the use of low blanching temperatures noticeably improved the firmness of the product when compared to conventionally blanched or processed products.

Aguilera-Carbo *et al.* (1999) carried out low temperature blanching (60, 65 and 70°C) for long times (45 and 60 min) before frying which improved both the firmness and the overall quality of the French fries. They proposed that low temperature blanching might provide a lower cost alternative to additives or partial drying, which are currently used to preserve the quality of French fries. Wu and Chang (1990) found that for three stem vegetables studied, relative firmness decreased most rapidly on boiling from fresh. Blanching at a temperature of 80°C resulted in rapid decrease in firmness indicating that at such a high temperature the thermal destruction of the vegetable tissue exceeded the firming effect of pre-cooking. Interestingly, they also observed that the firming effect of blanching was much less if measured after blanching, than if measured after blanching then cooking. This would imply that the benefits of low temperature blanching only become evident after cooking.

Table 1.5: Optimum blanching conditions reported for a range of vegetables

Authors	*Sample Type*	*Optimum Blanching Conditions*
Aguilera-Carbo *et al.* (1999)	French fries	45 min at 60 - 65°C gave greatest reduction in limpness after frying
Aguilar *et al.* (1997)	French fries	30-45 min at 60-65°C Firmness and some TPA parameters increased >200%
Taguchi *et al.* (1991)	Potato (cubes)	30 min at 75°C then boiled for 20 min gave max. fracturability
Canet and Hill (1987)	Potatoes (frozen)	10 min at 70°C followed by cooling and then 2 min at 97°C gave firmest product – 512 N compared to lowest value 199.4 N for 97°C for 2 min with no blanching
Brown *et al.* (1970)	Potatoes (frozen parfried)	15 min at 80°C followed by 1 min at 95°C resulted in highest degree of firmness
Wu and Chang (1990)	Sprouting broccoli Asparagus lettuce Large stem mustard	50°C for 30 min 60°C for 30 min 60°C for 30 min gave best firmness after boiling for 15 min
Quintero-Ramos *et al.* (1992)	Jalapeno pepper	55°C pre-blanch followed by 96°C for 3 min gave a firmness value of 779 N compared to 268 N for a single blanch at 96°C for 3 min

Quintero-Ramos *et al.* (1998) reported greatest loss of firmness for Jalapeno peppers blanched conventionally at 96°C for 3 min compared to samples blanched at temperatures of 55 - 80°C then blanched at 96°C for 3 min. Garcia-Reverter *et al.* (1994) carried out low temperature blanching on cauliflower and had similar findings. Cauliflower samples blanched at low temperatures (55 - 70°C) all exhibited higher values for firmness than those blanched at 100°C for 4 min. Speiss *et al.* (1987) studied the rheological behaviour of carrots and potatoes during cooking. A temperature range of 70 - 100°C was used. Rapid texture degradation was observed at temperatures above 70°C. Some reports have found a relationship between increased firmness and longer immersion times in the blanching liquid. Quintero-Ramos *et al.* (1992) reported an increase in firmness with increasing blanching time at low temperatures. At 55, 60 and 65°C firmness increased with increasing blanching time up to 90 min. Ludwig (1984) found that firmness appeared to increase with the immersion time in the water bath, up to 60 min (Andersson *et al.*, 1994). The inclusion of a cooling step between the low temperature and high temperature treatments has also been shown to further improve the texture (Steinbuch, 1976 and Canet and Hill, 1987). Verlinden *et al.* (2000) reported that potato samples that had not been blanched before cooking had lower maximum force values than for those blanched then cooled and cooked. They noticed that this effect was more important when blanching treatments were longer.

1.4.3 Suggested mechanisms for improved firmness during low temperature blanching

How is it that low temperature blanching improves the firmness of a cooked product sometimes even surpassing the firmness of the raw product? There are two mechanisms proposed to explain this firming effect:

(1) Gelatinisation and retrogradation of starch.
(2) Action of pectin methyl esterase on pectin at low blanching temperatures.

1.4.3.1 The role of starch in firming during low temperature blanching

Starch, being the next major component of potato after water (Section 1.2.3.1), will obviously contribute in some way to the texture of heat-treated potato. The question is, can improved firmness after low temperature blanching be explained by the behaviour of starch at these temperatures? First, the effect of heating on starch needs to be looked at. Undamaged starch granules are insoluble in cold water owing to the collective strength of the hydrogen bonds binding the chains of amylose and amylopectin together. However, as temperatures begin to rise to what is known as the initial gelatinisation temperature, water begins to be imbibed (Coultate, 1996).

The initial gelatinisation temperatures are characteristic of particular starches but usually lie in the range of 55 - 70°C (Coultate, 1996). Briant *et al.* (1945) studied starch in polarised light during heating of dilute suspensions from room temperature up to 85°C. The first sign of loss of birefringence[3] came at approximately 58°C and all birefringence was lost at approximately 70°C. This corresponds to the temperature range for blanching in which firming is observed (Andersson *et al.*, 1994). Gelatinisation can take place with or without the presence of external water. If there is sufficient water present in the tissues, as is the case in potatoes, then the starch granules will absorb it. As water continues to be imbibed, the granules swell to form a gel. In general, the gelled starch remains within the granules, although some of the amylose may diffuse through the cell wall (Andersson *et al.*, 1994).

After blanching when starch has gelatinised and the potato is allowed to cool, firming takes place due to *retrogradation*[4] of the gelatinised starch. Retrogradation in potatoes takes place slowly at temperatures of around 50°C but is accelerated at temperatures as low as 25°C (Andersson *et al.*, 1994). During retrogradation, starch molecules in solution become associated by hydrogen bonding, resulting in a

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[3] Starch granules, when viewed under a polarising microscope show the 'Maltese Cross' pattern that is characteristic of birefringent materials i.e. those that have a high degree of molecular orientation. Starch granules are crystalline and on heating there is a gradual loss of crystallinity that leads to gelatinisation. This loss of crystallinity is characterised by a loss of birefringence under the polarised microscope (Coultate, 1996).

[4] During retrogadation some of the crystallinity that is lost during gelatinisation is restored when the amylose molecules that leached out of the starch granule during gelatinisation associate together again (Coultate, 1996).

decrease in the solubility of the starch (Potter *et al.*, 1959). Kozempel (1988) proposed that after blanching when the potatoes are cooled the starch retrogrades during which time the straight chain amylose crosslink, become insoluble and give the potato cell a firm structure, which remains intact through cooking.

Starch probably does contribute in some way to the firming effect. However, Wu and Chang (1990) carried out a study to investigate whether low temperature blanching has a firming effect on vegetables containing negligible starch. If a firming effect was found then it could be concluded that the firming is not due solely to starch. Three vegetables were looked at: sprouting broccoli, asparagus lettuce and long stem mustard. Blanching temperatures of 40-80°C were used. In all three cases a firming effect, as a result of low temperature blanching was found indicating that there must be another explanation for the firming action. A number of other studies also show this firming effect in vegetables with negligible starch content (cauliflower, snap beans and tomatoes – Sterling, 1955; Hoogzand and Doesburg, 1961; Van Buren, 1968 and Hsu *et al.*, 1965)

1.4.3.2 The role of pectin methyl esterase (PME) in firming during low temperature blanching

The action of this enzyme on pectin during low temperature blanching is by far the most favoured theory for the firming effect at low temperatures. PME is a naturally occurring enzyme found in many fruits and vegetables. It was first identified by Fremy in 1840 (Sajjaanantakul and Pitifer, 1991). It is specific in its action acting on polyuronides (pectin molecules) containing an unesterified carboxyl group (-COOH) adjacent to a methylated carboxyl group (-$COOCH_3$) (Figure 1.4). It does not completely de-esterify pectin but stops at a certain degree of esterification (Sajjaanantakul and Pitifer, 1991). In cooked potato that has been blanched it has been found that the firmer the potato the less methoxylated pectin present (Andersson *et al.*, 1994), which would indicate that PME plays a role in firming i.e. the temperatures at which firming takes place (55 - 70°C) correlate to the temperatures where PME is most active and as a result pectin is de-methoxylated. The authors found that firmer potatoes will have higher amounts of de-methoxylated pectin than potatoes blanched at higher temperatures where PME has been destroyed.

Bartolome and Hoff (1972) investigated to what degree activation of PME occurs in the potato tuber during pre-treatments involving heat, and to what extent this reaction is responsible for the firming effect. Prior to this research it was widely believed that starch was responsible for this firming effect, as aforementioned. However, due to a number of studies published, as mentioned above, in which firming effects were observed in vegetables with negligible starch content (Sterling, 1955; Hoogzand and Doesburg, 1961; Van Buren, 1968 and Hsu *et al.*, 1965) Bartolome and Hoff concluded that the action of PME was a more likely cause of firming.

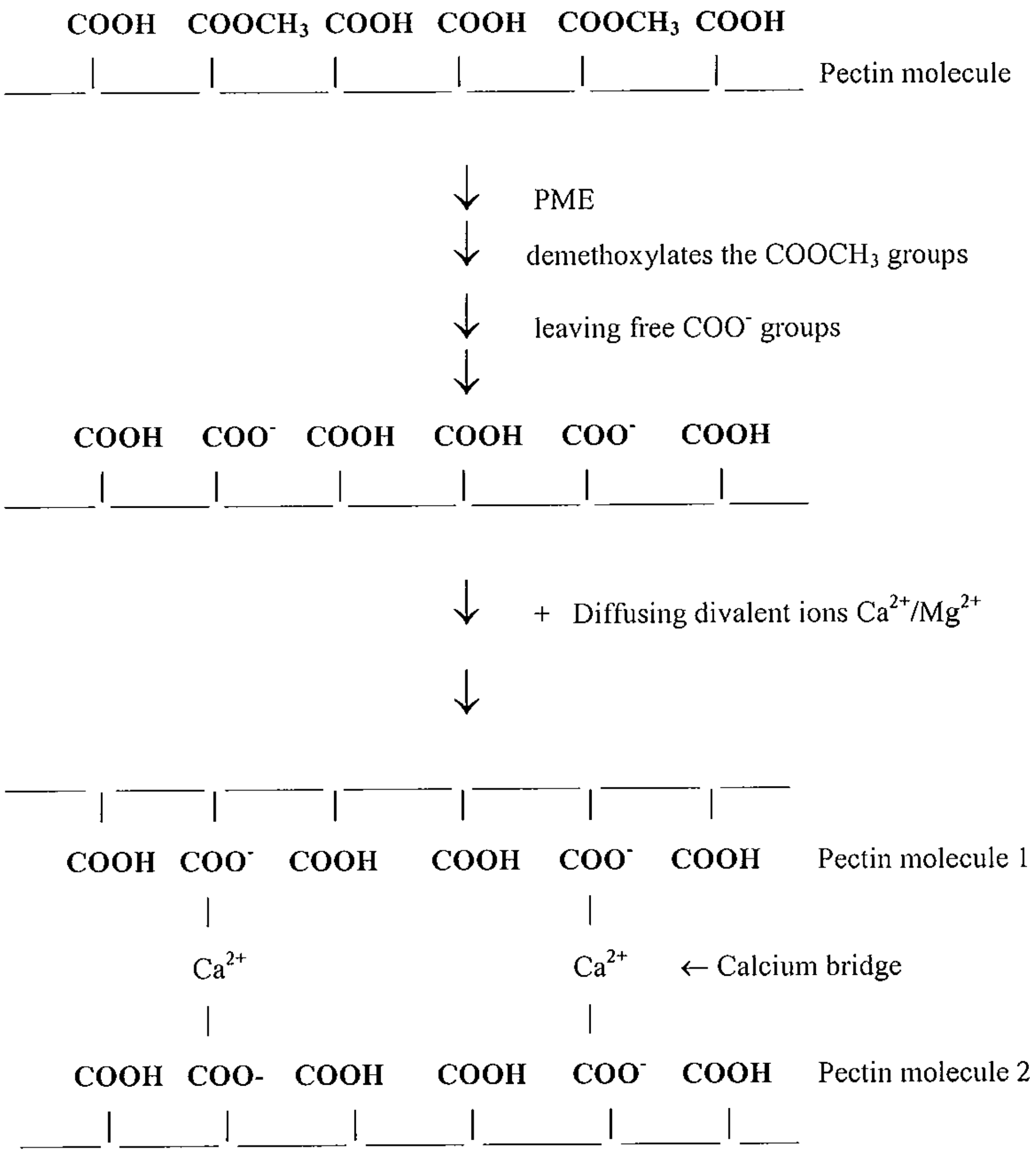
Bartolome and Hoff found a considerable effect of pre-heating on sloughing (disintegration). Pre-heated samples at 60°C and 70°C underwent negligible change in texture during boiling, while the non-treated and pre-boiled (100°C) samples suffered almost complete disintegration. PME activity was determined by measuring the amounts of free methanol produced (methanol is produced when PME acts on pectin). The results showed that the enzyme, although present, is not active to any appreciable extent until the tissue is heated to temperatures above 50°C. After heating for one hour at 60°C the enzyme had lost half its activity whereas it had negligible activity after the same treatment at 70°C. Tijskens *et al.* (1997), who studied PME activity at temperatures of 30, 50, 60, 70, 80 and 95°C reported that PME can denature completely at each temperature, provided there is sufficient time. PME appears to be rapidly inactivated at temperatures above 70°C (Andersson *et al.*, 1994).

Bartolome and Hoff (1972) proposed a mechanism for the firming action of PME. When the cell membrane is disrupted by heating above 50°C, solutes from the cytoplasm and probably also from vacuoles, diffuse into the intercellular space and activate the enzyme. Given sufficient time, the enzyme interacts with the accessible methyl ester groups ($-COOCH_3$) on the polyuronide chain to produce more, free carboxyl groups ($-COO^-$). Diffusing divalent ions, either calcium or magnesium, establish cross linkages between chains and render the tissue more resistant to further thermal degradation (Figure 1.6).

Since publication of these results, further evidence has been found to support the role of PME in firming. When vegetables are cooked, there is an increase in soluble pectin as a result of breakdown of the middle lamella. However, if firming is the result of the pectin chains being reinforced by the action of PME during low temperature blanching then there should be a negligible increase in the amount of soluble pectin after cooking. This agrees with the findings of Wu and Chang (1990) who reported that there was little change in the total pectin content after blanching, and after cooking following blanching, in a study of three stem vegetables. However, there were appreciable decreases in the total pectin content when the stem slices were directly cooked without blanching. This indicated pectin loss from the middle lamella during high temperature cooking which leads to textural degradation.

Fuchigami *et al.* (1995) proposed that there is a correlation between the pectic composition of the cell wall and softening of cooked vegetables. They found that vegetables easily softened during cooking contained more high methoxyl pectins than low methoxyl pectins. This would indicate that PME was destroyed before it had a chance to act on pectin (converting high methoxyl pectins to low methoxyl pectins) and help to reinforce the structure of the tissue. These results were in agreement with those of Wu and Chang (1990) regarding the amount of soluble pectin after pre-heating. The amount of galacturonic acid (a product of pectin breakdown – high amounts of galacturonic acid indicate high levels of PME activity) that remained in carrot samples following freezing and thawing was greatest for pre-heated samples and least for those that were boiled. They also reported that freezing and thawing had negligible effects on the pectin content. Again this indicates that the pectin molecules have been reinforced and remain insoluble on further heating or processing.

Figure 1.6: *Proposed mechanism for the firming action of PME on the structure of potato tissue (Bartolome and Hoff, 1972)*



Wu and Chang (1990) reported a different optimum pre-heating temperature for each of the three stem vegetables studied. The authors proposed that this might have been due to differences in the composition of the vegetables i.e. in the extent of lignification[5]. The optimum blanching temperatures recorded for each vegetable corresponded to the optimum temperature recorded for PME activity in each vegetable. Other authors have also attributed the firming effect at low blanching temperatures to the activity of PME (Aguilera-Carbo, 1999; Lee et al., 1979 and Steinbuch, 1976).

Some studies have found evidence to dispute the PME theory. Moledina *et al.* (1981) looked at PME activity and pectin changes during pre-cooking for dehydrated mashed potato. Their results agree with findings (Andersson *et al.*, 1994) that the optimum activity for PME lies in the range 55 - 70°C and that rapid inactivation of the enzyme occurs above 70°C. They also carried out texture measurements on potatoes that had been (1) cooked, (2) blanched then cooked and (3) blanched, cooled then cooked. Potatoes were cooked and blanched in both de-ionised water and water containing added calcium[6]. Blanching then cooking did not give significantly higher force values than for cooking alone without calcium addition ($P < 0.05$). Cooling between blanching and cooking steps significantly improved firmness with or without calcium. What was most interesting was that the firmness of the potato tissue which was blanched at 70 and 75°C, cooled and then cooked was significantly greater than tissue blanched at 65°C ($P = 0.01$). Generally, other studies have reported maximum improvement in firmness occurring with blanching temperatures where PME has its optimum. Moledina *et al.* concluded that it is not the activity of PME at low blanching temperatures that contributes to increased firmness, but rather the availability of calcium ions for cross-linking. These calcium ions become available at higher temperatures than those for which optimum PME activity occurs, that is, temperatures where complete starch gelatinisation takes place (above 70°C).

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[5] Lignification refers to the presence of lignin which is associated with the cellulose of the cell wall – the more lignin present, the more woody and rigid the stems.

[6] Calcium addition to blanching water has been shown, in some cases to improve the firmness of the vegetables and prevent sloughing (Personius and Sharp, 1939; Jaswal, 1970; Speiss *et al.*, 1987) – it is often added to the blanching water of vegetables to be canned.

Adams and Robertson (1986) agreed with the findings of Moledina *et al.* (1981) suggesting that the semi-permeability of the cell membranes is destroyed by heating at 60 - 70°C, and that divalent ions, such as calcium and magnesium are liberated from starch-phosphate groups and can diffuse into the cell wall and the middle lamella and cross-link with the pectin. Therefore, for this mechanism, PME is not essential provided there are sufficient free carboxyl groups on the polyuronides chains for cross-linking to take place. The degree of methylation of pectin, as already mentioned (Section 1.3.3), varies among fruits and vegetables. Adams and Robertson (1985) reported that the degree of pectin methylation in green beans is 61.8% so it would appear that approximately 40% of the available carboxylate groups are free for cross-linking (Adams and Robertson, 1986). However, if diffusion of divalent ions was all that was required then high temperatures would also result in firming. More research is necessary to validate this proposed mechanism.

In summary, although starch probably plays some role in firming during low temperature blanching, most evidence seems to point to PME activity at these blanching temperatures as being mainly responsible for the firming effect.

1.5 Kinetics of thermal softening of vegetables

Processes involving heat are important in providing a way of preserving perishable foods, thereby extending their shelf life. However, as has been seen, these processes can have a detrimental effect on the texture of the vegetables being processed, leading to undesirable softening due to the breakdown of cellular material. A knowledge of the physical changes that take place during these heating processes as a function of time and temperature will help the processor to optimise processing conditions. Such information is useful in designing improved thermal processes to maximise the quality attributes of the processed products (Mittal, 1994).

Kinetic modelling of the effects of heat on texture is a way of relating texture changes in vegetables to time and temperature changes under certain conditions. There have been many studies on the kinetics of thermal softening in various vegetables (Huang and Bourne, 1983; Harada and Paulus, 1985; Kozempel, 1988;

Mittal, 1994; Kasai *et al.*, 1994; Ramesh *et al.*, 1996). Rao and Lund (1986) reviewed the kinetics of thermal softening in vegetables. These authors stated that studies into the softening of foods can be approached by expressing data in terms of apparent rate constants:

$$\mathbf{dP/dt = -k_n P^n}$$

where P is the property used to characterise softening (e.g. puncture force), t is time and k_n is the reaction rate constant with order of change, n. If the reaction is first order then n = 1. In a first order reaction the plot of P against time is linear.

Another relationship that is commonly used in studies of thermal softening is the Arrhenius equation (Rao and Lund, 1986). This equation can be applied to data to investigate if the rate constant for the measured property is temperature dependent. The Arrhenius equation can be expressed as follows:

$$\mathbf{k = k_T\, e^{(-Ea/RT)}}$$

where E_a is the activation energy (KJ mol^{-1}), R is the gas constant, T is temperature in Kelvin and k_T is a constant.

Rao and Lund (1986) suggested that in order to obtain data on softening suitable for determining kinetic parameters, a food sample should be subjected to at least five different temperatures and at least five different time periods at each temperature. These authors concluded from the review that apparent first order kinetic expressions are suitable for expressing the degree of softening of a vegetable at a constant temperature. However, subsequent studies have concluded that the kinetics of softening of vegetables are more complex than was originally thought and that perhaps not all texture changes could be adequately described by first order expressions (Huang and Bourne, 1983; Bourne, 1987 and Mittal, 1994). These studies emphasised the need for further research in this area.

Huang and Bourne (1983) studied the rate of softening in several canned vegetables during the retort (canning) process. They found that the rate of softening with long process times at high temperature could not be described by simple first order kinetics, but was consistent with two simultaneous first order kinetic mechanisms. The softening curve for this process consisted of an initial steep negative slope that was almost linear (defined as Mechanism 1) but which curved off in a second straight line with a shallow negative slope at longer processing times (defined as Mechanism 2). Huang and Bourne (1983) went on to suggest that there are two different elements or 'substrates' within the vegetable upon which different mechanisms act. Mechanism 1 acts on substrate 'a' and it is during the action of this mechanism that the majority of softening takes place. Substrate 'a' was found to contribute approximately 85 to 97% of the firmness of the raw commodity. Therefore, the action of Mechanism 1 on this substrate leads to a huge loss of firmness. These authors speculated that Mechanism 1 is probably due to pectic changes in the interlamellar layer but did not give any explanation for mechanism 2.

Bourne (1987) investigated the effects of blanching at 74°C and 100°C for 4 min on the kinetics of thermal softening of canned carrots and green beans. The results of this study agreed with those of Huang and Bourne (1983) that the kinetics of thermal softening follow the two substrate first order kinetic theory.

Moreira *et al.* (1994) stated that it would be useful if additional methods could be found to clearly identify if there is one first order process or two processes taking place during vegetable softening. Moreira *et al.* (1994) set about developing a method to quantify textural changes due to processing and pre-processing treatments. It was intended that this method would allow the segregation of the effects of the pre-processing treatment on the texture of the raw product and on the sensitivity of the vegetable tissue to the main processing step in such a way that a combination of both would also describe total changes in texture. To this end these authors defined the following five parameters:

- **Pre-processing effect on the Initial Texture (PIT):** this quantifies the softening (if a negative value) or hardening (if a positive value) of the raw material due to the pre-treatment itself.
- **Pre-processing effect on the texture Variation due to Processing (PVP):** compares the change in texture that occurs during the processing

stage for potatoes that were pre-treated and the one that would occur if no pre-treatment had been used. When this parameter is zero the pre-treatment did not affect the sensitivity of the vegetable tissue to the main processing. If it is positive then less softening occurred during processing as a result of changes promoted by the pre-treatment, and the reverse if it is negative.

- **Total (pre-treatment + processing) effect on Product Texture (TPT):** this is the mathematical sum of the two previous parameters and quantifies the overall effect on texture. Positive values mean that the final product is less soft than if there had been no pre-treatment and negative values mean that the final product is softer than if there had been no pre-treatment.
- **Time Step Effect (TSE):** evaluates the effect of processing time (at constant temperature) on texture.
- **Time Temperature Effect (TTE):** combines the effect of time intervals with temperature changes on texture.

Mathematical formulae for calculating each parameter are given in Chapter 3, Section 3.5.6 (Results and Discussion).

Moreira *et al.* (1994) applied these parameters to the results from other studies and found that by using these parameters with the data from these studies additional conclusions could be made concerning this data, that had not been reported by the original authors. For example, these parameters were applied to the work of Canet and Hill (1987), who carried out stepwise blanching (70°C for 10 min followed by 97°C for 2 min) and a mixed method blanching, in which the first blanching step was replaced by a microwave treatment, on potatoes. They reported that overall the best firmness was achieved through stepwise blanching. However, microwave blanching followed by a short conventional blanch gave the best overall product in terms of firmness and vitamin C retention. By applying the first three parameters above i.e. PIT, PVP and TPT, it could be further concluded that as a result of the pre-processing using microwaves, the potatoes actually hardened during cooking, thereby compensating for the greater softening that the pre-processing itself caused to the raw tissues. It was decided, therefore, that for this current study it might be useful to apply some of these parameters in order to obtain information on the texture changes taking place in new potatoes during heat treatments and how the blanching treatments affect the sensitivity of the potatoes to the processing step.

Aims and Objectives

The aim of this study was to look at the effect on the texture of processed whole new potatoes when low blanching temperatures are applied before processing. This aim was achieved through the following objectives:

1. Investigate the effect of blanching temperatures in the range of 60 - 100°C on the texture of whole new potatoes.

2. Calculate rates of reaction for each of these blanching temperatures and attempt to segregate the effects on texture of low temperature blanching from the effects of high temperature blanching within the range of 60 - 100°C.

3. Determine the blanching temperature at which the enzyme pectin methyl esterase (PME), naturally present in potatoes, has its optimum activity and at which temperatures it is denatured.

4. Investigate whether blanching at low temperatures improves the firmness of potatoes before and/or after processing at processing temperatures of 95°C and 100°C.

5. Establish the best blanching temperature and processing temperature combination that maximises texture retention.

6. Carry out sensory analysis to determine whether panellists can differentiate between those potatoes that were pre-processed and those that were not and to see which instrumental textural parameters correlate well with sensory parameters.

2. Materials and Methods

2.1 Sampling

Two varieties of potato, *Solanum tuberosum L. cv.* Maris peer (from Portugal) and Nicola (from England), were used for this study. The potatoes were purchased on a daily basis from Marks and Spencer, Dublin. Marks and Spencer guaranteed that the potatoes were harvested and in the shop within a day so there was no storage involved. Since potatoes can undergo a lot of changes in composition during storage particularly in relation to starch (Lisinska and Leszczynski, 1989), which would affect texture, it was important to know the history of the potato from the time of harvest and details of any storage.

The potatoes had been pre-washed before purchase and were bought in 1 Kg lots in plastic bags. They were removed from the plastic bags after purchasing and allowed to come to room temperature before any tests were carried out. Only potatoes with a diameter in the range of 35 – 45 mm were used for the study.

2.2 Specific gravity measurement

Specific gravity is an important processing parameter used by potato processors to determine whether potatoes are suitable for processing. Specific gravity gives an indication of the dry matter content, which is essentially an indication of the amount of starch in the potato.

A quantity (3.63Kg) of average size potatoes were selected and placed into the basket of a hydrometer (Zeal Potato Hydrometer). A large plastic bin (182 L capacity) was filled with water. The whole weight of the basket was supported with one hand and the hydrometer was attached to the basket with the other hand. The hydrometer was lowered into the water until it floated freely and the specific gravity was read.

2.3 *Moisture content determination*

The whole potato was peeled, chopped and well mixed. A sample of this chopped potato (10 g) as a representative sample of the whole potato, was placed into a tared crucible. The sample was dried to a constant weight at 100°C. This required approximately 6 – 8 hours. The sample was allowed to cool and reweighed. Moisture content was calculated using the following equation:

$$\text{\% Moisture content} = \frac{\text{Original weight - Weight after drying}}{\text{Original weight}} \times 100$$

2.4 *Ash determination*

This method was based on the AOAC method 9.2.2.2 (1990)

The dried potato sample from the moisture content determination, kept in the same crucible, was heated using a Bunsen flame until the potato had turned black. This prevented the sample from igniting when placed into the furnace.

The crucible was then placed into the preheated furnace and left for 18 hours at 550°C.

After this time the furnace was switched off and the temperature was allowed to fall below 250°C before opening the door (the door was opened carefully to prevent losing any of the ash). Using gloves and a tongs the crucibles were quickly transferred to a desiccator and left to cool before reweighing. Ash content was calculated as follows:

$$\underset{\text{(dry weight basis)}}{\text{\% Ash content}} = \frac{\text{Weight before ashing – weight after ashing}}{\text{Weight after ashing}} \times 100$$

2.5 *Reducing Sugar and Starch determination*

The following method for reducing sugar and starch determination is based on the methodology outlined by Southgate (1991).

2.5.1 *Extraction of free sugars and preparation of a residue insoluble in 80% ethanol*

Reagents:

Ethanol (Reidel-de Haen, Germany)
Diethyl ether (Reidel-de Haen, Germany)

Determination:

The potatoes were peeled and finely chopped. Duplicate samples (10 g) were placed into weighed 100 ml beakers. 80% (v/v) ethanol (25ml) was added to each beaker. The sample was stirred with a glass rod while bringing to the boil on an electric hot plate. This process took approximately 5 min.

The sample was filtered through a Whatman 541 paper using a glass funnel into a 100 ml volumetric flask (this filtrate and subsequent filtrates were kept at room temperature for sugar analysis).

The process above of adding ethanol to the sample and boiling was repeated with three further portions (25 ml) of 80% (v/v) aqueous ethanol. The filter was allowed to drain between successive extractions. In the second and subsequent extractions it was necessary to stir the mixture continuously during heating to avoid losses through bumping.

The residue was then extracted in the beaker and on the filter in a similar way with three portions of diethyl ether. The extracts were discarded.

The residue was allowed to dry in air and returned to the original beaker when it was completely dry and crumbled easily.

The beaker and it's contents were heated at 98 - 100°C for 10 min in an air oven to remove residual solvent, allowed to cool overnight to equilibrate with the laboratory atmosphere, then reweighed. Samples prepared in this way contained 8 - 10% moisture.

The residue was finely ground with a pestle and mortar and stored in airtight containers at room temperature.

2.5.2 *Enzymatic hydrolysis of starch*

Reagents:

Dimethylsulphoxide (DMSO) for UV spectroscopy (Fluka)
Hydrochloric acid (Reidel-de Haen, Germany)
Sodium hydroxide (Reidel-de Haen, Germany)
Amyloglucosidase from Aspergillus niger (Fluka)
Acetate buffer (0.1M, pH 4.6)
Triethanolamine hydrochloride (Fluka)
$MgSO_4.7H_2O$ (BDH)
β-Nicotinamide adenine dinucleotide phosphate disodium salt (Fluka)
Adenosine-5′-triphosphate disodium salt hydrate (Fluka)
$NaHCO_3$ (Reidel-de Haen, Germany)
Hexokinase (Fluka)
Glucose-6-phosphodehydrogenase (Fluka)
Phosphoglucose isomerase (Fluka)

2.5.3 *Extraction of starch from insoluble residue*

Three portions (approx. 100 mg) of the ground insoluble residue extracted from the potato in Section 2.5.1 were mixed with DMSO (20 ml) and 8M HCl (5 ml) then heated in a water bath at 60°C for 30 min.

This was then diluted with water (50 ml), neutralised with 5M NaOH, allowed to cool to room temperature and made up to 100 ml. The solution was filtered through Whatman 541 filter paper using a glass funnel.

0.2ml of this solution was mixed with acetate buffer (0.2 ml). Amyloglucosidase (0.02 ml; 10 mg/ml) was added and the solution was incubated at 20 - 25°C for 15 min.

The amount of glucose present was determined using the hexokinase method detailed in Section 2.5.4.

2.5.4 Hexokinase method for determining reducing sugar content

This method was used to measure the amounts of reducing sugars (glucose and fructose) and starch present in the potato samples. For starch determination, the amount of glucose produced by the enzymatic hydrolysis of starch in Section 2.5.3 allows the amount of starch present to be measured The amount of reducing sugars present in the potato was determined using the hexokinase method with the filtrates from Section 2.5.1.

The reaction is catalysed by hexokinase and leads to the production of the respective 6-phosphates in the presence of adenosine triphosphate (ATP):

$$\text{glucose} + \text{ATP} \xrightarrow{\text{hexokinase}} \text{glucose-6-phosphate} + \text{ADP}$$

$$\text{fructose} + \text{ATP} \xrightarrow{\text{hexokinase}} \text{fructose-6-phosphate} + \text{ADP}$$

The enzyme glucose-6-phosphodehydrogenase oxidises glucose-6-phosphate in the presence of NADP to 6-phosphogluconate and reduced NADP (NADPH) is formed. The amount of NADPH formed is equivalent to the amount of glucose-6-phosphate and glucose, and can be measured by changes in optical density at 340 nm.

On completion of the reaction, fructose-6-phosphate is converted to glucose-6-phophate with phosphoglucose isomerase, which leads to the production of more NADPH proportional to the amount of fructose present.

Reagents:

Triethanolamine buffer: Triethanolamine hydrochloride (11.2 g) and $MgSO_4.7H_2O$ (0.2 g) dissolved in water (150 ml). pH was adjusted to 7.6 with 5M NaOH (approx. 4 ml) then made up to 200 ml.

NADP: NADP (Na_2) (50 mg) was dissolved in water (5 ml). This solution is stable for 4 weeks at 4°C (Southgate, 1991).

ATP: ATP (Na_2) (250 mg) and $NaHCO_3$ (250 mg) were dissolved in water (5 ml). This solution is stable for 4 weeks at 4°C (Southgate, 1991).

Hexokinase, glucose-6-phosphodehydrogenase: Hexokinase solution (0.5 ml; 2 mg/ml) was mixed with glucose-6-phosphodehydrogenase solution (0.5 ml; 1 mg/ml). This solution is stable for 1 year at 4°C (Southgate, 1991).

Phosphoglucose isomerase: Phosphoglucose isomerase (2 mg) was dissolved in water (1 ml).

The solution to be analysed should contain between 0.4 and 0.8 g glucose and fructose per litre; if stronger solutions are to be analysed they must be diluted accordingly.

Triethanolamine buffer (3 ml) at 20 - 25°C was pipetted into a 3 ml cuvette. NADP solution (0.1 ml) was added to the cuvette followed by ATP solution (0.1 ml) and the sample (0.2 ml).

The contents were mixed and the optical density at 340 nm (E_1) was measured.

The hexokinase suspension (0.2 ml) was then added and, after mixing, the reaction was allowed to go to completion for 10 - 15 min. The reaction was considered complete when the optical density remained constant. If the reaction had not gone to completion after 15 minutes, the optical density was read at 5 min intervals until it was complete. The optical density was measured again (E_2).

Phosphoglucose isomerase solution (0.02 ml) was added and after mixing and leaving for 10 min the optical density was read (E_3).

$$E_2 - E_1 = \Delta E \text{ glucose}$$

$$E_3 - E_2 = \Delta E \text{ fructose}$$

Calculation:

The volume of the mixture for measuring glucose was 3.42ml and for fructose 3.44ml with a sample volume of 0.2ml

$$\Delta E \text{ glucose} \times 0.495F = \text{g glucose/litre}$$

$$\Delta E \text{ fructose} \times 0.497F = \text{g fructose/litre}$$

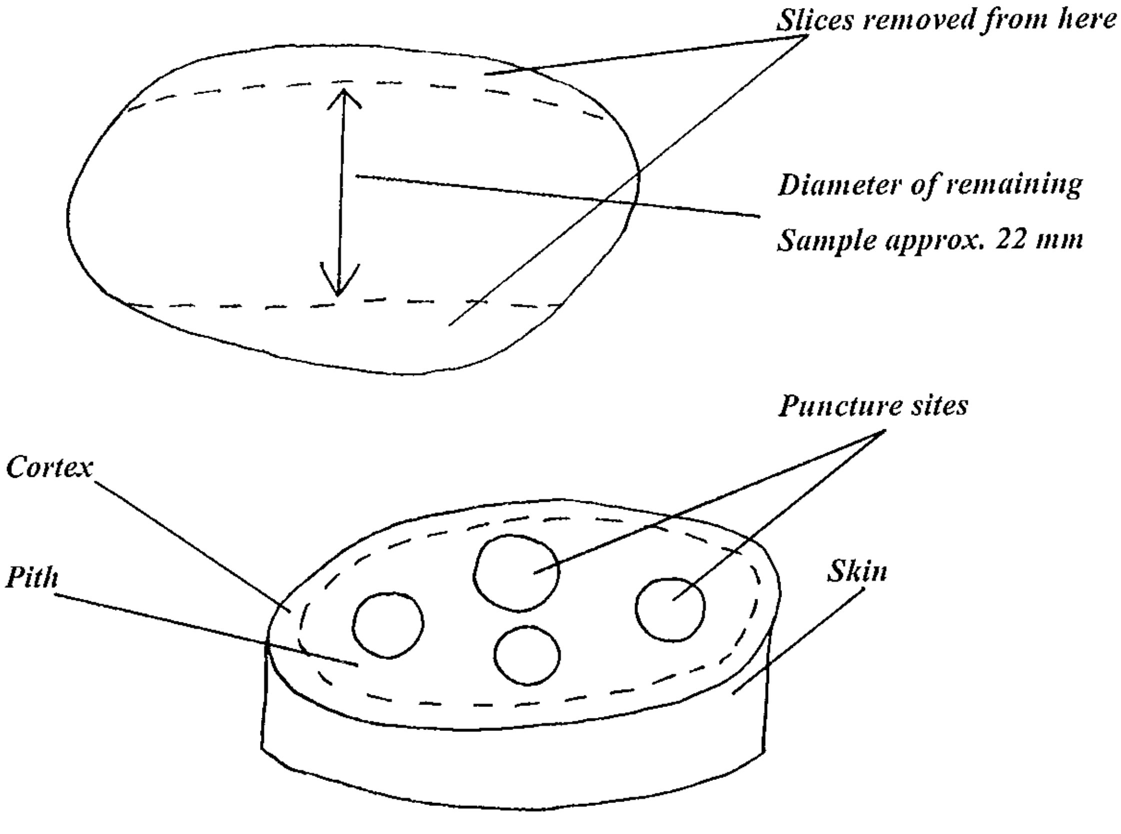
where F is the dilution factor. F is 17.1 for glucose and 17.2 for fructose.

*2.6 **Blanching method***

Potatoes (within the range of 35 - 45mm diameter) were put into a cylindrical shaped wire basket (18 cm high with diameter 13 cm – hole size in basket, 5 mm diameter) and placed into a thermostatically controlled water bath (Grant W14) with tap water. The blanching temperatures studied were 60, 65, 70, 75, 80, 90 and 100°C. Wire baskets were used for ease of removal from the water after the allotted blanching time and at the same time to ensure that potatoes were in contact with the water and that there was a good flow of water in and around them. Samples of three potatoes were taken every 5 min and immediately cooled for 5 min in ice water.

Two slices were removed longitudinally from each side of the potato leaving a longitudinal piece of about 22 mm wide (Figure 2.1).

Figure 2.1: Sampling procedure for texture measurement of potatoes and positioning of puncture sights for puncture test



2.6.1 Texture measurement after blanching

The texture of the potato was measured using an Instron Universal Testing Machine (4464 Instron Corp.). This consists of a moving bar, called a crosshead, to which various attachments can be fixed for different texture measuring tests. The crosshead can be programmed to move at a set speed and to stop and return to starting position at any stage during and after the test. The sample is placed on a stainless steel platform and subjected to some form of displacement from the attachments affixed to the crosshead. In this case the potato sample, resting on its side on the platform was punctured using a probe (7 mm diam.). Crosshead speed was set at 200 mm/min. A load cell of 500 N was used. Four puncture tests were performed per potato in the pith area (Figure 2.1). A plot of force (kN) against displacement (mm) was produced by the Instron Series IX software. Maximum puncture force (kN) was recorded.

2.7 Pectin methyl esterase (PME) Activity Determination

Reagents:

Pectin from citrus peel – DE 63 - 66% (Fluka)
NaCl (Reidel-de Haen)
NaOH (Reidel-de Haen)
Bromothymol blue (3′, 3″-Dibromothymolsulfonephthalein) (Sigma)

This was based on the method devised by Hagerman and Austin (1986) for determining the PME activity in plants that was later adapted specifically for potatoes by Tijskens *et al.* (1998).

2.7.1 PME extraction

PME activity was determined for samples blanched at 65, 75, 80 and 90°C for times of 5, 10, 15, 20, 25 and 30 min. Potatoes were blanched as described in Section 2.6. Potato samples were removed from the blanching water every 5 min. PME activity in raw potatoes was also determined. A cubed sample of approximately 1cm^3 was cut from the centre of the potato for PME extraction. For blanched samples the potatoes were plunged into ice water for 1 minute to cool, then a cube was cut from the centre and again placed into ice water to further cool before freezing. This cube was finely chopped and placed into a glass vial for freeze-drying. The sample was then frozen with liquid N_2 and freeze-dried over night (approx. 18 h).

The freeze-dried sample was finely ground in a pestle and mortar and placed into an airtight container.

This sample (30 mg) was weighed out into a centrifuge tube. Ice-cold water (1 ml) was added to the tube and stirred continuously with a magnetic stirrer for an hour at 1 to 4°C using an ice-bath. This mixture was then centrifuged (Sigma 2K15 Centrifuge) at 10000 x g for 3 min at 4°C. The supernatant (liquid) was removed and ice-cold 1M NaCl (1 ml) was added to the tube. This was stirred continuously for a further hour at 1 to 4°C. Following re-centrifugation at 10000 x g for 3 minutes the supernatant (liquid) containing the enzyme was recovered for activity determination.

2.7.2 Activity Determination

Pectin assay solution: 0.04% Bromothymol blue (7.5 ml) was added to 0.2% pectin in 0.1M NaCl (120 ml). The pH was adjusted to 7.8 using NaOH and the volume was made up to 150 ml with de-ionised water. The pH was maintained by bubbling through O_2-free N_2 continuously to prevent CO_2 from the air dissolving and changing the pH.

Method:

Pectin assay solution (2.9 ml) was added to 3 ml cuvettes. The cuvettes were flooded with O_2-free N_2 and covered with parafilm.

The supernatant recovered in Section 2.7.1 (100 µl) was added to the cuvette and the absorbance was followed at 616 nm using a UV-spectrophotometer (Milton Roy spectronic 1201) for 1 min.

A standard curve was prepared by adding galacturonic acid (0-0.09 µmol) to the pectin assay solution and measuring the absorbance at 616 nm. The standards were run every time a new assay was carried out.

Activity was expressed in µmol/min/g (Dry Weight).

2.8 Processing method

Potatoes (within the range 35 - 45 mm diameter) placed in wire baskets (dimensions as in Section 2.6) were blanched by immersing in tap water in a thermostatically controlled water bath (Grant W14). Blanching temperatures of 65°C and 75°C were used for times of 5, 10, 15, 20, 25 and 30 min. The potatoes were removed from the water after the allotted time, cooled in ice water for 5 min, then processed at 95°C or 100°C for times up to 25 min. Samples of four potatoes were taken from the water bath every 5 min for texture measurement.

2.8.1 Texture measurement after processing

Texture was measured as before using the Instron Universal Testing Machine (4464 Instron Corp.) except in this case a single blade, 1 mm thick, was attached to the crosshead and the potato was sheared longitudinally to a depth of 25 mm (The reasons for changing the method of texture measurement is detailed in Chapter 3, Results and Discussion). For the shear test the whole potato with its skin intact was placed on the steel platform of the Instron and sheared. Crosshead speed was set at 50 mm/min. A plot of force (kN) against displacement (mm) was produced by the Instron Series IX software during and after the test. Maximum shear force (kN), maximum slope before fracture (N/mm) and work to fracture (J) were recorded.

2.9 Sensory analysis

A taste panel, consisting of 8 trained tasters from the Dublin Institute of Technology Food Product Development Centre, was given 6 samples of potatoes subjected to various treatments, to taste and evaluate for the following attributes:

Hardness, denseness, moistness, fibre content, chewiness and palatability

The panellists were also asked to rate the overall product and to give their opinions on each potato tasted.

The procedure for tasting was based on the procedure detailed by Truong *et al.* (1997) for sensory texture profile analysis of cooked sweet potatoes.

The samples were prepared and labelled as shown in Table (2.1).

Table 2.1: Treatments for potatoes for sensory analysis

Sample	**Treatment**
A	Blanched at 65°C for 20 min then processed at 95°C for 20 min
B	Blanched at 65°C for 20 min then processed at 95°C for 25 min
C	Blanched at 65°C for 20 min then processed at 100°C for 15 min
D	Blanched at 65°C for 20 min then processed at 100°C for 20 min
E	Processed at 100°C for 15 min
F	Processed at 95°C for 20 min

Blanching and processing were carried out as before in a thermostatically controlled water bath with the potatoes in wire baskets. The potatoes were cooled in ice water after processing, for 5 min.

One potato sample from each treatment group was presented to each taster on a numbered paper plate. The tasters rated each sample using a 7-point scoring system. The questionnaire given to each taster is shown in Figure (2.2).

Figure 2.2: Questionnaire completed by the taste panel during the tasting

QUESTIONNAIRE

|——|——|——|——|——|——|

1 2 3 4 5 6 7

Weak Strong

	Sample A	*Sample B*	*Sample C*
Hardness/ Firmness (1 = soft, 7 = hard)			
Denseness (1 = airy/puffy/light, 7 = dense/heavy)			
Moistness (1= dry, 7 = moist)			
Chewiness (number of chews)			
Fibres (1 = not fibrous, 7 = very fibrous)			
Product palatability (1 = not palatable, 7 = very palatable)			
Overall product (1 = very bad, 7 = very good)			

<u>Methods of assessment:</u>

First bite:

Bite with the front teeth and evaluate for:

a) Hardness/firmness: amount of force necessary to bite completely through the sample

b) Denseness: degree to which the sample is solid, compactness of the cross-section

c) Moistness: degree to which the sample is moist

Mastication:

Chew at a constant rate of one chew per second and evaluate for:

a) Chewiness: number of chews required to prepare the sample for swallowing

b) Fibres: amount of stringy fibres perceived

3. *Results and Discussion*

3.1 *Sampling*

New potatoes available in Ireland include British Queens, Finna and Home Guard. However, these potato varieties were not chosen for this study due to lack of continual availability. Two varieties of new potato, Maris peer from Portugal and Nicola from England, were chosen instead because they could be obtained all year round. The potatoes were purchased daily from a Marks and Spencer's outlet in Dublin. The diameters of the potatoes used for the study were in the range 35 – 45 mm which corresponds to those used in industry.

3.2 *Potato composition*

As a starting point for this study, the two potato varieties were analysed to determine their composition. Moisture, ash, starch, reducing sugar content and specific gravity were measured and are represented in Table (3.1).

Table 3.1: Composition and specific gravity of Maris peer and Nicola potatoes

	Cultivar	
Chemical Component	***Maris peer (Portugal)***	***Nicola (England)***
Dry matter (%)	17.0	17.1
Moisture (%)*	81.6	81.0
Ash (%)*	4.2	3.8
Starch (%)*	12.7	13.3
Reducing sugars (%)*	1.9	2.1
Specific gravity	1.07	1.07

* Calculated on fresh weight basis

Moisture and ash content were measured using A.O.A.C methods. Starch and reducing sugars were measured using an enzymatic analysis. Details of these methods are described in Chapter 2 (Materials and Methods). Each value in Table (3.1) represents the mean of three analyses. There was no significant difference found between the chemical composition or specific gravity of Maris peer and Nicola varieties ($P < 0.05$).

3.3 Blanching Process

3.3.1 Choosing a method for texture measurement

It is important to spend some time choosing a method for measuring texture. If the correct method is not used then the results will be inaccurate and the information derived from these results will be useless. Bourne (1983) emphasised the importance of choosing the correct method and outlined four steps for doing so:

1. Eliminate unsuitable tests – not all tests are suitable for all food types. For example, an extrusion test is no good for a crispy product such as a potato crisp.
2. Preliminary selection – narrow down the possible tests to two or three suitable tests. The possible test principles that should be considered are:

   Puncture
   Deformation
   Extrusion
   Cutting – shear
   Snapping – bending
   Viscosity - consistency
   Penetration
   Crushing
   Tensile
   Texture profile analysis (TPA)

   This can be made easier by considering how a person would assess the texture i.e. by squeezing, punching with a finger, biting etc.
3. Final selection – once the tests have been narrowed down to those that are suitable, the tests should be applied over the whole range of textures that will normally be encountered with the food.
4. Refine test conditions – variables such as sample size, crosshead speed etc. should be studied and set for the test.

For the purposes of this study, the texture of the whole potato was to be measured so it was necessary to develop a method of measuring texture to suit this criterion. In most of the literature cited for this study, potatoes were not sampled whole for blanching or subsequent texture measurement. There were two exceptions. Jankowski (1992) cooked potatoes whole to study the influence of starch retrogradation on the texture of cooked potatoes. However, for the texture measurements cylindrical samples were taken from the potato. Bourne and Mondy (1967) tested the texture of whole potatoes using the puncture test with an Instron Universal testing machine. However, the potatoes were not cooked or blanched beforehand. In general, regular shaped samples, such as cubes, cylinders or French fry shapes, are cut from the potato. Using regular shaped samples makes it easier for the Instron to calculate various different parameters. In the case of mature potatoes, sampling whole would not be practical due to the irregularities in the shape of the potatoes. However, in the case of new potatoes, sampling whole is possible with low variations since the potatoes are generally uniform in shape. Also, for this study only potatoes with diameters in the range of 35 – 45 mm were used. This meant that the shape and size of the potato remained consistent throughout the study.

The steps detailed above were followed in order to aid the development of a valid texture measuring method for this study. Texture measuring methods of uniaxial compression, shearing and puncture testing were considered. The first section of the study involves blanching of whole potatoes over a range of temperatures for the purpose of obtaining information on how the texture of the whole potato is affected during blanching at these different temperatures. Therefore, it was essential that the method chosen would provide as much information about the behaviour of the whole potato as possible. After some consideration, puncture testing was chosen. There were several reasons for deciding to use this method:

- At this stage it was not clear how the texture of the whole potato would change and if the changes would be uniform, so it was necessary to chose a method that would give detailed information.
- Using a probe allowed for the measurement of the texture in different parts of the potato tuber, in particular allowing the differentiation between

the cortex and the pith areas, where differences have been reported (Anzaldua – Morales and Bourne, 1992). Also, by taking measurements in different parts of the tuber it was possible to determine whether or not there were significant differences in the texture of these different areas.

- Several measurements could be taken from the same tuber. Due to the small size of the new potatoes used, multiple measurements would not be possible with other methods of texture measurement such as shearing or compression.

Once the method had been decided upon, it was necessary to test it to see if it would give the desired information over the range of textures that would be seen in the potato at different processing temperatures i.e. raw, fully processed and an intermediate texture. For this test potatoes were blanched using tap water in a thermostatically controlled water bath under the following conditions:

(a) 80°C for 10 and 25 minutes (representing intermediate texture – between raw and fully cooked)
(b) 100°C for 10 and 25 minutes (representing fully cooked texture)
(c) No blanching – raw potato

The texture was then measured using three different probe diameters:

(1) 3mm
(2) 5mm
(3) 7mm

The three probe sizes above were chosen from a larger selection ranging from 2 – 10 mm. The 2 mm probe was too thin and it was felt that it would not discriminate sufficiently well between the different levels of texture at different temperatures and would penetrate too small an area. The 10 mm probes were too thick and would not allow for multiple puncture sites to be tested on each potato sample. The selection of probe sizes to be tested was thus narrowed down to 3, 5 and 7 mm. On testing each probe on potatoes subjected to each of the treatments above, it was found that the 3 and 5 mm probes gave Instron curves that were too difficult to interpret. As presumed with the 2 mm probe, the 3 and 5 mm diameter probes were too thin and picked up too many of the natural variations in the potato (the raw potato in particular) making the fracture point too hard to identify. The 7 mm diameter probe gave the best results in terms of giving the most information on the texture profile of the potato and allowing multiple readings to be taken from each potato sample.

The test with the 7 mm probe was found to be suitable for the requirements of this section of the study as it gave low standard deviation readings. Potatoes were tested raw, after processing to give an intermediate texture between raw and cooked and after fully processing to represent a range of textures. The results from these preliminary tests also showed that there was no significant difference between the cortex and pith in these potatoes with respect to texture ($P < 0.05$) (Table 3.2). This was expected since it is only as the potato matures that the cortex and the pith begin to differentiate in terms of composition.

Table 3.2: Puncture force for pith and cortex areas of new potatoes (Maris peer)

Treatment	*Pith Puncture force (KN)**	*Cortex Puncture force (KN)**	*Standard deviation*	*P-value*
Raw	41.2	44.0	2.1	0.57
80°C for 25 min	26.3	25.1	2.7	0.36
100°C for 25 min	1.7	1.7	0.9	0.12

* Mean of 10 puncture force readings

A wide range of crosshead speeds have been used in studies on texture ranging from 10mm/min (Taguchi *et al.*, 1991) to 500 mm/min (Anzaladua-Morales *et al.*, 1992). An increase or decrease in crosshead speed has been shown to be proportional to the force required to achieve a certain level of deformation (Shama and Sherman, 1973). It was difficult when attempting to set experimental parameters for texture measurement in this study as different studies used different sample sizes and different crosshead speeds making comparisons very difficult.

The ideal situation would be that the crosshead speed used reflects the chewing rate in the mouth for the particular food being tested. Rosenthal (2000) states how important the speed of movement of the jaw and the tongue within the mouth is in our perception of food texture. Tornberg *et al.* (1985) showed that when chewing meat, the jaw can move between 200 and 400 cm/min in contrast to typical instrumental testing machines, which operate at around 20 cm/min. High viscosity foods tend to require relatively low shear rates whereas low viscosity foods require relatively high shear rates (Shama and Sherman, 1973). In order to determine the best crosshead speed for the purposes of this study, it was necessary to try using different speeds and to investigate which speed gave the best results. Speeds of 50, 100, 150, 200, 250 and 300 mm/min were tested on potatoes treated in the same way as for the probe test. The slower speeds of 50 – 150 mm/min gave clustered data points in the Instron curve and made interpreting the information difficult. 300 mm/min was a little too fast and tended not to give as much information or as clear a picture of the internal structure of the potato, as speeds of 200 or 250 mm/min. In the end, 200 mm/min was chosen for this study, as there was little or no difference between this and 250 mm/min.

3.3.2 ***Sampling Procedure for Texture Measurement***

For the actual texture test two thin slices were taken from either side of the whole potato in a longitudinal direction, i.e. from bud end to stem end (as illustrated in Figure 2.1 in Chapter 2), so that the potato would sit steadily on the platform throughout the test. In previous attempts to measure the texture of the whole potato the results gave too much variation due to excessive movement of the potato during the test. Another advantage in removing these slices was that the position of the cortex and the pith could be clearly seen, which meant that measuring the texture of each area separately was made easier.

3.3.3 ***Blanching results***

Blanching experiments were carried out at this stage to investigate the effect of a variety of temperatures on texture. The blanching temperatures chosen were 60, 65, 70, 75, 80, 90 and 100°C. This range covered both the low blanching temperatures (60 - 75°C) and the conventional blanching temperatures (80 - 100°C) so that their effect on texture could be compared. Potatoes were blanched at each temperature for up to1 hour. This allowed the build up of a texture degradation profile with increasing time.

Generally, in the literature, texture measurements are taken after the processing stage for samples that have undergone a pre-processing treatment, but not after the pre-processing (blanching) stage itself. This means that determining the contribution of each stage to the softening or hardening of the product is not possible. In this study the contribution of pre-processing and processing time and temperature to overall loss of texture, or to improved firmness of texture, was investigated. Both the blanching step and the processing step were looked at separately so that conclusions could be drawn about the role of each process in overall texture change.

For blanched potatoes maximum puncture force was taken to be indicative of the point of fracture of the potato, i.e. the amount of force necessary to penetrate the potato. A typical Instron graph, showing load (kN) against displacement (mm) for the raw potato, is shown in Figure (3.1). It can be seen from the curve the point at which the probe punctures the potato (the first sharp peak) and the series of small jagged peaks that are produced as the probe passes on through the potato. These jagged peaks are probably the result of the probe rupturing the cell walls of the potato tissue, which are still intact in the raw potato, as it passes through. Dobraszczyk and Vincent (1999) describe what happens when a probe is pushed into a fresh apple, which is similar to what would happen in a potato. The cells ahead of the probe can be squashed, broken and compressed but if the cells can be separated from each other without being broken (for example, when processing using high temperatures), they will not present sufficient resistance to be broken and compressed and will simply move aside to allow the probe to pass. The mean maximum puncture force for the raw potato was 0.03 kN and 0.04 kN for Maris peer and Nicola varieties respectively. The typical Instron curve (Figure (3.1)) changed in both shape and in the steepness of the peaks as the processing of the potato progressed (Figure 3.2 (a), (b) and (c)). This may be due to the solubilisation of the pectic substances in the middle lamella as processing advances, leading to cell separation. This means that the probe passes between the cells rather than having to break through them, as in the raw potato, so the curve becomes smoother.

Figure 3.1: *Instron graph showing a typical curve of load against displacement for raw potato*

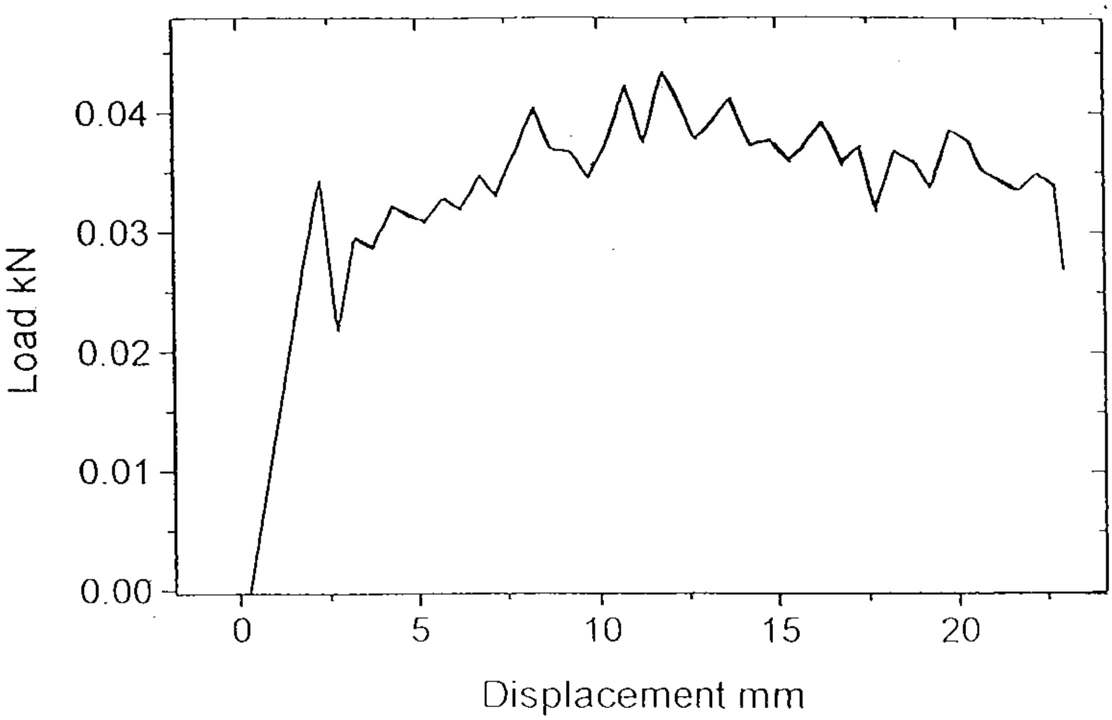
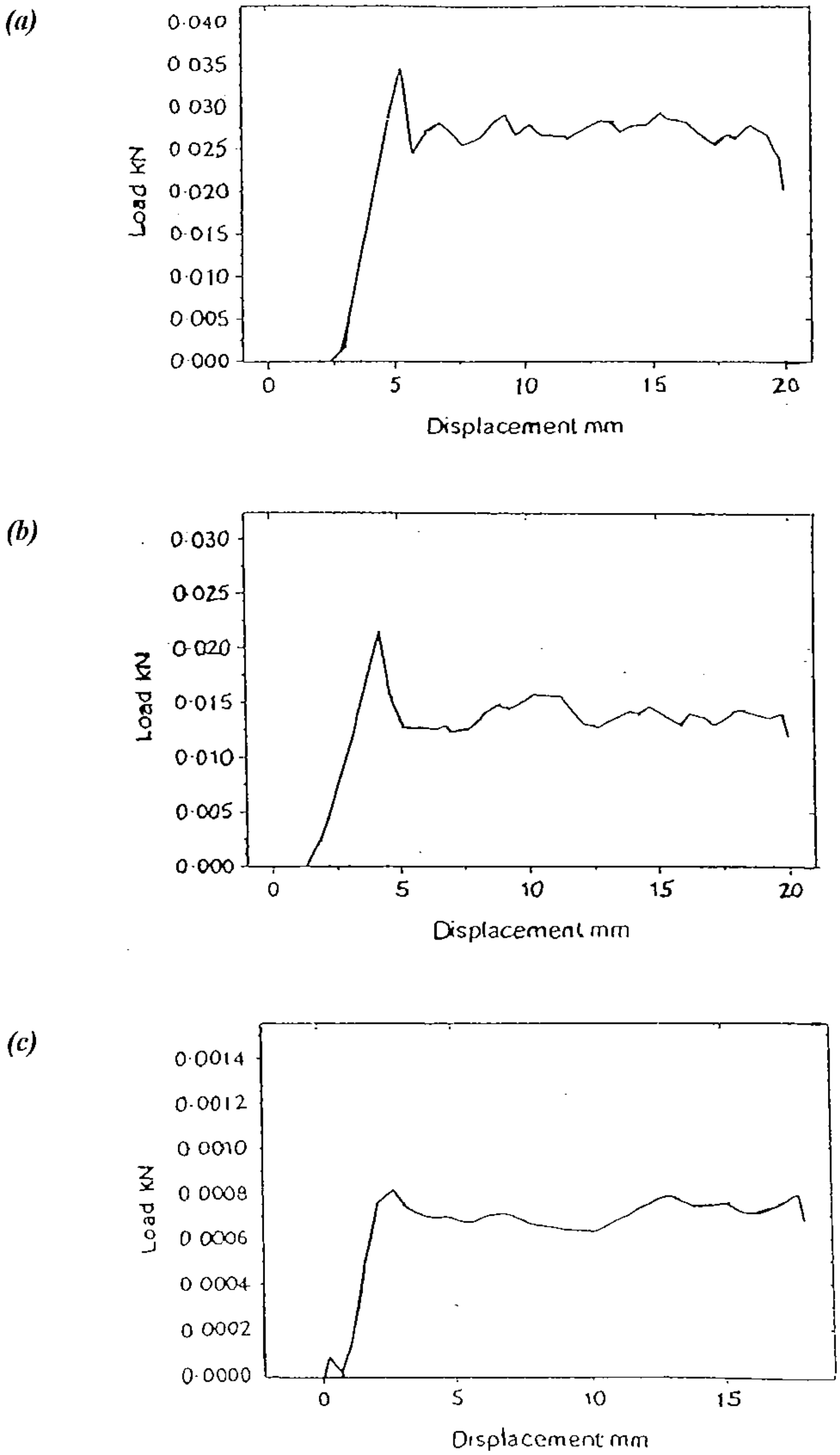


Figure 3.2: *Instron curves of load against diplacement for potatoes blanched at (a) 60°C for 20 min (slightly processed) (b) 80°C for 20 min (intermediate processing) and (c) 100°C for 25 min (fully processed)*



The texture degradation profile for the blanching temperatures used is shown in Figures (3.3) and (3.4) for potato varieties Maris peer and Nicola. What is immediately obvious from these graphs is that the most rapid degradation in texture occurs at 100°C. The degradation profile at 100°C for both varieties is practically identical with rapid softening taking place up to 20 min then levelling off at 25 min after which there are no further significant changes in texture. This temperature is the normal cooking temperature when boiling potatoes and so the degradation profile at 100°C gives a picture of the structural breakdown that typically occurs when cooking potatoes in a domestic situation. No texture measurements were taken after 40 min at 100°C because the potato had almost completely disintegrated at this stage of heating. After 15 min at this temperature, when slices were cut from either side of the potato for texture measurement (as illustrated in Figure 2.1 in Chapter 2), cracks could be seen running longitudinally through the potato. The width of these cracks increased as the blanching time increased until, at 40 min, it was practically impossible to find an area of the potato that could be punctured i.e. that had not already cracked due to thermal degradation of the structure.

There is also a rapid loss of texture at a blanching temperature of 90°C though not as rapid as for 100°C. A steady decline in firmness is observed with increasing blanching time. Maris peer appeared to level off slightly after 40 min whereas the puncture force values for Nicola continued to fall after 40 min, though at a slower rate. It could be presumed that this deterioration continued after 1 hour until it reached a level of approximately 0.001 kN, which could be taken to indicate complete loss of structure, as seen with 100°C at 40 min for both potato varieties. In fact at blanching temperatures of 90°C and 100°C it appears that the process involves two steps, with an initial rapid decline in firmness followed by a slower decline.

After blanching at 100°C for 40 min there is a 96.67% and 96.15% loss in firmness for Maris peer and Nicola varieties respectively, compared to the raw potato. In general, as the blanching temperature decreases the rate of texture loss decreases until at 60°C and 65°C there is practically no change in texture with increasing blanching time. For both potatoes at temperatures of 60 - 75°C the change in texture from raw to the end of the blanching time is only of the magnitude of 8 N or less. At

80°C a less rapid decrease in firmness than at 90 and 100°C is observed although the softening is still more rapid than at 60, 65, 70 or 75°C for both Maris peer and Nicola. The softening of texture at 80°C and 90°C can be quantified as a decrease of 12.77 N and 26.76 N respectively for Maris peer and 24.9 N and 31.16 N respectively for Nicola over the 60 min blanching period. These figures represent a loss in texture of 42.43% (80°C) and 88.93% (90°C) for Maris peer and 67.48% (80°C) and 84.44% (90°C) for Nicola compared to the raw potato.

The results shown in Figures (3.3) and (3.4) exhibit a similar trend to those reported by Fuchigami *et al.* (1995) for carrots, and Speiss *et al.* (1987) for potatoes. The former used temperatures of 60, 70, 80, 85, 90 and 100°C for pre-heating and Speiss *et al.* (1987) used 70, 80, 90 and 100°C. Fuchigami *et al.* (1995) applied the blanching temperatures up to a time of 60 min. They reported little change in firmness (measured as maximum force) at 60°C or 70°C over the 60 min, but as the temperature increased there was an increase in the rate of softening. Speiss *et al.* (1987) used times up to 120 min and reported similar trends i.e. increase in rate of softening with increasing temperature. Both studies show almost complete loss of structure at 100°C after 10 min heating. Although this time is slightly less than for the times found in this study for complete disintegration, in the two studies aforementioned potato discs and slices were used, so thermal degradation would be expected to take place at a faster rate than for whole potatoes.

Figure 3.3: *Change in texture (maximum puncture force) with time of whole new potatoes cv. Maris peer blanched at 60, 65, 70, 75, 80, 90 and 100°C*

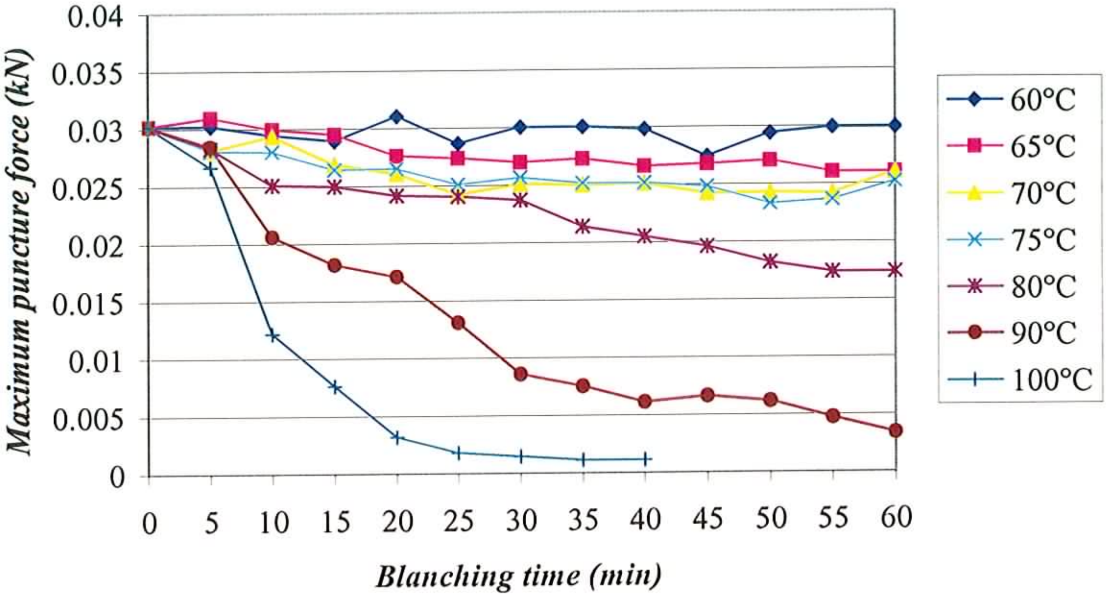


Figure 3.4: *Change in texture (maximum puncture force) with time of whole new potatoes cv. Nicola blanched at 60, 65, 70, 75, 80, 90 and 100°C*

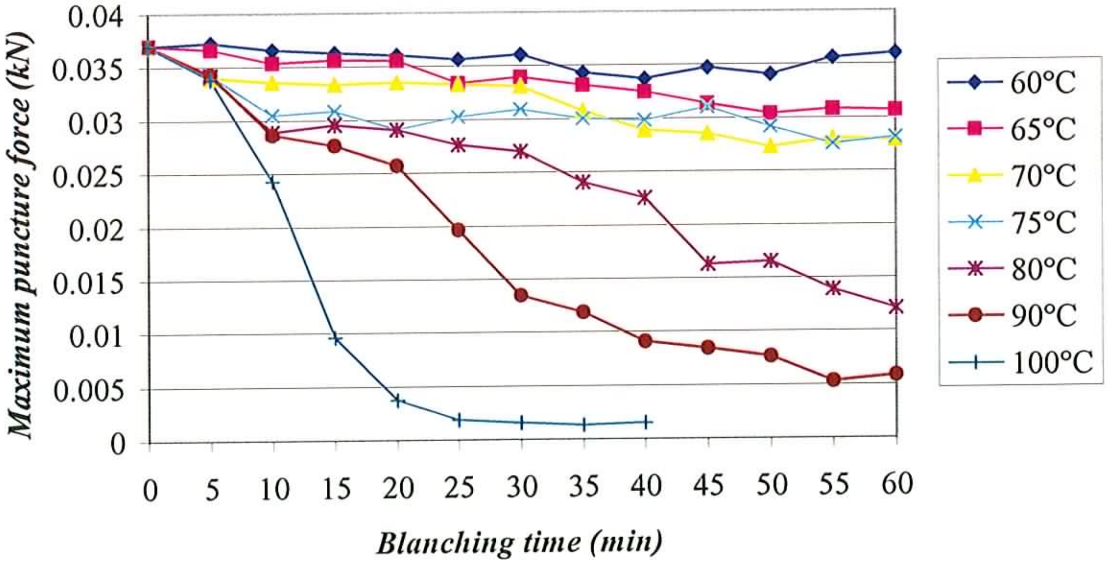


Table 3.3: Mean puncture force values (kN) and standard deviations for blanching temperatures of 60, 65, 70 and 75°C

Blanching time (min)	***Maris peer***		***Nicola***	
	Mean of 4 blanching temperatures	Standard. deviation	Mean of 4 blanching temperatures	Standard. deviation
0	0.03009	0	0.0369	0
5	0.02927	0.00149	0.03549	0.00166
10	0.02913	0.00083	0.03390	0.00267
15	0.02789	0.00149	0.03393	0.00248
20	0.02774	0.00227	0.03347	0.00318
25	0.02628	0.00204	0.03304	0.00221
30	0.02690	0.00222	0.03341	0.00215
35	0.02681	0.00237	0.03196	0.00204
40	0.02662	0.00223	0.03114	0.00225
45	0.02576	0.00155	0.03133	0.00257
50	0.02597	0.00277	0.03012	0.00287
55	0.02592	0.00284	0.03043	0.00371
60	0.02677	0.00212	0.03061	0.00379

From Figures (3.3) and (3.4) it appeared that the blanching temperatures could be grouped into three groups according to their effect on texture. Since there was little change in texture at temperatures of 60, 65, 70 and 75°C these could be placed into one group. The mean puncture force was calculated at each time for these four different temperatures, that is, the mean of the puncture force values at 5 min for 60, 65, 70 and 75°C, 10 min for 60, 65, 70 and 75°C etc. The standard deviation was also calculated for each time to see if there was, in fact, any actual difference between the effects of these four temperatures on texture (Table 3.3). Figures (3.5) and (3.6) show the mean of the four temperatures and their standard deviations. It appears from these

Figure 3.5: *Texture degradation profile for potato variety Maris peer showing mean puncture force values and standard deviations for blanching temperatures of 60 - 75°C and puncture force values for blanching temperatures of 80, 90 and 100°C*

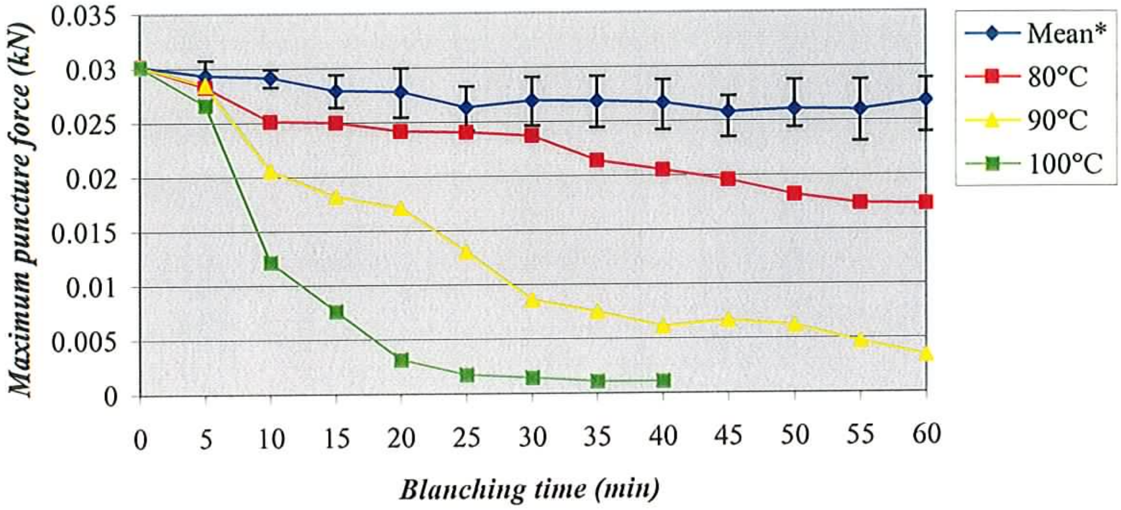
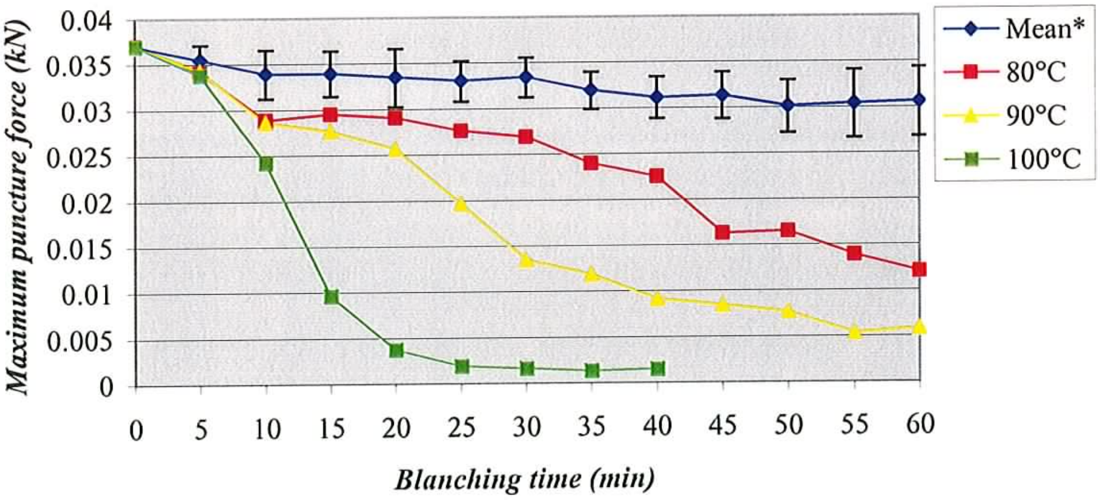


Figure 3.6: *Texture degradation profile for potato variety Nicola showing mean puncture force values and standard deviations for blanching temperatures of 60 - 75°C and puncture force values for blanching temperatures of 80, 90 and 100°C*



* *Mean is the average of the puncture force values for blanching temperatures of 60, 65, 70 and 75*°C

graphs that the effect on potato texture of each temperature in the 60 - 75°C range is not different but that the effect on texture of these temperatures is different from that of 80°C, 90°C and 100°C.

Analysis of the blanching temperatures, using ANOVA (ANalysis Of VAriance), showed that these temperatures could be grouped according to their effect on texture. The mean texture values at 60 - 75°C were significantly different to those at 80°C for Maris peer ($P = 0.00059$) and Nicola ($P = 0.0027$). Those values obtained at 80°C were significantly different from those at 90°C for both potato varieties ($P < 0.05$). 80°C could be viewed as an intermediate blanching temperature at which a certain degree of degradation occurs, though not as rapidly as at 90°C and 100°C. There is no significant difference between 90°C and 100°C up to 10 min blanching for Maris peer and up to 15 min blanching for Nicola ($P > 0.05$). However, after these times the effect of temperature on texture at 90°C and 100°C becomes significantly different ($P < 0.05$). Even so, the difference between the softening effect of 80°C and 90°C blanching temperatures is greater than the difference between the softening effect at 90°C and 100°C for both potato cultivars. Therefore, the blanching temperatures can be grouped as follows according to the severity of their effects on texture:

(1) 60, 65, 70 and 75°C – negligible softening
(2) 80°C – intermediate softening
(3) 90 and 100°C – rapid softening

The lack of softening at the lower temperatures (60 - 75°C) is probably due to the insufficient heat present to bring the pectic substances of the middle lamella into solution, thereby leading to cell separation and structural breakdown. In addition, at these temperatures PME has its optimum activity and may be responsible for reinforcing the bonds between the pectin molecules, preventing any significant textural deterioration.

3.3.4 Rates of reaction and activation energies – Arrhenius equation

The rate of reaction (k), for blanching temperatures of 80, 90 and 100°C were calculated from the slope of the plot of ln F_t against time, where F_t is maximum puncture force at any time t, k is the kinetical rate constant (min^{-1}) and F_0 is the puncture force of the unblanched potato i.e. at t = 0. The relationship between Ln F and t is:

$$\ln F_t = kt - \ln F_0$$

If a straight line can be plotted through the data then the slope of the line gives the rate of reaction (k). k values for blanching temperatures of 60, 65, 70 and 75°C could not be determined since there was minimal change in texture with time. The k values for 80, 90 and 100°C were then used to construct an Arrhenius plot. The Arrhenius equation can be presented as follows:

$$\mathbf{k = k_0\, e^{-Ea/(RT)}}$$

where R = universal gas constant (8.314 J K mol^{-1})

T = temperature (K)

E_a = energy of activation (JK mol^{-1})

K_0 = initial rate constant (min^{-1})

This equation can be rearranged and expressed in the following way:

$$\mathbf{\ln k = - E_a /RT + \ln k_0}$$

By plotting ln k against 1/T, both energy of activation (E_a) and the initial rate constant k_0 can be deduced. If a straight line can be drawn through the data points then it can be said that the process is temperature driven.

Table 3.4: *k values for blanching temperatures of 80, 90 and 100°C and the calculated parameters for the Arrhenius plot for the potato variety Maris peer*

Temperature (°C)	k value (min^{-1})	R^2	Temperature (K)	1/T (K^{-1})	ln k
80	0.009	0.97	353.15	0.002832	-4.71
90	0.036	0.97	363.15	0.002754	-3.32
100	0.110	0.96	373.15	0.00268	-2.21

Table 3.5: *k values for blanching temperatures of 80, 90 and 100°C and the calculated parameters for the Arrhenius plotfor the potato variety Nicola*

Temperature (°C)	k value (min^{-1})	R^2	Temperature (K)	1/T (K^{-1})	ln k
80	0.0175	0.92	353.15	0.002832	-4.046
90	0.035	0.97	363.15	0.002754	-3.352
100	0.101	0.92	373.15	0.00268	-2.293

Figure 3.7: *Arrhenius plot for blanching temperatures 80, 90 and 100°C for potato variety Maris peer*

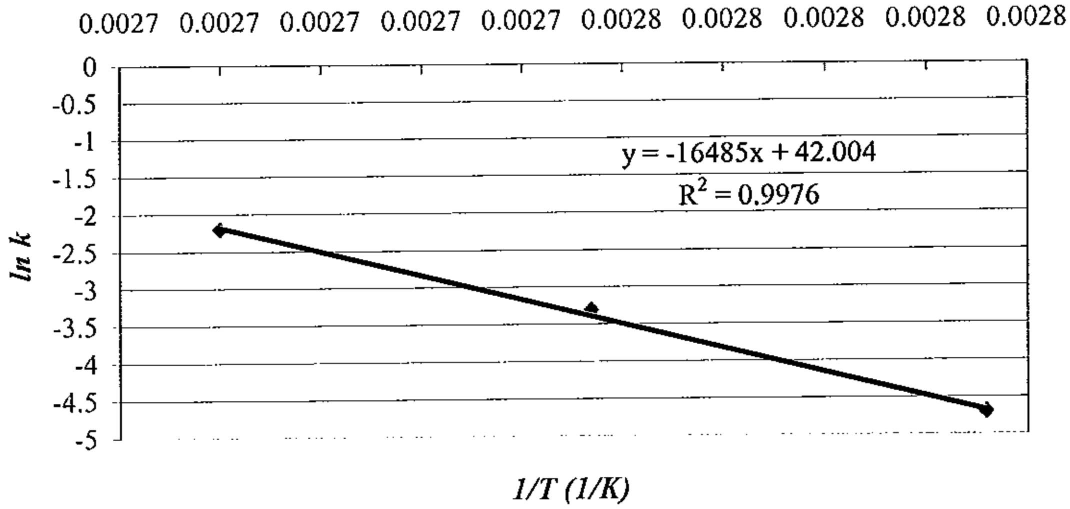


Figure 3.8: *Arrhenius plot for blanching temperatures 80, 90 and 100°C for potato variety Nicola*

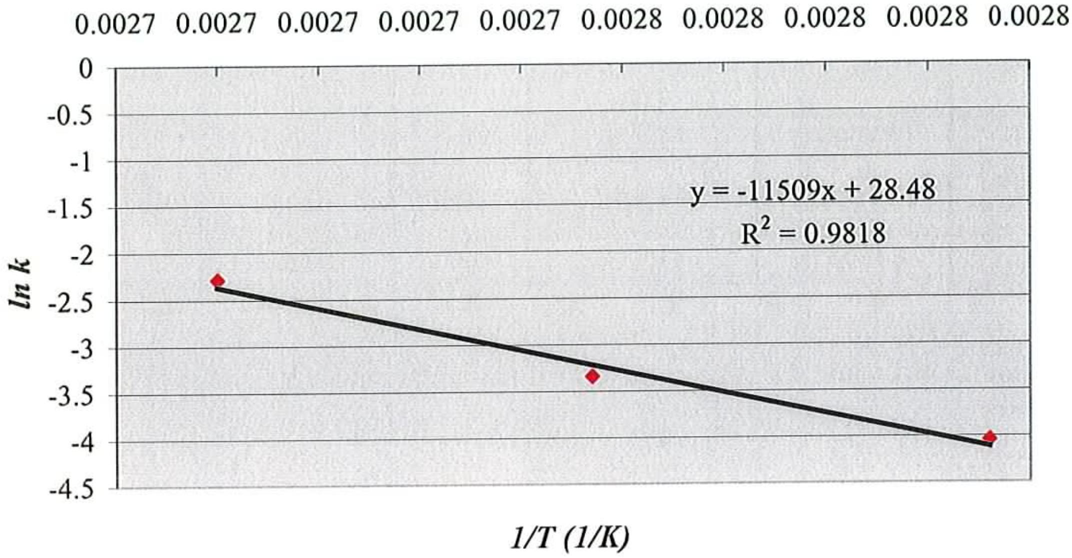
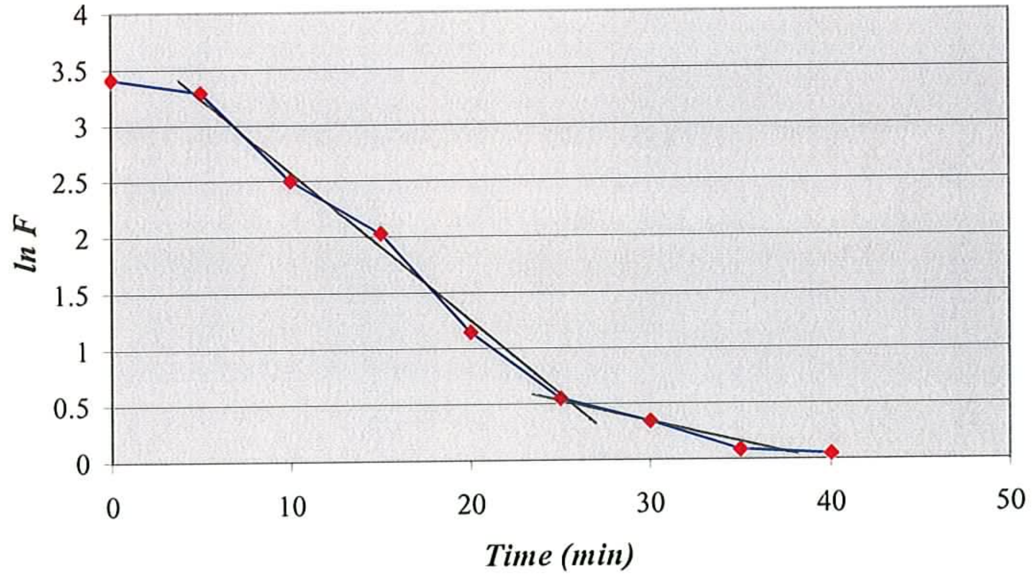


Figure 3.9: *Two softening phases for a blanching temperature of 100°C for Maris peer new potatoes. Phase 1 is from 0 – 25 min and Phase 2 is from 25 – 40 min*



From both Arrhenius plots (Figures 3.7 and 3.8) it can be seen that the blanching process is indeed temperature dependent at these higher temperatures with high R^2 values obtained for both potato varieties. E_a values were calculated as 137.06 KJmol^{-1} and 95.68 KJmol^{-1} for Maris peer and Nicola potatoes respectively. However, in order for these values to be of any use further potato varieties would need to be studied in order for comparisons to be made.

Table 3.6: *Ea and R^2 values from Arrhenius plots of different blanching temperature groups*

	Ea (KJ mol^{-1})		**R^2**	
Temperature (°C)	**Maris peer**	**Nicola**	**Maris peer**	**Nicola**
80, 90 and 100	137.06	95.68	0.99	0.98

The rate of textural degradation increases as the blanching temperature increases as seen in Figures (3.3) and (3.4). This is also seen with increasing k values as temperature increases (Tables 3.4 and 3.5). The process appears to be temperature dependent at temperatures of 80, 90 and 100°C since a straight line can be drawn through the data points on the Arrhenius plots for both potato varieties (Figures 3.7 and 3.8). Two separate phases of softening were evident for blanching temperatures of 90°C and 100°C. This is shown in Figure (3.9) for potatoes blanched at 100°C. Bourne (1987) reported that the texture kinetics for high temperature treatments for long processing times could be described using a double exponential decay model that assumes the existence of two simultaneous first order softening processes with different rates. Speiss *et al.* (1987) also observed that at blanching temperatures of 80, 90 and 100°C the shear strength of carrots and potatoes decreased according to two first order mechanisms. In this present study, at 100°C blanching temperature, the first and more rapid phase of softening occurred between 0 – 25 min, followed by a second phase between 25 – 40 min, where there is little texture degradation taking place. The k values for Phase 1 are 0.137 and 0.118 min^{-1} compared to k values of

0.0297 and 0.037 min^{-1} for Phase 2 for Maris peer and Nicola varieties respectively. The k values for the two phases of degradation at 90°C are shown in Table (3.7).

Table 3.7: *k values (min^{-1}) for two phases of softening at blanching temperatures of 90 and 100°C for potato varieties Maris peer and Nicola*

	Maris peer		*Nicola*	
	Phase 1	Phase 2	Phase 1	Phase 2
90°C	From 0 - 40 min k = 0.0438 $R^2 = 0.97$	From 40 - 60 min k = 0.0463 $R^2 = 0.93$	From 0 – 35 min k = 0.0332 $R^2 = 0.92$	From 35 – 60 min k = 0.0274 $R^2 = 0.83$
100°C	From 0 – 25 min k = 0.137 $R^2 = 0.99$	From 25 – 40 min k = 0.0297 $R^2 = 0.85$	From 0 – 25 min k = 0.118 $R^2 = 0.90$	From 25 – 40 min k = 0.037 $R^2 = 0.99$

From the overall results of blanching at temperatures of 60 - 100°C it can be seen that by using low temperatures for blanching it is possible to minimise the texture degradation of the potato. The question is whether or not this lack of texture degradation is due to the lesser degree of thermal degradation at lower temperatures or whether PME is activated at these temperatures leading to a firmer texture. At this stage, although it is clear that low temperatures help to prevent or slow down the rate of texture breakdown, a second, high temperature step for a short period of time would be required if low temperatures were to be used for the initial blanch. This is because the enzymes present in the potato that can cause further structural degradation (PME) and browning of the potato (peroxidase) after blanching, have not been destroyed. Blanching at a high temperature will be sufficient to inactivate these enzymes. It was observed during blanching at 90°C that times of greater than 5 minutes are needed for destruction of the enzyme peroxidase throughout the potato. Lack of browning of the potato when cut and exposed to air indicates that peroxidase has been destroyed. In these experiments when potatoes were cut for texture measurement, browning occurred in potatoes that had not been heated for longer than 5 minutes at 90°C. This was evidence that peroxidase was still present and so a treatment of 90°C for 5 min or longer would have to be used in conjunction with a low temperature blanch to ensure destruction of this enzyme. Canet and Hill (1987) used a specific test, which identified the presence of the peroxidase enzyme, as a measure of the effectiveness of the high temperature blanching step in inactivating enzymes. They found that 2 minutes at 97°C was sufficient to destroy peroxidase in cylindrical samples of potato and thus it could be considered effective in inactivating other enzymes present, namely PME. Moreno-Perez *et al.* (1996) also reported that a temperature of 94°C for 3 minutes was considered adequate for inactivation of these enzymes in cube shaped samples of sweet potato.

3.4 Pectin Methyl Esterase (PME) Activity

3.4.1 Choosing a method for measuring PME activity

Since the activity of the enzyme PME, a naturally occurring enzyme in fruits and vegetables, has been proposed to play a role in improved firmness at low blanching temperatures, its activity, in the temperature range used in this study, was investigated. The mechanism put forward to explain this firming effect involves the de-methylation of the carboxyl groups on the pectin molecules by PME leaving them free to bond with Ca^{2+} and other divalent ions forming bridges between adjacent pectin molecules. This reinforces the structure of the vegetable tissue making it less susceptible to breakdown during further processing (Section 1.4.3.2 – Introduction).

Blanching temperatures of 65, 75, 80 and 90°C for times of 5 – 30 min were used. These temperatures were chosen to include both high temperatures, where the enzyme is reported to be inactivated and low temperatures in the range of the reported optimum temperature for PME activity, that is, 50 - 70°C (Andersson *et al.*, 1994). Since there was negligible texture degradation at 60, 65, 70 and 75°C, and little difference between the effect on firmness at any of these temperatures, 65°C and 75° C were chosen as representative of this group to investigate whether this texture retention was due to the low temperature itself or to the activation of PME at these temperatures.

There are three main methods for measuring PME activity:

1. Spectrophotometric (Hagerman and Austin, 1986)
2. Titrimetric (Moledina *et al.*, 1981 and Alonso *et al.*, 1995)
3. GLC (Bartolome and Hoff, 1972)

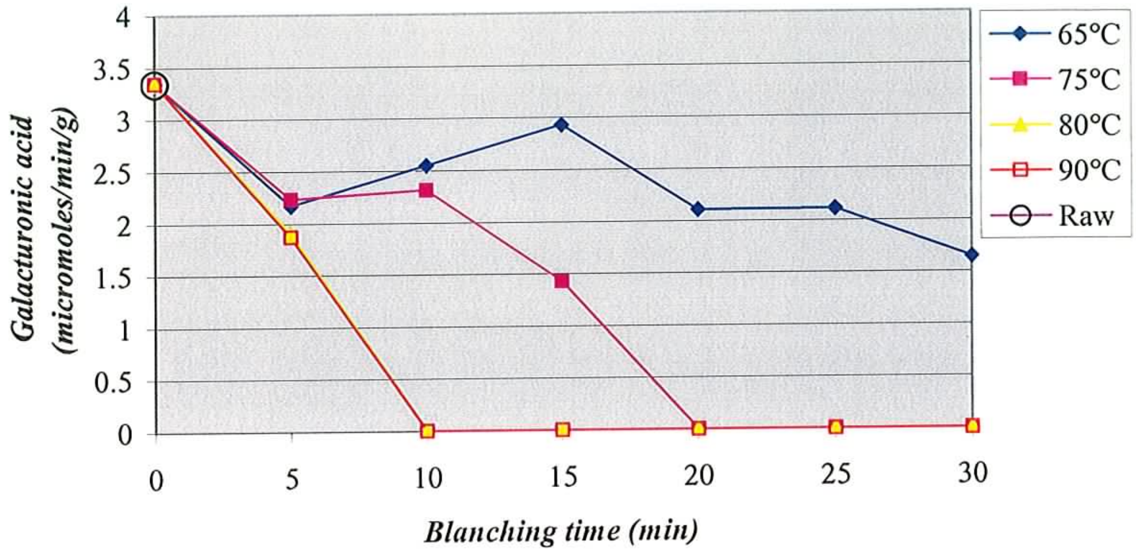
In this study it was not possible to have direct access to a GLC. The titrimetric method was reported to have less sensitivity than the spectrophotometric method. The spectrophotometric method was therefore chosen. This method was originally devised by Hagerman and Austin (1986) for determining PME activity in plants and had been adapted specifically for potatoes by Tijskens *et al.* (1998). Samples for PME determination were taken from the whole potato after blanching as described in Chapter 2. Three samples were used for each determination and each measurement was made in triplicate.

3.4.2 Results of PME activity determination

PME activity at blanching temperatures of 65, 75, 80 and 90°C was investigated in this study to determine if PME activity at these temperatures could be related to patterns of texture degradation observed during blanching. The results of the determination are shown in Figure (3.10).

It is apparent from this graph that PME is activated when blanching at both 65 and 75°C but is rapidly inactivated at 75°C after 10 min and at 80 and 90°C after 5 min. There is a significant effect of blanching temperature on PME activity ($P < 0.05$). The observed activity at blanching temperatures of 65°C and 75°C is significantly different ($P = 0.03$), as is the activity at 65°C and 80°C ($P = 0.00034$) and 65°C and 90°C ($P = 0.00031$). However, differences were not siginificant when PME activities were compared at 75°C and 80°C ($P = 0.157$) or at 75°C and 90°C ($P = 0.189$). This is in agreement with the observations of Andersson *et al.* (1994) that PME is rapidly inactivated above 70°C.

Figure 3.10: PME activity at 65, 75, 80 and 90°C expressed as micromoles of galacturonic acid produced per minute per gram



Note: Raw (control) value is 3.34 micromoles/min/g

Aguilera-Carbo *et al.* (1999) reported a significant difference in the effect on PME activity in potatoes between blanching temperatures of 65°C and 70°C ($P < 0.05$). They also used a blanching temperature of 60°C but found no significant difference between this and 65°C. They reported an optimum activity at 60 - 65°C for 45 min. After 45 min the PME activity began to fall off. Aguilera-Carbo *et al.* (1999) therefore concluded that a treatment of 70°C or above inactivates PME. In addition they noticed a significant difference ($P < 0.05$) between the texture values for blanching temperatures of 60°C and 65°C compared to 70°C. Texture values for 60°C and 65°C treatments were much greater than those for 70°C, which corresponded to PME activity at these temperatures i.e. greater activity at 60°C and 65°C than at 70°C, therefore indicating a potential relationship between improved firmness and PME activity at low blanching temperatures.

In Figure (3.10) an initial decrease in activity at 5 min followed by an increase in activity for 65°C and 75°C was observed. This decrease could be attributed to the fact that the sample was taken from the centre of the potato and the core of the potato had not reached the water bath temperature by 5 minutes so the enzyme may not have been fully activated. At all of the temperatures tested activity is seen to eventually decline with a more rapid decrease observed at higher temperatures (80°C and 90°C). Tijskens *et al.* (1998) reported that the activity of PME decreases with time at the different blanching temperatures used in their study (30, 50, 60, 70, 80 and 95°C) for potatoes and carrots. At higher temperatures the rate at which the activity decreased was faster than at lower temperatures. They also noted that a heat resistant activity, that is, an activity that remains after treatment, seems not to exist as the observed activity at all temperatures tended to decrease to zero. This implies that the enzyme can be denatured completely at each temperature, provided there is sufficient time. Optimum activity for PME was reported by Tijskens *et al.* (1998) to be at 50°C for 6 min. The optimum activities reported for PME in different studies varies. This is probably due to variation in composition, variety used and sample size. However, all reported figures lie in the range of 50 - 70°C.

Optimum activity for PME in this study was observed at 65°C after a 15 min blanching period (2.92 μmol/min) (Figure 3.10). At 75°C there was a rapid fall off in activity after 10 min with complete inactivation after 20 min blanching. At the higher temperatures of 80°C and 90°C inactivation is rapid after 5 min. The fact that there is some activity at 5 min for both 80°C and 90°C may again be due to incomplete heat penetration at this time. However, Fuchigami *et al.* (1995) found that carrots heated at 80°C for 10 min, at 85°C for 5 min or at 90°C for 3 min, then cooked, were firmer than their control (cooked at 100°C with no pre-blanch) suggesting that PME may be active for very short times at these temperatures. This would result in a slight firming effect compared to carrots that had received no pre-treatment. These results are in agreement with those found in this study i.e. a certain amount of enzyme activity for short times at high temperatures. The finding that PME was rapidly inactivated at 75° C and higher agrees with the findings in the literature (Andersson *et al.*, 1994; Fuchigami *et al.*, 1995; Moreno-Perez *et al.*, 1996; Bartolome and Hoff, 1972 and Moledina *et al.*, 1981).

Despite the many studies undertaken to determine the role of PME in after cooking firming with low temperature blanching, the mechanism for its action, and the extent to which it contributes to this firming is still not clear. However, there is strong evidence pointing towards PME activity at low blanching temperatures being a major contributor to improved firmness after cooking. The next stage of this study involved further processing of the potatoes, both with and without low temperature blanching. The results of this may provide further information on the relationship between PME and improved firmness at low blanching temperatures.

3.5 Potato Processing

3.5.1 Aim of potato processing

This stage of the study was carried out to investigate the behaviour of the potatoes with further heat treatment and whether or not a low temperature pre-treatment led to improved firmness in the fully processed product. This step was intended to represent further processing of potatoes after blanching (as would be carried out in industry) and to include processing of the potatoes with and without a pre-processing treatment. To this end, processing temperatures of 95°C and 100°C were chosen using times of 5 up to 25 minutes. From previous results it has been seen that texture rapidly degraded with increasing time at temperatures of 90°C and 100°C and that major structural degradation took place upon processing at times up to 25 minutes. Thus, it was considered that these times were sufficient for processing. It could be assumed therefore that this would also be true for a processing temperature of 95°C. A processing temperature of 95°C was used instead of 90°C to see how much difference there was in the effect on potato structure when using processing temperatures that were only 5°C apart.

As mentioned previously, the use of high temperatures in blanching is necessary, whether as a single high temperature blanch or as the high temperature step in a two step blanching process, to inactivate enzymes. For these experiments processing was carried out in a thermostatically controlled water bath. This method was chosen because immersion in water is the way in which potatoes were mostly cooked by the potato processors contacted for this study. In addition, new potatoes are most often cooked in water in a domestic situation.

3.5.2 Method for texture evaluation after processing

In Section 3.3.1 the puncture test, using a probe, was employed for measuring the texture of the blanched potatoes. This method allowed for detailed information to be collected on both the internal structure of the potato and the textural changes taking place with both increasing blanching time and temperature. However, with the higher blanching temperatures, particularly 100°C, the test became less efficient and resulted in high coefficients of variation for longer immersion times. This was due to cracking of the potato structure making it difficult to take measurements with the probe. This led to a lot of time and samples being wasted as it was necessary to repeat blanching experiments many times for potato samples blanched at 90°C and 100°C in order to obtain useable texture values. In light of this fact, alternative methods for textural evaluation of processed potatoes were considered.

The main methods for texture measurement available include puncture testing, shear, compression and extrusion. Extrusion was not suitable due to the fact that the potato was being tested whole, and puncture testing had already been used. This left shearing and compression tests.

(1) ***Compression*** was tested using a 9 cm diameter plunger. The potatoes to be tested were treated in the following way before texture measurement:

1. Blanched at 65°C for 20 min then processed at 95°C for 5 up to 25 min
2. Blanched at 65°C for 20 min then processed at 100°C for 5 up to 25 min
3. Processed at 95°C for 5 up to 30 min
4. Processed at 100°C for 5 up to 30 min
5. No treatment – raw

This range of treatments was chosen both to include a varying range of texture levels and to cover some of the types of treatments that would be used in this part of the study. The potatoes were blanched and tested whole. There were two drawbacks in using this method that became apparent almost straight away. The first was that the computer software used (Series IX) in conjunction with the Instron Universal Testing Machine requires that the area of each potato be inputted prior to each test. Normally, this would not pose a problem when regular shaped samples are cut from the potato for testing (Fuchigami *et al.*, 1995; Taguchi *et al.*, 1991, and Truong *et al.*, 1998).

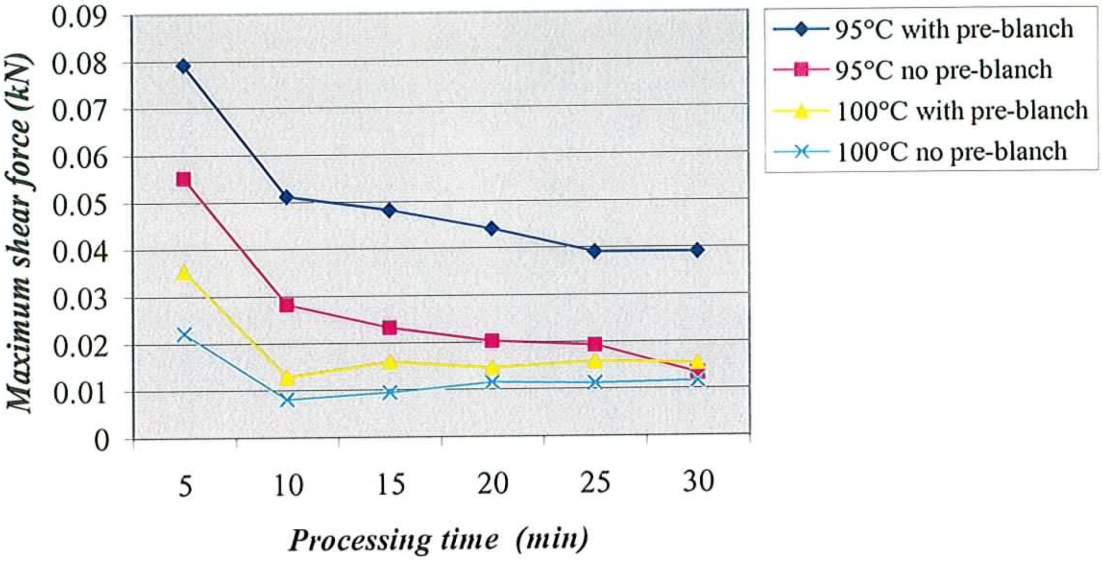
However, since the potato was being tested whole for this study, the area of each potato had to be measured manually and this, combined with irregularities in the potatoes meant that a certain amount of error was involved which would be carried over into the texture values, making them unreliable.

The second drawback arose from the test results themselves. It became apparent after initial testing of raw samples, and treatments 1 and 2 above, that the test was not sufficiently discriminating between different levels of firmness and in many cases the fracture point was difficult to identify on the curve produced by the Instron software i.e. force vs. displacement. As a result of these two situations the test was deemed unsuitable for the requirements of the processing experiments.

(2) Shearing using a single blade (1 cm thick) was then tested. Single-blade shearing has been shown to be useful in determining the texture of potatoes and carrots (Edwards, 1999). Potatoes were treated in the same way as for compression and were blanched, processed and tested whole. For the texture measurement potatoes were sheared both longitudinally (from bud end to stem end) and perpendicular to the long axis of the potato. Also, since new potatoes are most often served with their skins on and since leaving the skins on reduces labour and/or time during processing, the decision was taken to carry out the experiments with the skins on.

For the test, maximum shear force was taken to be indicative of fracture (Alvarez and Canet, 1999; Lin and Schyvens, 1995, and Speiss *et al.*, 1987). The results from the experiments showed trends similar to those obtained with the puncture test in Section 3.3.1, i.e. rapid decrease in firmness followed by a slower rate of degradation at 95 and 100°C (Figure 3.11). The test proved to be discriminating for the studied treatments giving useful data and clearly defined fracture points and thus appeared to suit the requirements of the study. As a result the shearing method was chosen for the processing experiments. It was found that texture values recorded for potatoes sheared longitudinally and perpendicular to the long axis of the potato were not significantly different for any of treatments studied ($P > 0.05$) so it was decided that shearing would be carried out longitudinally to cover as much of the potato as possible during the test.

Figure 3.11: Maximum shear force of potatoes processed at 95 and 100 °C for 0 – 30 min with and without a pre-blanching treatment of 65 °C for 20 min



The shear force versus time curves obtained for those potatoes processed after being blanched (Figure 3.11) gave a good indication of the trends that could be expected from the actual processing experiments, i.e. that low temperature blanching appeared to improve the texture of the potato after processing.

Before beginning processing it was necessary to establish a shear force value that would approximate an edible potato product, i.e. to obtain a value that represented a fully processed potato. In order to do this, Marks and Spencer 'New Potatoes with Butter, Parsley, Chives and Mint' were purchased. This was the only product that could be found in supermarkets where new potatoes had been used whole and with their skins intact. The potatoes were cooked according to the microwave instructions on the packet i.e. $5^{1}/_{2}$ min at 750 W. The average shear force value after cooking was 3 N. Having established that a fully processed potato should give a shear force value of approximately 3 N, the next stage was to identify the processing treatments (or pre-processing and processing treatments) that would result in a shear force within the limits of this value and to investigate how using a pre-treatment at low temperatures before processing affects the end texture and edibility of the potato.

3.5.3 Results from processing with and without a pre-treatment

For these treatments only the Maris peer variety of new potato was used. At this stage of the study the Nicola variety was not frequently available in the supermarkets, so to avoid unnecessary disruption of the experiments the Nicola variety was excluded. However, due to the similarity in the behaviour of both potato varieties in previous sections of the study, it could be expected that Nicola would behave in much the same way as Maris peer in this part of the study.

In order for various comparisons to be made the texture of potatoes that underwent the following treatments was measured by shearing:

No treatment - raw potato
Potatoes blanched at 65°C and 75°C for 5 up to 30 minutes
Potatoes processed at 95°C and 100°C for 5 up to 30 minutes
Potatoes blanched at 65°C for 5, 10, 15, 20, 25 and 30 min then processed at 95°C or 100°C for 5, 10, 15, 20 and 25 min
Potatoes blanched at 75°C for 5, 10, 15, 20, 25 and 30 min then processed at 95°C and 100°C for 5, 10, 15, 20 and 25 min

These treatments included both a single blanching treatment at 65°C or 75°C, a single processing treatment at 95°C or 100°C, and a two-step treatment involving a pre-processing step at either 65°C or 75°C followed by a processing step at 95°C or 100° C. This allowed the effect of a pre-processing step on the texture of the processed product to be compared with the texture of potatoes processed without a pre-treatment.

Blanching (pre-processing) temperatures of 65°C and 75°C were chosen since these temperatures produced minimal texture degradation of potatoes during blanching. Although the best temperature for blanching appeared to be 65°C, since this is the temperature where PME has its optimum activity, it was necessary to include 75°C as well. This was done to determine whether the higher level of PME activity at 65°C would result in a firmer potato after processing compared with a potato pre-treated at 75°C, where PME activity was lower. It was expected that a blanching temperature of 75°C would not have the same firming effect as 65°C since there was a significant difference between the effects of these two temperatures on PME activity ($P < 0.05$).

The texture values for blanching at 65°C and 75°C are shown in Figure (3.12) and those for processing (with no pre-treatment) at 90, 95 and 100°C are shown in Figure (3.13). A processing temperature of 90°C is shown purely for comparison. Maximum shear force was taken to be indicative of the fracture point of the potatoes.

It can be seen from Figure (3.12) that shear force at 65°C generally increases with increasing blanching time. However, at 75°C shear force increases up to 15 min blanching time then decreases to 20 min and levels off. This is consistent with the findings for PME activity at 75°C blanching temperature i.e. that PME activity falls off after 10 min at 75°C and is completely inactivated after 15 min. At 65°C the fact that the shear force values continue to increase may be due to the fact that the firming effect of the PME strengthens the structure of the potato making it firmer and it continues to have a firming effect as blanching time increases. This is reflected in the PME activity at 65°C (Figure 3.10), which shows PME activity increasing as blanching time increases up to 15 min then dropping off slightly at 20 min, but continuing to remain active up to 30 min. However, despite the slight difference in the behaviour of the potato at blanching temperatures of 65°C and 75°C there was no significant difference found between the shear force values for these temperatures ($P < 0.05$).

Figure 3.12: Texture degradation profile for potatoes blanched at 65 °C and 75 °C

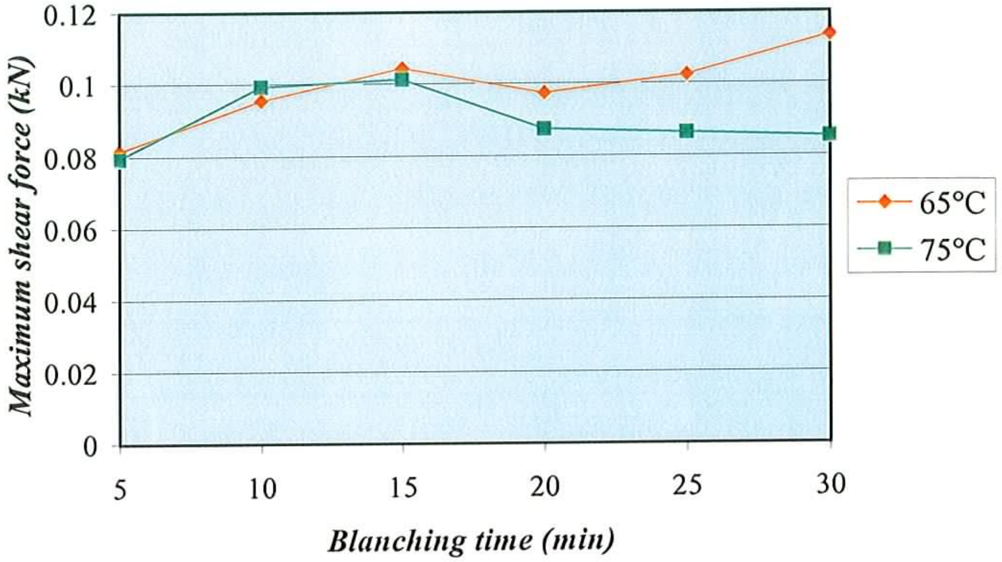
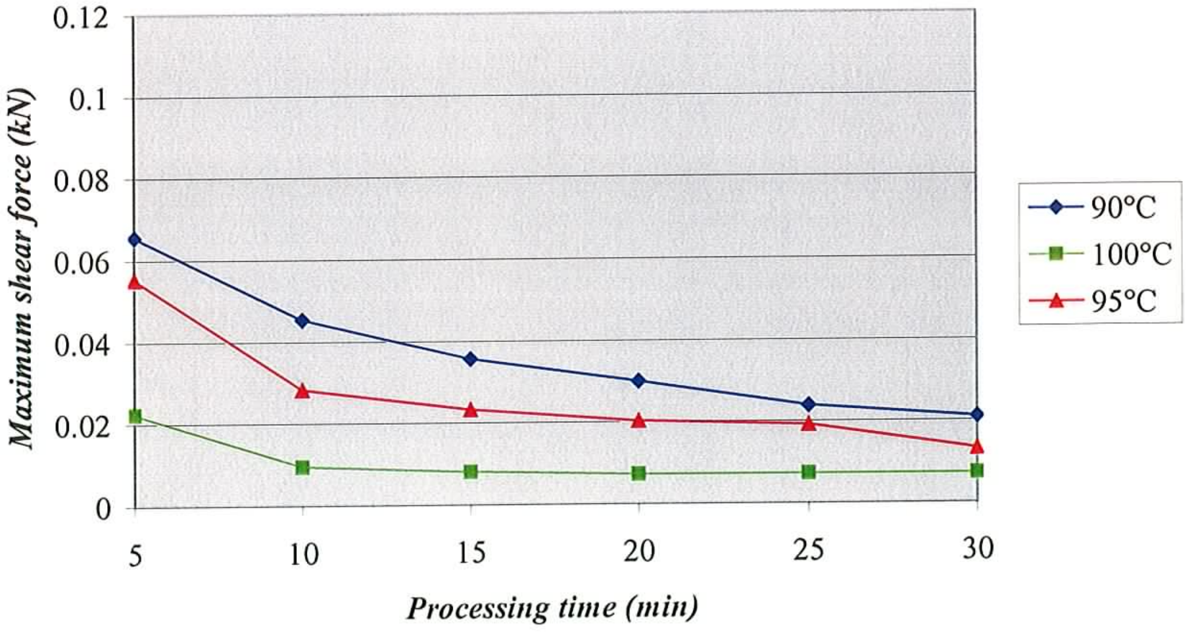


Figure 3.13: Texture degradation profile for potatoes processed at temperatures of 90, 95 and 100 °C showing maximum shear force versus processing time



From Figure (3.13) it is immediately apparent that significant texture degradation had taken place at the higher temperatures of 90, 95 and 100°C compared to the degradation profile seen in Figure (3.12). This is similar to what was seen in the blanching experiments in Section 3.3.1. The fact that the same trends were observed, using a different texture measuring method, provides confidence in the method. It also demonstrates, however, the importance of the method chosen for measuring texture, since different methods give different values for the fracture point, for the same treatment. For example, the force value for the raw potato obtained by puncture testing was 30 N compared to a value of 73 N by shearing (the value of 73N for the shear force of raw potatoes is the mean of 25 samples).

As seen before the use of higher blanching temperatures results in a greater and more rapid loss of structure than the use of low blanching temperatures such as 65°C and 75°C, where the change in texture is almost negligible. The change in texture at 90, 95 and 100°C represents a loss of firmness of 71.55, 82.19 and 84.37% respectively, compared to the raw potato.

This compares to an overall increase in firmness for temperatures of 65°C (54.79% increase) and 75°C (16.44% increase), over the 30 min blanching period. Other authors have reported this phenomenon i.e. an increase in firmness to values greater than those for raw or fresh samples. Truong *et al.* (1998) studied the effect of low temperature blanching on the firmness to processed sweetpotatoes (steam cooked for 20 min at atmospheric pressure) using compression testing to measure the changes in texture. Low temperature blanching was carried out in the range of 50 - 80°C for times of 15 – 274 min, using a treatment in boiling water for 2 min and a fresh sample as controls. As expected samples boiled for 2 min were softer than fresh samples, but both behaved similarly after steam cooking. However, after blanching at 60°C the force values exceeded those recorded for the fresh samples, with force increasing as blanching time lengthened. This is in agreement with observations made in this study at blanching temperatures of 65°C and 75°C. Many authors report that the firming effect of low temperature blanching increases with increasing blanching time (Verlinden *et al.*, 2000; Quintero-Ramos *et al.*, 1992). However, using stepwise regression analysis, Truong *et al.* (1998) produced a model which implied that in the range of blanching temperatures of 55 - 75°C, blanching temperature apparently had a stronger effect on firmness than blanching time and the optimum blanching temperature for best firmness was calculated at about 62°C.

Figures (3.14 – 3.17) show the trends for texture degradation (indicated by a decrease in shear force with time) when potatoes are processed with no pre-treatment (95°C and 100°C) and with a pre-treatment (blanching at 65°C and 75°C followed by processing at 95°C or 100°C). The difference in the behaviour of the potato when processed at 95°C compared to 100°C (without any pre-treatment) is clear. Even though the temperature difference is only 5°C the loss of firmness at 100°C over 25 minutes is much more rapid than at 95°C over the same time. It takes 20 minutes at 95°C to reach a stage where texture changes are minimal compared to only 10 minutes at 100°C, indicating a much greater destructive effect on the potato tissue when processed at 100°C. In addition, it would appear from Figures (3.14 – 3.17) that using a pre-treatment does improve the texture of the potato after processing. However, when ANOVA analysis was carried out on the results, it revealed that not all the apparent differences in texture were significant at the 5% level.

3.5.4 ANOVA analysis of shear force values for potatoes processed with and without a pre-treatment

ANOVA analysis was used in order to answer certain questions:

1) Is there a significant difference in the final texture of the processed potato when a blanching temperature of 65°C is compared to 75°C?
2) Does the processing temperature used have a significant effect on the final texture?
3) Is there a significant difference between the firmness of the processed product in the presence and absence of a pre-treatment?

All of these questions were looked at with respect to shear force values obtained upon texture measurement.

Figure 3.14: *Maximum shear force values for potatoes blanched at 65 ˚C followed by processing at 95 ˚C*

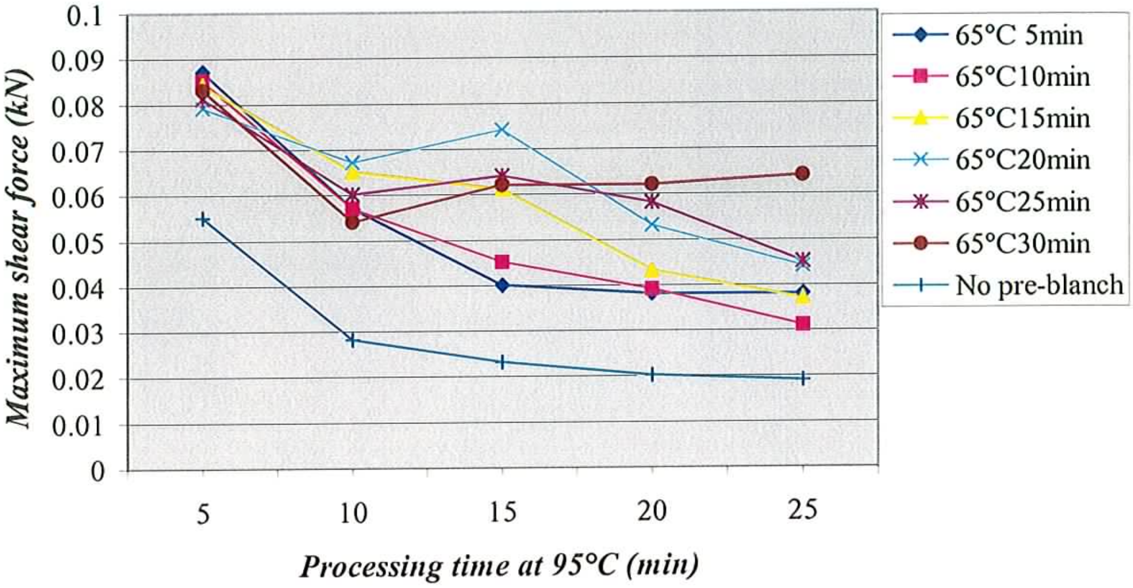


Figure 3.15: *Maximum shear force values for potatoes blanched at 75 ˚C followed by processing at 95 ˚C*

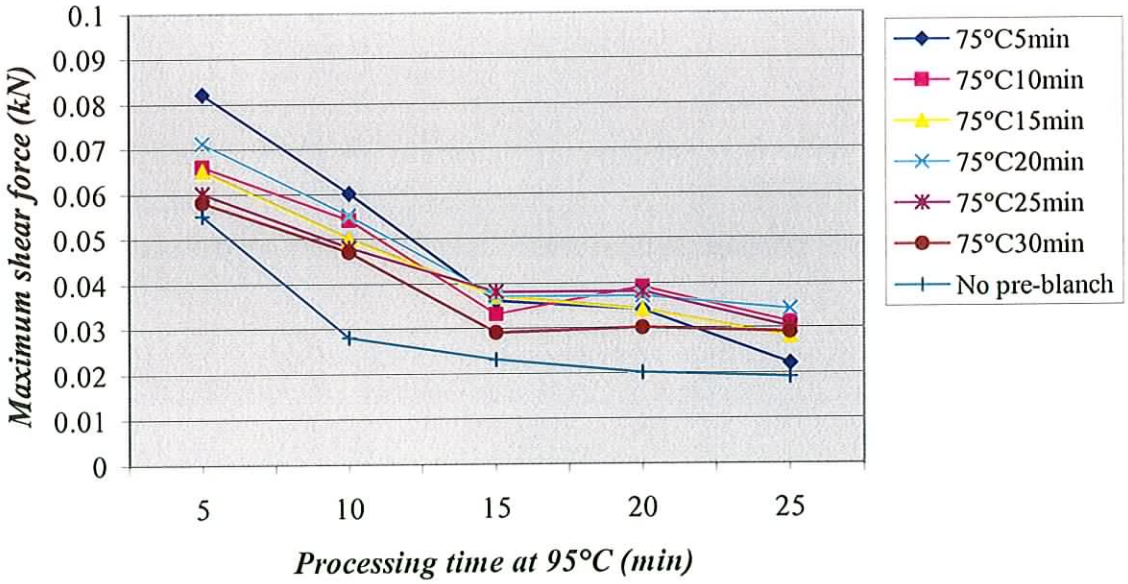


Figure 3.16: Maximum shear force values for potatoes blanched at 65°C followed by processing at 100°C

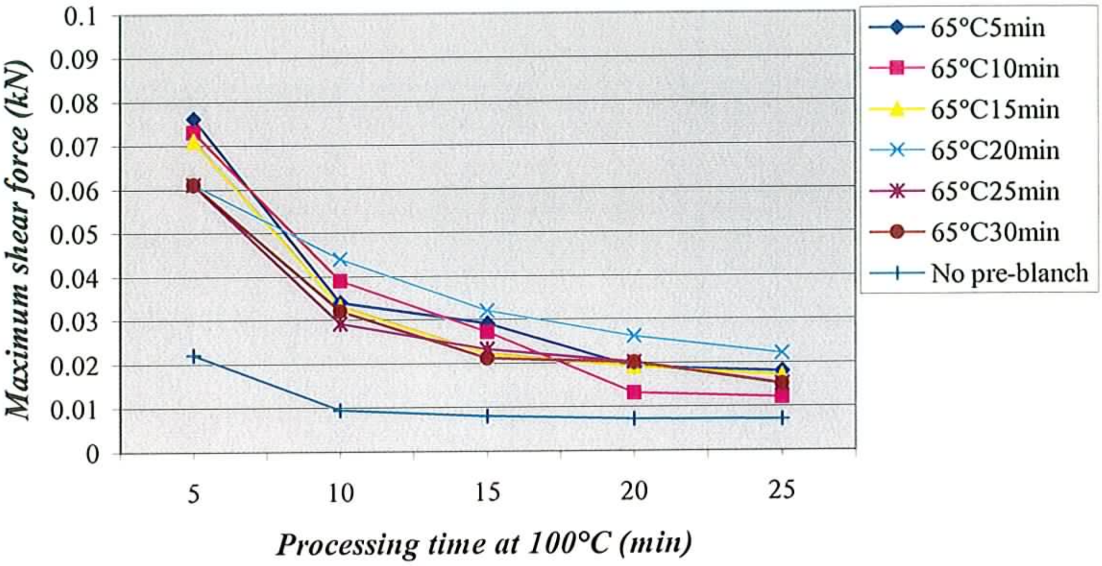
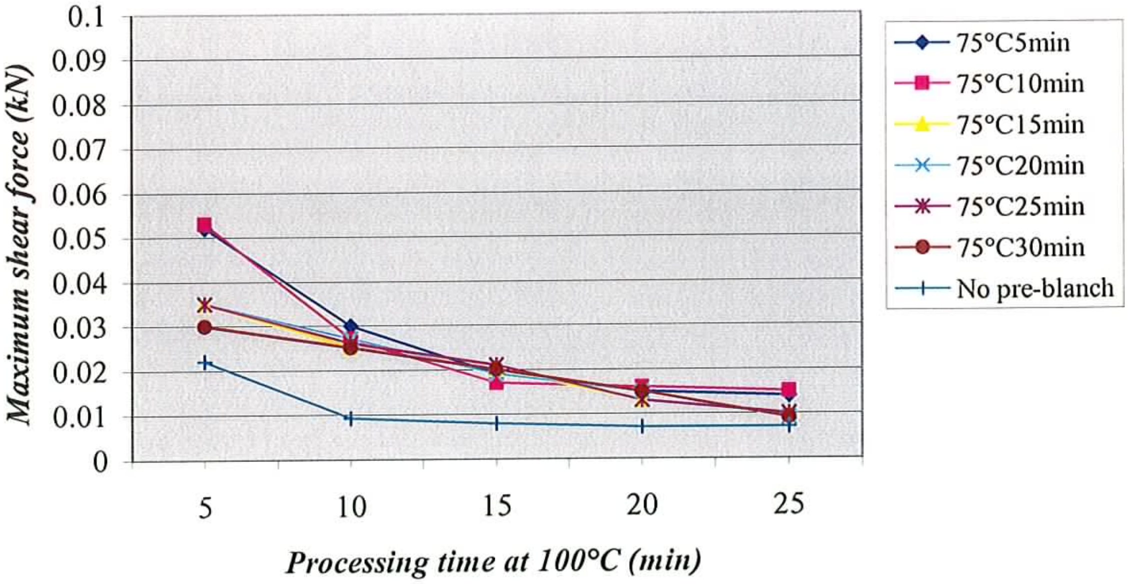


Figure 3.17: Maximum shear force values for potatoes blanched at 75°C followed by processing at 100°C



As already mentioned, it appears from Figures (3.14 – 3.17) that a pre-treatment results in higher shear force values after processing than those obtained for processing without a pre-treatment, and therefore gives a firmer end product. ANOVA analysis combined with visual observations during the pre-processing and processing experiments yielded results that both agreed with and refuted this.

Firstly, looking at the effect the blanching temperatures used for the pre-treatment i.e. 65°C and 75°C, have on the texture after processing, it was found that there was a significant difference between the firmness of potatoes blanched at 65°C then processed at 95°C and those pre-processed at 75°C ($P < 0.05$). The same was true for potatoes pre-processed then processed at 100°C. Potatoes blanched at 65°C gave a firmer product than those at 75°C after processing for both processing temperatures. What is most interesting about this finding is that when texture was measured after the blanching step, i.e. before processing, there was no significant difference between shear force values for 65°C and 75°C ($P > 0.05$). So, it would appear from this that the firming effect of low temperature blanching only becomes evident after processing.

This agrees with the findings of Verlinden *et al.* (2000) and Wu and Chang (1990). In the former study, which used ring shaped samples of potatoes, it was reported that while potatoes blanched (55, 65 and 75°C; 15 and 30 min) prior to cooking (boiled 7.5 and 15 min) were firmer than those cooked without any pre-treatment, the firming effect of blanching became apparent only after cooking. Wu and Chang (1990) also observed that while there was little or no firming effect for vegetables (stems of sprouting broccoli, asparagus lettuce and large stem mustard) when texture was measured after blanching (50, 60 and 70°C) a firming effect was observed when texture was measured after blanching then cooking (boiling, 15 min).

Table 3.8: *Summary of ANOVA analysis for shear force values showing whether there is a significant difference between using a blanching temperature of 65 ‘C and 75 ‘C for times of 5 up to 30 min on the firmness of the processed product i.e. effect of blanching temperature used eg. significant difference between potatoes blanched at 65 ‘C and those blanched at 75 ‘C when processed at 95 ‘C for 5 min (*$P = 0.00147$*)*

	P* - value	
Processing time (min)	**Processed at 95°C**	**Processed at 100°C**
5	0.00147	0.000258
10	0.0239	0.00459
15	0.00178	0.00688
20	0.0117	0.0176
25	0.0167	0.0125

* $P < 0.05$ significant difference

Table 3.9: *Summary of ANOVA analysis for shear force values showing whether or not there is a significant difference between the firmness of potatoes processed at 95 ‘C and 100‘C after blanching at either 65 ‘C or 75 ‘C for 5 up to 30 min i.e. effect of processing temperature used eg. Significant difference between potatoes processed at 95 ‘C and those processed at 100‘C for a time of 5 min after blanching at 75 ‘C (*$P = 0.000389$*)*

	P* - value	
Processing time (min)	**Blanched at 65°C**	**Blanched at 75°C**
5	0.000389	0.000513
10	9.43×10^{-6}	3.07×10^{-7}
15	0.000167	1.05×10^{-6}
20	6.77×10^{-5}	5.19×10^{-8}
25	0.000266	3.69×10^{-6}

* $P < 0.05$ significant difference

Table 3.10: *Summary of ANOVA analysis for shear force values showing whether or not there is a significant difference between the texture of potatoes processed at <u>95 ‘C</u> with no pre-treatment and those processed at 95 ‘C for the same times when pre-treated at 65 ‘C and 75 ‘C eg. no significant difference between potatoes processed at 95 ‘C for 5 min with and without a pre- treatment at 65 ‘C (P = 0.0821).*

	P* – value	
Processing time (min)	**65°C**	**75°C**
5	0.0821	0.197
10	0.0883	0.138
15	0.027	0.180
20	0.0062	0.105
25	0.0062	0.141

* $P < 0.05$ significant difference

Table 3.11: *Summary of ANOVA analysis for shear force showing whether or not there is a significant difference between the texture of potatoes processed at <u>100 ‘C</u> with no pre-treatment and those processed at 100 ‘C for the same times when pre-treated at 65 ‘C and 75 ‘C eg. no significant difference between potatoes processed at 95 ‘C for 5 min with and without a pre- treatment at 65 ‘C (P = 0.0821).*

	P* – value	
Processing time (min)	**65°C**	**75°C**
5	0.057	0.08
10	0.092	0.089
15	0.071	0.098
20	0.0086	0.091
25	0.06	0.089

* $P < 0.05$ significant difference

The fact that blanching at 65°C gives higher shear force values after processing at both 95°C and 100°C than blanching at 75°C may be related to PME activity at these temperatures since PME has its optimum activity at 65°C and in fact had higher levels of activity at 65°C for all times after 5 min. Wu and Chang (1990) reported that the blanching temperatures which gave the best firmness after processing for each vegetable corresponded to the temperature for optimum PME activity for each vegetable, implying a relationship between PME activity and improved firmness after processing. Also, Stanley *et al.* (1995) found a high degree of correlation ($R^2 = 0.995$) between firmness with low temperature blanching and the degree of pectin methyl esterification, which would suggest a mechanism for firming based on PME activity. However, in the case of this current study more work is needed in order to say with certainty that PME is responsible for the improved firmness.

The effect of the processing temperature used, on the firmness of the end product, was also considered, i.e. the use of 95°C or 100°C. Examining the graphs showing the change in firmness (shear force) with processing time (Figures 3.14 – 3.17) it has already been shown that processing at 100°C appears to have a greater softening effect on potato texture than at 95°C, both with and without a pre-treatment. For 95°C the highest shear force value attained, when values for processing with and without a pre-processing treatment are considered, is 64 N at the end of processing (after 25 min) compared to only 22 N at 100°C. This is nearly three times the value of the force of the highest shear force value achieved by a processing temperature of 100 °C at the end of the processing time. ANOVA analysis of the shear force values obtained for these temperatures (95°C and 100°C) shows that a processing temperature of 100°C does have a greater destructive effect on the structure of the potato as there is a significant difference between the firmness of potatoes processed at 95°C and those at 100°C at all processing times ($P = 0.032$). Also potatoes processed at 95°C with a pre-treatment gave shear force values significantly different to those processed at 100°C with a pre-treatment, irrespective of the blanching temperature used for pre-processing ($P < 0.05$). So overall, processing at 95°C, with and without a pre-treatment, results in less textural degradation than at 100°C. It may be that potatoes processed at 95°C, with or without a pre-treatment, would be suited to further processing since the potatoes are firmer than those processed at 100°C and it has already been seen that a processing temperature of 95°C for greater than 5 min is sufficient to destroy peroxidase enzyme which causes browning in potatoes if not inactivated.

So far it has been found that the firmness of the end product is affected by both the blanching temperature used and the processing temperature used. However, it remains to be seen whether or not this firming effect has produced a product that is significantly firmer than potatoes which were processed without any pre-treatment, since this was the desired result.

Again ANOVA provided some interesting results. It was found that although using a pre-treatment at 65°C before processing at 100°C produced a potato that was significantly firmer than that pre-processed at 75°C, it did not actually produce a product that was significantly different to that processed at 100°C with no pre-treatment ($P > 0.05$). The only two step process i.e. blanching followed by processing, that significantly improved firmness compared to a single step processing treatment, was a blanch at 65°C for 10 min or longer, followed by processing at 95°C.

Despite the fact that a pre-treatment at 65°C prior to processing at 100°C did not give rise to a firmer product than one produced by processing at 100°C with no pre-treatment, there was a difference in the potatoes that had received a pre-treatment compared to those that had not, from a visual perspective. During the processing and blanching experiments it was noticed that potatoes processed at 100°C with no pre-treatment began to disintegrate rapidly after 10 min processing. The skins began to wrinkle and become loose (detached from the flesh of the potato), sometimes coming off with the least amount of friction. Often the potatoes would have small pieces missing or hanging off when they were removed from the processing water. They were difficult to handle at this stage and great care had to be taken to avoid further disintegration prior to texture measurement. On the other hand, potatoes that had received a pre-blanch at 65°C did not disintegrate at any time during the processing, even after 25 min. Their skins remained intact and the flesh remained firm to the touch. This agrees with the findings of Bartolome and Hoff (1972) who found that potato samples pre-blanched at 60°C and 70°C gained in weight whereas those boiled at 100°C suffered almost complete disintegration. In this respect, using a pre-blanch was beneficial for ease of handling during further processing.

It would appear that blanching at 65°C before processing at 100°C has the effect of enabling the potato tissue to withstand the thermal effect of such a high temperature for longer than if there had been no pre-treatment. The observations made during the blanching and processing experiments using 75°C as the blanching temperature were not the same as for 65°C. The potatoes still tended to disintegrate and the skins to wrinkle after 15 min at 100°C and 20 min at 95°C, particularly when the longer blanching times at 75°C were used. This would point to the fact that a pre-blanching temperature of 75°C does not lead to any significant improvement in the quality of the processed potato, be it firmness or appearance or suitability to further processing, unlike pre-processing at 65°C.

Shear force values for potatoes that have been pre-blanched at 65°C are mostly higher than for potatoes pre-blanched at 75°C, at all blanching times and for both processing temperatures (Figures 3.16 and 3.17). In contrast to the firming effects brought about by a pre-treatment at 65°C, a pre-treatment at 75°C seems to have no effect. There is no significant difference in texture when a 75°C pre-treatment is used prior to processing at 95°C or 100°C for any blanching time compared to processing without a pre-treatment at 95°C and 100°C (Tables 3.10 and 3.11). At 75°C, the fact that PME reaches its optimum activity at 15 min and is, thereafter, rapidly inactivated, means that the structure of the potato tissue is not sufficiently strengthened or reinforced (if the relationship between PME and the firming effect is accepted) to withstand further textural degradation at the high processing temperatures used.

As already mentioned, for processing at 95°C, there is a significant difference between the texture of potatoes processed without a pre-treatment and those that received a pre-treatment at 65°C for 15, 20, 25 and 30 min (Table 3.10). This corresponds to the times when PME has its optimum activity at 65°C and may provide evidence for the relationship between PME and this firming effect. If this was the case then the reason that there is no significant difference at 65°C for 5 and 10 min could be due to lack of complete heat penetration into the whole potato at these times because of thermal lag, resulting in incomplete activation of PME.

In summary, it appears that 65°C is the best blanching temperature of the two blanching temperatures used, for improving the texture and appearance of the potato after processing. There is some evidence that PME may be involved in the firming effect at 65°C since it is more active, for longer, at 65°C than for 75°C. However, more research in this area is required.

3.5.5 *Calculated instrumental parameters – maximum slope before fracture (E_{max}) and work to fracture (W_f)*

Two other instrumental parameters besides shear force were calculated from the force vs. displacement curves produced by the Instron software (Series IX): maximum slope before fracture (E_{max}) and work to fracture (W_f). Maximum slope before fracture (N/mm) is calculated from the steepest part of the force vs. displacement curve, before the fracture point. This gives us a measure of the ratio of force to displacement. If the potato fractures with little displacement then the slope will be high. However if there is a lot of displacement before fracture, i.e. a lot of 'give' in the potato, then the slope will be smaller. Work to fracture (J) is an indication of the amount of energy input required up to the point of fracture of the potato. It is equal to the area under the force vs. displacement curve, from zero displacement to the displacement at the point of fracture.

Typical trends for both E_{max} and W_f at a processing temperature of 100°C are shown in Figures (3.18 - 3.21). They generally follow the same pattern as for shear force, i.e. decreasing with processing time. The trends for these parameters at a processing temperature of 95°C are similar to those for 100°C, with higher values

Figure 3.18: Maximum slope before fracture (E_{max}) values for blanching potatoes at 65°C then processing at 100°C

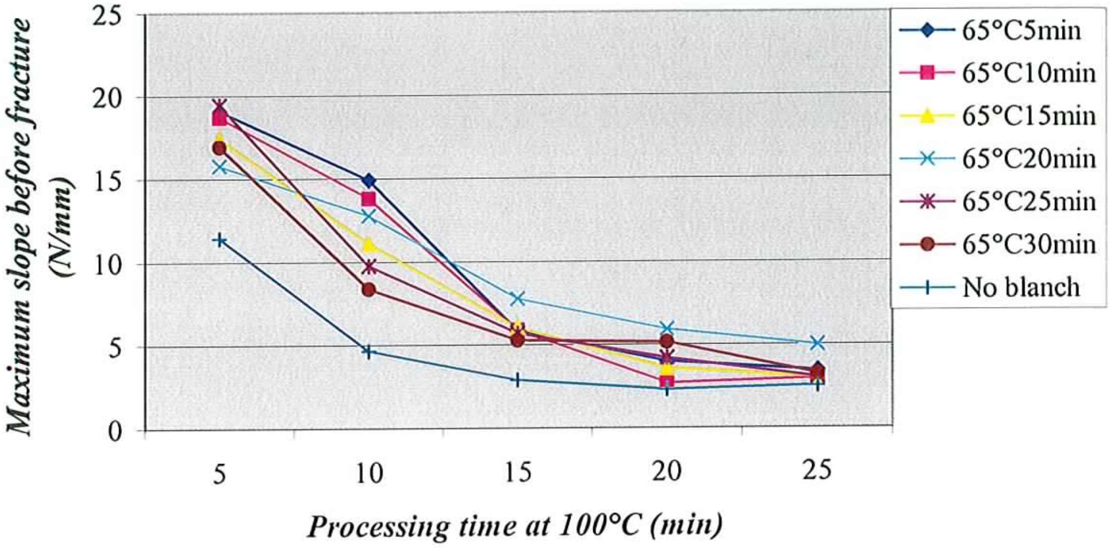


Figure 3.19: Maximum slope before fracture (E_{max}) values for blanching potatoes at 75°C then processing at 100°C

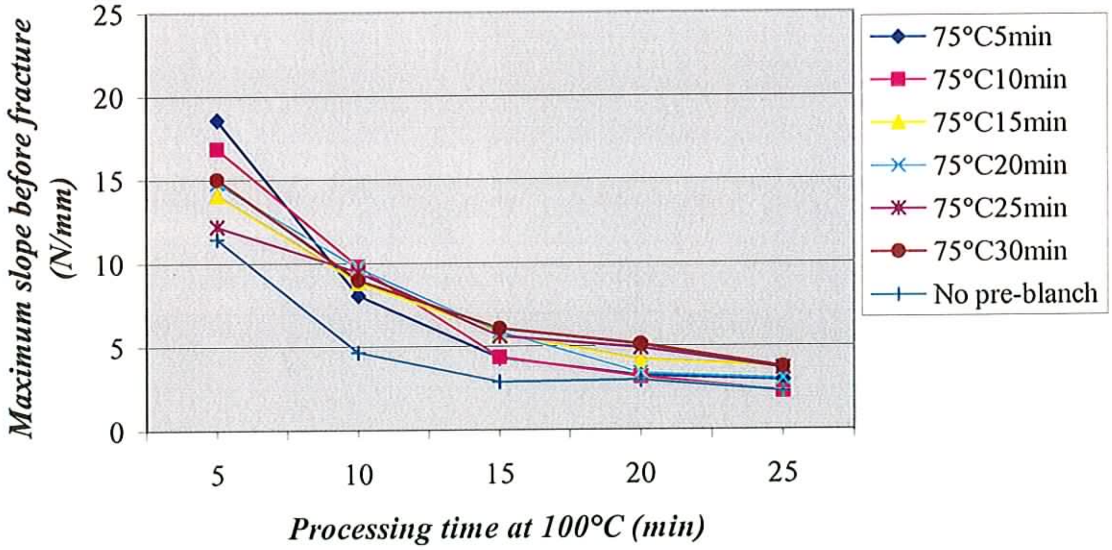


Figure 3.20: Work to fracture (W_f) values for blanching potatoes at 65°C then processing at 100°C

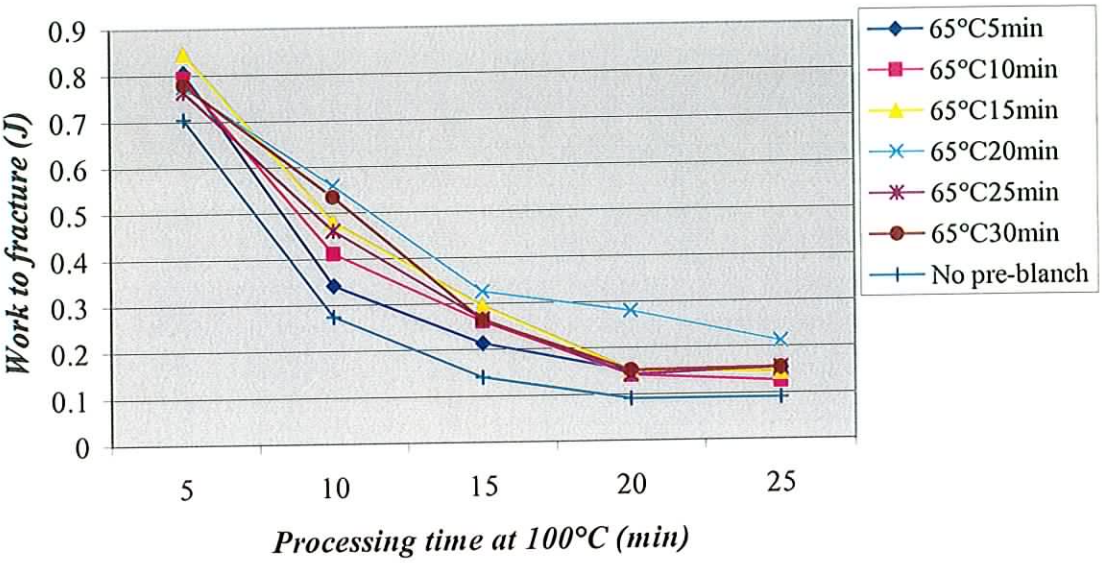
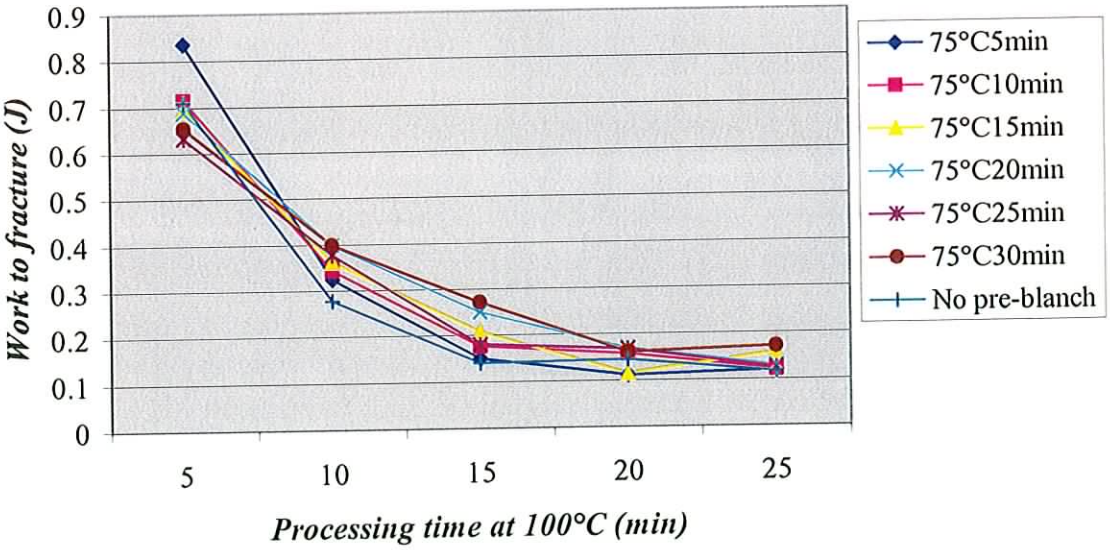


Figure 3.21: Work to fracture (W_f) values for blanching potatoes at 75°C then processing at 100°C



attained for both parameters for a processing temperature of 95°C, with and without pre-treatments compared to those for 100°C.

In general, a high E_{max} value indicates a lack of elasticity or 'give' in the potato and would imply that fracture happened after a very small amount of displacement. These higher values are typical of the raw product, those that are processed at high temperatures for very short times (up to 10 min) and those that are pre-processed at low temperatures followed by processing at high temperatures for the shorter processing times. In all these cases the structure of the potato tissue is strong so there is very little displacement at high force values leading to a high slope value. As processing progresses, cell separation takes place and this allows the potato to compress slightly before fracture by shearing. The increased displacement up to fracture with lower force values gives a lower slope.

With W_f, high values indicate that a greater amount of energy must be inputted into the system to bring about fracture. Again, these higher values are seen with the raw product, potatoes that have only had short times at high temperatures and those pre-processed at low blanching temperatures prior to processing for shorter processing times.

ANOVA analysis was carried out on these parameters mainly to determine if the pre-treatments of 65°C and 75°C had any effect on these values after processing and to find out what individual effects the blanching and processing temperatures had.

For E_{max} there is no significant difference between using a blanching temperature of 65°C or 75°C either at processing temperatures of 95°C or at 100°C ($P > 0.05$). For W_f, however, there is a significant difference between using a blanching temperature of 65°C compared to 75°C when processed at 100°C for 5, 10 and 15 min, but not at 95°C. From Figures (3.20) and (3.21) it can be seen that the W_f values are slightly higher and more differentiated for a blanching temperature of 65°C than for 75°C. This provides more evidence for the fact that the enzyme PME is more active at 65°C than at 75°C and so the potato structure better withstands processing at 100°C when blanched at 65°C than at 75°C, giving a stronger, more elastic product. After 15 min at 100°C, however, the thermal effect of 100°C takes over as has been seen previously and the effect of the two blanching temperatures on W_f is no longer significantly different. The potato becomes softer and more easily sheared.

There is a significant difference between the effect of the processing temperatures, with both pre-processing treatments, for both E_{max} and W_f ($P < 0.05$). The exception is for W_f, for a blanching temperature of 65°C where there is no significant difference between processing at 95°C for 5 min or for 100°C for 5 min. At all other processing times, for both blanching temperatures, there is a significant difference between both of the processing temperatures used. This provides evidence for the fact that there is a big difference between using 95°C and using 100°C for processing, with respect to texture degradation, even though the difference between the two temperatures is only 5°C. Using a temperature of 100°C leads to a product that disintegrates easily on application of force and that requires little input of energy to bring about fracture. However, using a lower processing temperature in combination with a low temperature pre-processing treatment, particularly at 65°C, strengthens the potato making it less breakable and more suitable for further processing.

3.5.6 Quantifying textural changes due to blanching and processing treatments

The results from blanching and processing experiments from Section 3.5.3 were analysed using parameters defined by Moreira *et al.* (1994) whereby they developed a method to quantify textural changes due to processing and pre-processing treatments. It was intended that this method would allow the segregation of the effects of the pre-processing treatment on the texture of the raw product and on the sensitivity of the vegetable tissue to the main processing step in such a way that a combination of both would also describe total changes in texture. These parameters were applied to the results of this present study to quantify the structural changes that result from the pre-processing treatment, the processing treatment, and the combined effect of both treatments. The parameters defined by Moreira *et al.* (1994) and applied in this section are recapped here and are described in more detail in Chapter 1, Section 1.4:

Pre-processing effect on the Initial Texture (PIT): this quantifies the softening (if a negative value) or hardening (if a positive value) of the raw material due to the pre-treatment itself – in this case the pre-processing treatment was blanching

Pre-processing effect on the texture Variation due to Processing (PVP): compares the change in texture that occurs during the processing stage for the vegetable product that was blanched and the one that would occur if no blanching had been used.

Moreira *et al.* (1994) also make an important point, stating that if a given pre-treatment is used there are two effects on texture that should be assessed independently.

1. The effect of the pre-treatment on the texture of the raw product.
2. The effect of the pre-treatment on the sensitivity of the vegetable tissue to the main processing step.

It is not always the case that if there is an improvement in the firmness of a product after pre-processing that this will be seen after the main processing treatment. It may be that the pre-treatment makes the product more sensitive to the processing method than it would have been had there not been a pre-treatment. Using these parameters provided an excellent way of investigating the contribution of both the pre-treatment (blanching) and the main processing treatments used in this study, to texture degradation and the combined effect of both treatments on the texture of the final product. Each parameter was calculated using the shear force values obtained for the pre-processing and processing treatments in Section 3.5.3.

Table 3.12: Summary description of parameters and the formulae used for their calculation

Parameter	Formula	Possible Values
Pre-processing effect on the Initial Texture **(PIT)**	$\ln \dfrac{F_{T0}}{F_{R0}}$	(+) value = hardening effect 0 = no effect (-) value = softening effect
Pre-processing effect on texture Variation due to Processing **(PVP)**	$\ln \dfrac{(F_T / F_{T0})}{(F_R / F_{R0})}$	(+) value = more hard 0 = no effect (-) value = more soft

F_{R0} – maximum load force in the raw product before processing (N)

F_R - maximum load force in the raw product after processing (N)

F_{T0} – maximum load force in the raw product after blanching (N)

F_T – maximum load force in the blanched product after processing (N)

Figure 3.22: Schematic representation of the relationship of nomenclature with processing steps

$$\begin{tikzcd}
F_{T0} \arrow[r] & {} \arrow[r, "\text{Processing of pre-processed material}"] & {} \arrow[r] & F_T \\
F_{R0} \arrow[u, "\text{Pre-processing treatment}"] \arrow[r] & {} \arrow[r, "\text{Processing of Raw material}"'] & {} \arrow[r] & F_R
\end{tikzcd}$$

PIT values show the change in texture after blanching compared to the texture of the raw potato, i.e. the effect of blanching on the texture of the raw potato. Upon plotting the PIT values against blanching times for blanching temperatures of 65°C and 75°C it can be seen that both temperatures caused a hardening of the potato to a value greater than the hardness of the raw potato, i.e. all positive values (Figure 3.23). This phenomenon has already been discussed in Section 3.5.3. The plot also shows that at 65°C we see a more or less consistent increase in hardness as blanching time increases, whereas for 75°C there is an increase in hardness up to 15 min after which the potato begins to soften though still maintaining a texture harder than that of the raw potato. As aforementioned this may be linked to the results obtained for PME activity at these temperatures. PME activity was higher for all blanching times at 65° C than at 75°C and may have resulted in a residual firming effect at 65°C that lasted even after the activity of the enzyme began to decrease.

PIT values for high (conventional) blanching temperatures of 90, 95 and 100° C (Figure 3.24) were also calculated in order to make comparisons with the effect of the low blanching temperatures on the texture of the raw potato. These values show softening in all cases compared to the raw product. At these high temperatures PME has been destroyed and cannot reinforce the structure of the potato, so the texture of the potato succumbs to the thermal degradation typical of such high temperatures. As the temperature increases the PIT values decrease with the lowest PIT values recorded for a processing temperature of 100°C. Many of these observations have already been made in Section 3.5.3 but this parameter was included to illustrate its usefulness in simplifying information and making it easier to identify patterns in the results. In summary, the PIT values show that the use of a low temperature blanch, particularly at 65°C, results in hardening and this hardening may be related to the activity of PME at these blanching temperatures.

Figure 3.23: *PIT values showing the effect of blanching treatments at 65 and 75 °C on the texture of the potato compared to the raw potato*

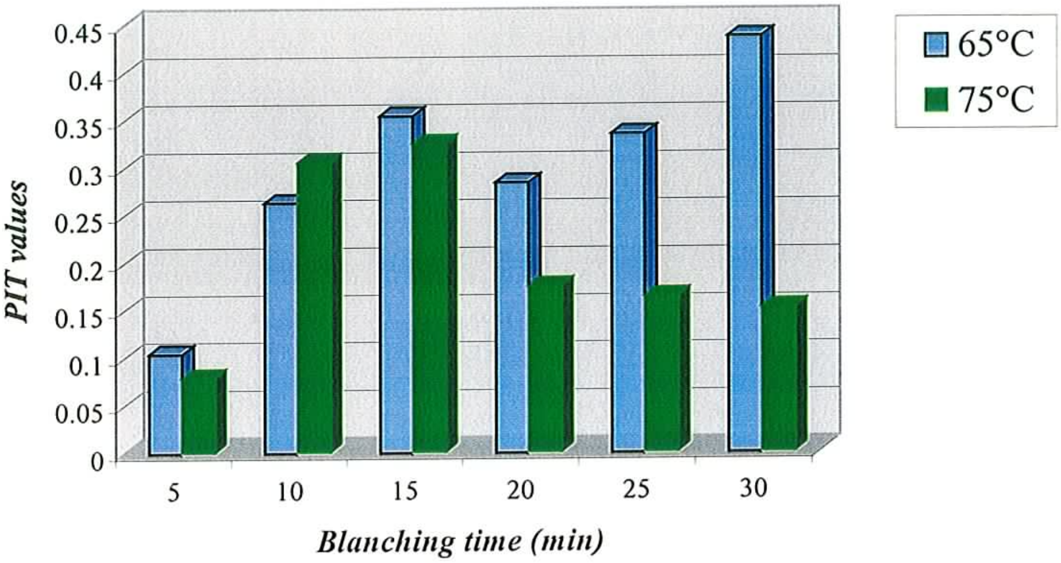
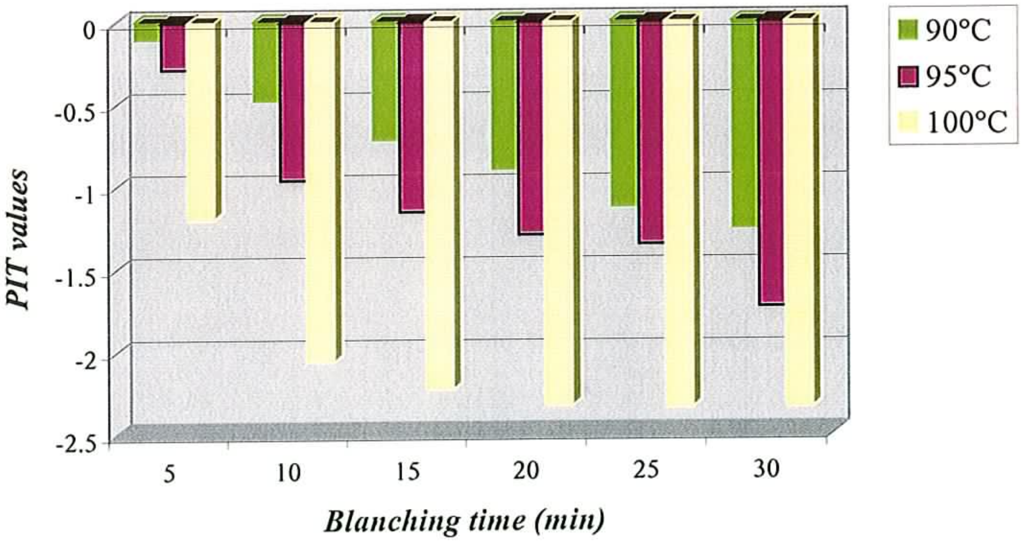


Figure 3.24: *PIT values showing the effect of processing temperatures of 90, 95 and 100 °C on the texture of the potato compared to the raw potato*



The next issue addressed was whether the blanching step made the potato tissue more sensitive to the main processing treatment or did it result in a firmer texture than that which would have been achieved had there been no pre-treatment. The *PVP parameter* was applied to answer this question. PVP values show the change in texture that takes place after processing when a pre-treatment has been used compared to when there was no pre-treatment. If the PVP values are positive then less softening has occurred as a result of using a pre-treatment. On the other hand, if the values are negative, this indicates that the pre-treatment has made the vegetable tissue more sensitive to the main processing treatment and so more softening has occurred than if there had been no pre-treatment.

When a processing temperature of 95°C was used with both pre-processing temperatures (65°C and 75°C) the general trend, seen in Figures (3.25 and 3.26), is that more hardening occurred when a low temperature blanch was used compared to when there was no blanching treatment, since practically all the PVP values are positive. Therefore, it can immediately be stated that the use of a low temperature blanch, at either 65°C or 75°C, did not make the potato tissue more sensitive to the processing treatment, but instead resulted in hardening of the potato tissue. The trends in Figures (3.25 and 3.26) at each blanching time indicate that, as processing time increases at 95°C, the use of a blanching treatment becomes more significant. After 5 min at 95°C there is little destructive effect with or without a blanching treatment and so any firming effect resulting from a blanching treatment would not be evident at this processing time, so PVP values are low. However, as processing time increases the PVP values rise as the difference between the texture of potatoes that received a pre-blanch and those that did not becomes more obvious. Without a pre-treatment the potato tissue succumbs to the thermal effect of a processing temperature of 95°C, but a pre-treatment allows the tissue to withstand this destructive effect and to maintain its structural integrity, giving a firmer product. Therefore, the difference between the texture achieved with and without a pre-treatment becomes greater as the processing time increases and so the PVP values increase indicating that a firmer product was achieved through the use of a pre-treatment. It is not clear why there are small

Figure 3.25: *PVP values showing the changes in texture during processing at 95 °C as a result of blanching at 65 °C compared to when there is no blanching*

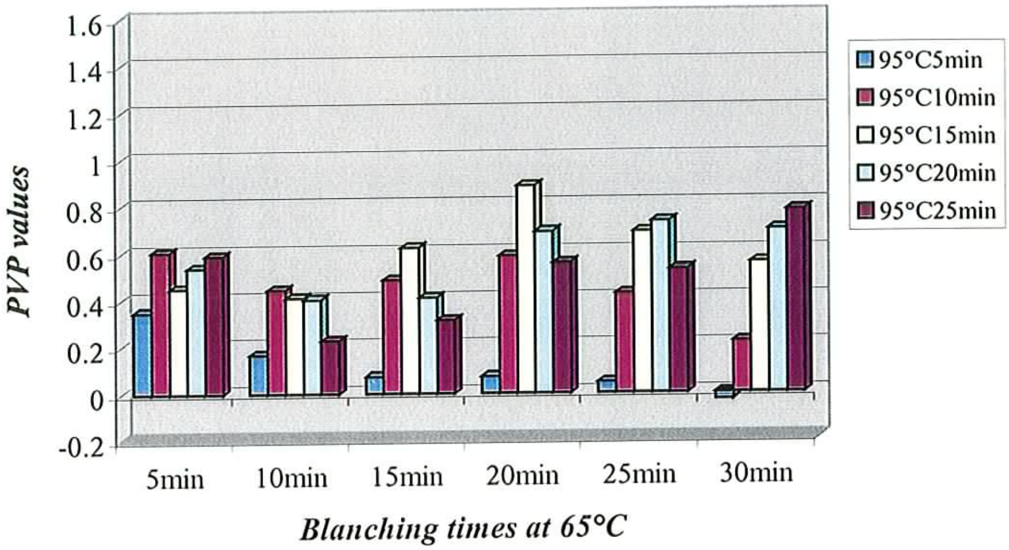


Figure 3.26: *PVP values showing the changes in texture during processing at 95 °C as a result of blanching at 75 °C compared to when there is no blanching*

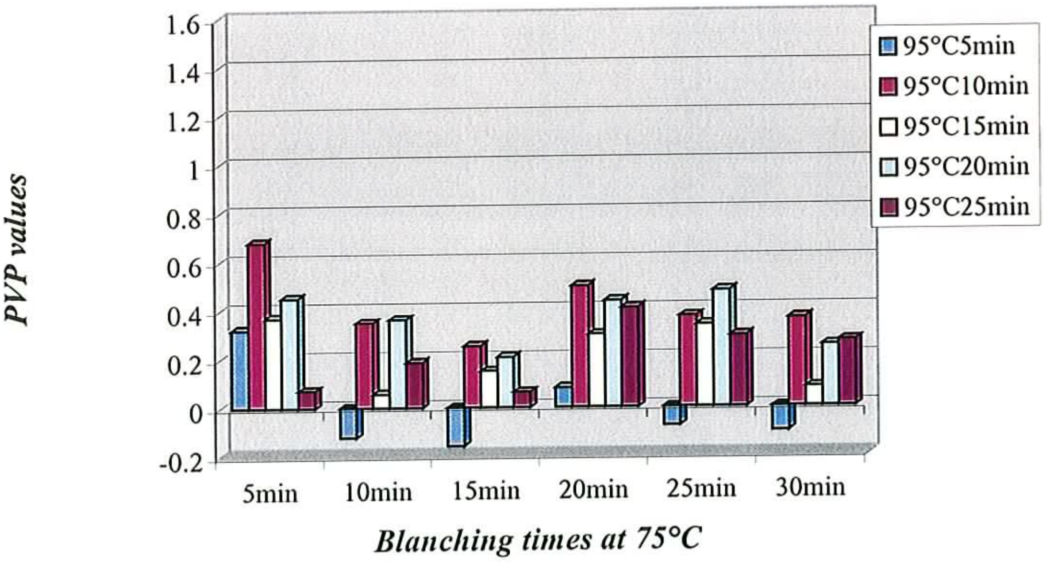


Figure 3.27: *PVP values showing the changes in texture during processing at 100°C as a result of blanching at 65°C compared to when there is no blanching step*

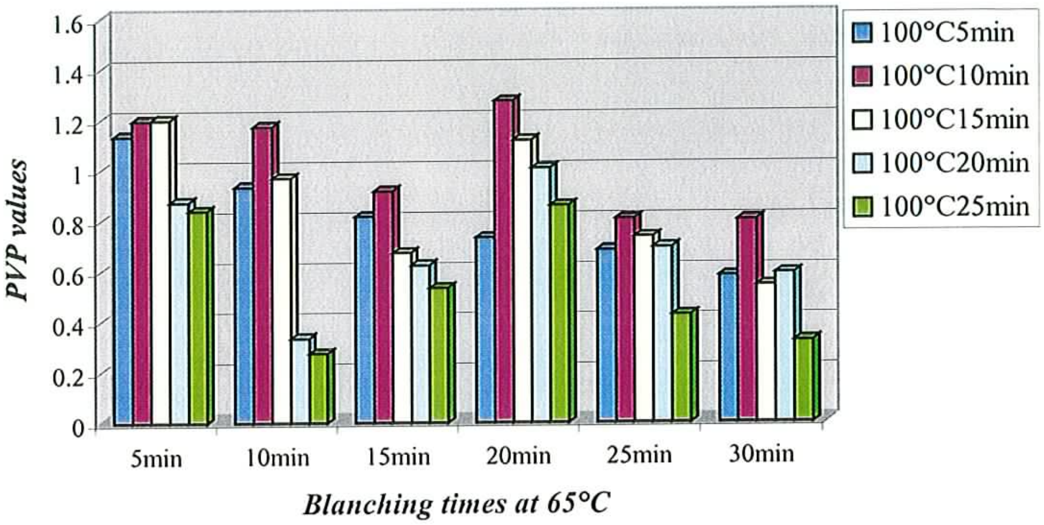
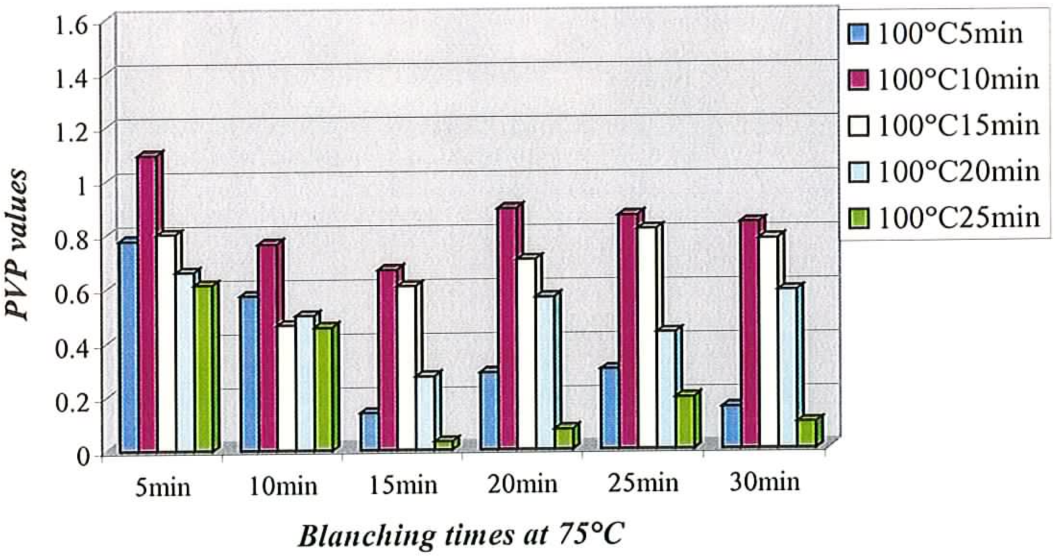


Figure 3.28: *PVP values showing the changes in texture during processing at 100°C as a result of blanching at 75°C compared to when there is no blanching step*



irregularities seen in the trends at each blanching time for blanching temperatures of 65°C and 75°C after processing at 95°C.

When a processing temperature of 100°C is used with both blanching temperatures (65°C and 75°C) it can be seen that much higher PVP values were obtained in comparison to those obtained for a processing temperature of 95°C (Figures 3.27 and 3.28). The maximum PVP value at 95°C is 0.885 compared to 1.273 at 100°C (both of these maximums were calculated when a pre-treatment at 65° C was used). This would suggest that using a low temperature blanching treatment, be it at 65°C or 75°C, before processing has a much greater hardening effect on potato texture at a processing temperature of 100°C than at a processing temperature of 95° C, compared to the texture after processing with no pre-treatment. In simple terms this means that the effect on texture when using a pre-treatment, with respect to improving firmness, is greater at 100°C than at 95°C when compared to the end texture of potatoes after processing with no pre-treatment.

However, this is not to say that a processing treatment at 100°C following a low temperature blanch gives a firmer product than that at 95°C. The reason why the PVP values at 100°C are greater than at 95°C is that because the destructive effect of a temperature of 100°C on potato structure is so much greater than that at 95°C, the use of a low temperature pre-treatment before processing at 100°C makes a greater difference to the firmness of the end product when compared to the texture of the end product produced by a single high temperature processing step.

It is in a situation such as this that the application of these parameters is especially beneficial. Earlier in this discussion it was seen from ANOVA results that blanching potatoes at 65°C or 75°C prior to processing at 100°C did not significantly improve the texture of the processed potato when compared to potatoes which had been processed at 100°C with no pre-treatment ($P > 0.05$). This could lead to the conclusion that there was, in fact, no benefit to using a low temperature blanch before the processing treatment. However, what the PVP values have shown is that there is a hardening effect when using a low temperature treatment prior to processing at 100° C, particularly when using a blanching temperature of 65°C.

When the PVP values in Figures (3.27) and (3.28) are compared for pre-processing temperatures of 65°C and 75°C at a processing temperature of 100°C, it can be seen that the hardening effect is maintained at 65°C with increasing processing time but that the PVP values fall to almost zero at a processing time of 25 min when a blanching temperature of 75°C is used, particularly after a blanching time of 10 minutes.

So, in fact a pre-treatment, particularly at 65°C, is beneficial to the firmness of the end product. This agrees with visual observations during blanching and processing that potatoes pre-blanched at 65°C then processed are firmer than those processed with no pre-treatment and that sloughing and disintegration is greatly reduced.

The trends seen for each blanching time at both blanching temperatures when processed at 100°C (Figures 3.27 and 3.28) are similar to those seen for a processing temperature of 95°C. However, in this case the benefit of using a pre-treatment is evident from the very beginning of processing, i.e. after 5 min at 100°C. Particularly in the case of a pre-treatment of 65°C, the PVP values are high at the beginning of processing. A slight fall in the values occurs at processing times of 20 and 25 min for a blanching temperature of 65°C but the pre-treatment still has an effect in helping to maintain the structural integrity of the potato and so the difference between potatoes that are pre-blanched and those that are not is quite significant and is illustrated by high PVP values.

At 75°C the firming effect of the pre-treatment is most evident at blanching times of 5 and 10 min, since a bigger drop in the PVP values is seen at longer blanching times. This corresponds to PME activity at this blanching temperature where optimum PME activity was seen at blanching times of 5 and 10 min (Section 3.4.2).

In summary, what has become clear from using these parameters with the data from the blanching and processing experiments is that it appears that the optimum blanching and processing temperature combination that results in the best texture retention compared to that achieved by a single step processing treatment, is a 65°C blanch followed by processing at 100°C. However, a processing temperature of 95°C with a pre-treatment of 65°C gave the best results in terms of maximum shear force values i.e. hardest/firmness potatoes.

3.6 Sensory Analysis

It is important that texture measurements obtained by instrumental methods correlate well with sensory parameters as there is no point in having an objective method which does not give a true indication of the textural qualities or edibility of the product being tested. An instrumental method for evaluating the texture of a foodstuff is preferable to a sensory method since it is easier, faster and requires less training. A sensory trial was carried out on potatoes subjected to some of the treatments used in this study to see whether or not the method used for instrumental analysis of texture would correlate well with sensory evaluation. In particular, it was of interest to see if differences could be perceived between potatoes that were processed with and without pre-treatments. The selection of treatments chosen are shown in Table (3.13).

Table 3.13: *Treatments applied to whole new potatoes for sensory analysis*

Sample	**Treatment**
A	Blanched at 65°C for 20 min then processed at 95°C for 20 min
B	Blanched at 65°C for 20 min then processed at 95°C for 25 min
C	Blanched at 65°C for 20 min then processed at 100°C for 15 min
D	Blanched at 65°C for 20 min then processed at 100°C for 20 min
E	Processed at 100°C for 15 min
F	Processed at 95°C for 20 min

The values obtained for the instrumental parameters of shear force, work to fracture, and maximum slope before fracture for each of the treatments used for the sensory trial are shown in Table (3.14). These values were taken from the results given in Section 3.5.3.

Table 3.14: *Values for Shear force (N), Work to fracture (J) and Maximum slope before fracture (N/mm) for each treatment in sensory trial*

Treatment	Force (N)	Work (J)	Slope (N/mm)
A	53	11.47	0.50
B	44	8.65	0.40
C	32	7.72	0.33
D	26	5.88	0.28
E	9.3	2.83	0.14
F	20	7.09	0.27

Treatments A - D were chosen in order to look at the effect of low temperature blanching prior to processing on the edibility and perceived texture of the potato, compared to treatment E, which represented traditional cooking, and treatment F, which represents a lower processing temperature (potatoes processed at this temperature for 20 min or more had a cooked appearance). The question addressed was whether or not the texture of a potato that had received a low temperature pre-treatment followed by processing at 95°C or 100°C, corresponded to an edible product? This was an interesting question to have answered because very high shear force values were obtained for potatoes blanched at 65°C for 20 min then processed at 95°C for 20 min (53 N) compared to those values for processing at 95°C for 20 min without a pre-treatment (20 N) (Table 3.14). It had already been found from carrying out blanching and processing experiments that the structure of potatoes that had undergone treatment E had almost completely disintegrated and so were definitely edible (Edibility in this context refers to potatoes which would be processed with a view to being consumed whole as part of a salad or ready-meal thus requiring a certain level of structural integrity to be maintained). Those given treatment F also had a texture that would be considered 'cooked' and so were most likely edible. However, would potatoes that were processed for the same time and at the same temperature but given a pre-treatment also be considered edible despite having much higher shear force values? One of the aims of this study was to identify a range of shear force values (or other instrumental values) that would represent an edible potato product. This sensory trial would hopefully aid in establishing this range.

A trained taste panel from the Dublin Institute of Technology (D. I. T.) Food Product Development Centre carried out the sensory analysis. The taste panel procedure was modified from the procedure detailed by Truong *et al.* (1997). These authors used a six member panel to assess the sensory texture profiles of steamed cylindrical samples of sweetpotatoes. The panel assessed each sample for moistness, springiness, cohesiveness, hardness, denseness, chewiness, adhesiveness, chalkiness and fibres. The tasting procedure was detailed in the study and was modified for this current study by testing whole potato samples for the following sensory parameters only:

Hardness – amount of force necessary to bite completely through the sample

Denseness – degree to which the sample is solid, compactness of the cross section

Moistness – degree to which the sample is moist

Chewiness – number of chews required to prepare the sample for swallowing (chewing at a constant rate of one chew per second)

Fibres – amount of stringy fibres perceived

Overall palatability

Overall palatability was included because it was felt that it was important to assess the palatability of potatoes that had received a blanching treatment before processing (A – D) and thus, whether or not they were suitable for immediate consumption i.e. edible, compared to potatoes which had not received a pre-treatment and were fully processed (E and F). The taste panel in this study used a seven point scoring system to score each sample. If hardness is taken as an example, then a score of 1 indicates that the panellists found the potato very soft and a score of 7 would indicate that they found it very hard. Scoring in between these two extremes represents intermediate levels. Figure (3.29) shows an example of the scale used for the sensory test. A sample of the scoring sheet given to each panellist is shown in Chapter 2 (Figure 2.2).

Figure 3.29: Scoring scale for sensory testing of potatoes

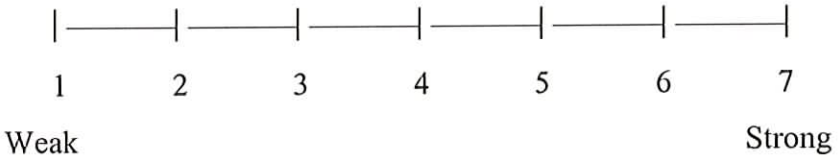
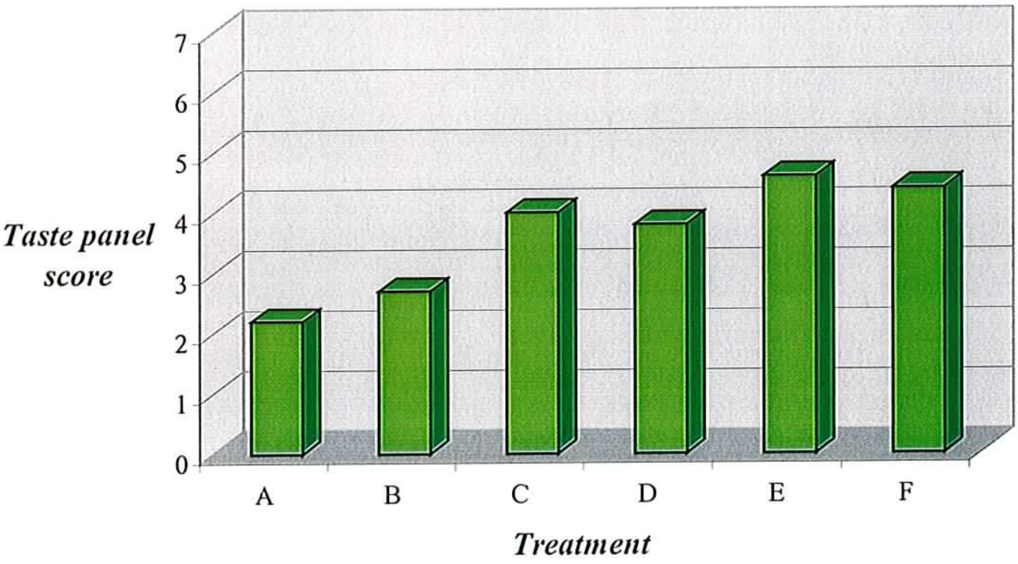


Figure 3.30: Overall preference of Taste Panel showing Taste Panel scores for each treatment



Overall preference is shown in Figure (3.30). Panellists were required to state which sample they preferred and why, and to rate this preference out of 7. The two treatments that were preferred by the panellists were those that most closely resembled traditional cooking of potatoes, i.e. treatments E and F. The shear force values for these treatments are 9.3N and 20N respectively (Table 3.14) Those potatoes that were least favoured were potatoes that had been pre-blanched at 65°C for 20 min then processed at 95°C for both 20 and 25 min (A and B) with shear force values of 53N and 44N respectively. Treatments C and D lay between A, B treatments and E, F treatments for overall preference. Panellists had been asked to give their comments on each sample. Typical comments for A and B were:

"Tastes undercooked"
"Hard, undercooked, starchy mouthfeel, strong aftertaste"
"Skin quite tough, hard, could be cooked more"
"Texture bitty and sticky"
"Skins very tough – needs longer cooking time"
"Too hard in texture"
"Not very palatable"

A lot of comments made reference to the skin being too tough after these treatments. On the other hand comments for treatments E and F were more favourable:

"Skin is thin (good)"
"Good-nice appearance and texture"
"Good flavour"
"Nice potato, not too hard"
"Good texture"
"Good product, just right for everything including flavour"

Comments for treatments C and D included:

"Good texture but a little dry"
"Skin tough but potato cooked"
"Unpleasant taste"
"Prefer fluffier potato"
"Nice taste and texture"

"Tough skin"
"Quite moist"
"Slight aftertaste"

Interestingly, although panellists preferred treatments C and D to A and B, they also remarked on the toughness of the skin for treatments C and D, as for A and B. This apparent toughening of the skin was noticed in the results from Section 3.5, where the shear force values increased rather than decreased as expected with increasing processing time after processing at 95°C for up to 25 min with a pre-treatment at 65° C. This was especially the case for potatoes blanched at 65°C for 20, 25 and 30 min, then processed at 95°C for up to 20 min (Figure 3.14).

Table 3.15: Average scores of taste panel (mean of eight scores) based on a seven-point scale

	Treatments					
	A	B	C	D	E	F
Attributes						
Hardness	6.4	5.6	4.2	3.9	3.4	4.4
Denseness	6.1	6.1	4.8	4.9	4.5	5.0
Moistness	3.5	4.7	5.3	5.3	5.0	4.8
*Chewiness	8.6	10	8.6	8.0	4.6	9.2
Fibres	4.5	4.4	3.3	3.4	2.9	3.6
Palatability	2.2	3.0	4.1	3.9	5.0	4.4
**Overall Preference	2.2	2.7	4.0	3.8	4.6	4.4

* Not based on the seven-point scale. Score refers to the average number of chews to prepare the sample for swallowing

** Panellists were asked to score for overall preference out of 7

It is possible that this toughening may be due, in some way, to PME activity at the low blanching temperatures (65°C) (Section 3.4.2), particularly at longer times. It is worth noting that using a pre-blanching step of 65°C before processing at 95°C gave the potato such a firm texture that panellists rated it too hard and undercooked, whereas the same processing treatment without a blanching step gave a potato that was considered edible.

Table 3.16: *R^2 values showing correlation of instrumental parameters of shear force, work to fracture and maximum slope with sensory attributes and some sensory attributes correlated with other sensory attributes*

Attributes	***R^2 Values***
Shear force vs. Hardness	0.8745
Shear force vs. Denseness	0.8238
Shear force vs. Moistness	0.4643
Shear force vs. Fibres	0.8295
Work to fracture vs. Hardness	0.899
Work to fracture vs. Denseness	0.8061
Work to fracture vs. Moistness	0.513
Work to fracture vs. Fibres	0.8441
Maximum slope vs. Hardness	0.8651
Maximum slope vs. Denseness	0.7113
Maximum slope vs. Moistness	0.5226
Maximum slope vs. Fibres	0.7867
Hardness vs. Denseness	0.9295
Hardness vs. Moistness	0.7305
Denseness vs. Moistness	0.5686

The importance of correlating sensory attributes with instrumental parameters of texture for a particular product has been mentioned. R^2 values were calculated for the correlation of various instrumental parameters with the sensory parameters. The aim was to identify which instrumental parameters would give the best indication of the changes taking place in a particular sensory attribute of the potato so that this relationship could be exploited in further instrumental tests. It can be seen from the R^2 values in Table (3.16) that shear force, work to fracture and maximum slope all correlated well with hardness ($R^2 > 0.86$). Shear force and work to fracture correlated well with denseness ($R^2 > 0.806$). However, none of the instrumental parameters correlated well with moistness ($R^2 = 0.49, 0.52, 0.51$ respectively).

From observations made during blanching and processing experiments (Section 3.5) it has been discussed previously how potatoes that received a pre-treatment before processing (A, B, C and D) retained their structural integrity and appeared to be more moist than those potatoes which were processed with no pre-treatment (E and F). Looking at the results obtained for taste panel scores in Table (3.15), it is interesting to note that panellists scored treatments C and D highest for moistness, followed by treatments E and F. However, although the panellists picked up on the fact that potatoes given treatments C and D were more moist than those that received treatments E and F, they scored A and B the lowest even though, from observations during blanching and processing experiments, potatoes given treatments A and B appeared to be more moist than those potatoes that had received treatments E and F. It is possible that the taste panel were equating edibility or palatability with moistness, that is, not recognising the moistness of a potato that was completely inedible, such as those given treatments A and B. In fact the comments made by the panellists support this. All comments for treatments A and B focused on the fact that the potatoes were hard, undercooked, had tough skins and an unpleasant taste, whereas comments for C, D, E and F included remarks about the moistness of the samples such as "quite moist" and "good texture but a little dry" for C and D, and "nice increased moistness", "slightly soggy" and "too moist" for samples E and F. It seems as if the panellists felt that because the potatoes from treatments E and F were falling apart and quite soft, they were also moist. In actual fact potatoes that had received a pre-treatment before processing appeared to be much more moist and much firmer.

There was quite a difference noticed between potatoes that received treatment E and those that were given treatment F. Although both appeared 'cooked', F scored much higher for hardness, denseness and chewiness than E, even though the comments for both were quite favourable for edibility and palatability. So, in this respect that taste panel picked up the different processing temperatures used. However, because the panel were only given a very small number of treatments to test compared to the number of treatments applied in this study it is hard to draw any definite conclusions from the results. Further testing involving more treatments is necessary. What was clear from carrying out this sensory trial is that using a low temperature pre-treatment before processing changes the structure of the potato, or reinforces it, to such an extent that the potato is no longer considered edible or palatable. This in itself was a valuable finding and agreed with the results from the application of the parameters detailed by Moreira *et al.* (1994) i.e. that using a low temperature pre-treatment has a definite hardening effect.

From the results of the sensory trial and the earlier results from the texture measurement of par-cooked potatoes purchased from Marks and Spencer's, it seems that a potato that is considered edible is within the range of 3 – 20 N. However, since only a small number of treatments were used for this sensory trial this range can only be considered a rough estimate.

Since potatoes that received a low temperature blanching treatment prior to processing were considered too hard to eat and had retained their moistness as previously discussed, it seems that they would be ideal for further processing, considering the degree to which the structural integrity was maintained through low temperature blanching. Such potatoes would hold their shape and the structure would probably withstand additional heating, refrigeration or freezing.

Figure (3.31) shows the relationship between shear force and palatability. As shear force increases palatability decreases. This makes sense since a hard potato will not be desirable for eating. Work to fracture and maximum slope are also inversely related to palatability (Figures (3.32) and (3.33)). These three instrumental parameters also have an inverse relationship with overall product preference. Therefore, the harder or more dense the potato, the less it is preferred. Moistness did not correlate well with palatability and it may be that a flourier, drier texture would be preferred.

R^2 values were also determined for correlation of sensory parameters with each other. Hardness correlated well with denseness, which is not surprising (R^2 = 0.93). However, denseness and hardness did not correlate well with moistness (R^2 = 0.57 and 0.73 respectively) and moistness was inversely related to chewiness. This is in agreement with findings of Truong *et al.* (1997), who reported an inverse relationship between denseness and moistness, and chewiness and moistness.

Figure 3.31: Relationship between shear force and palatability

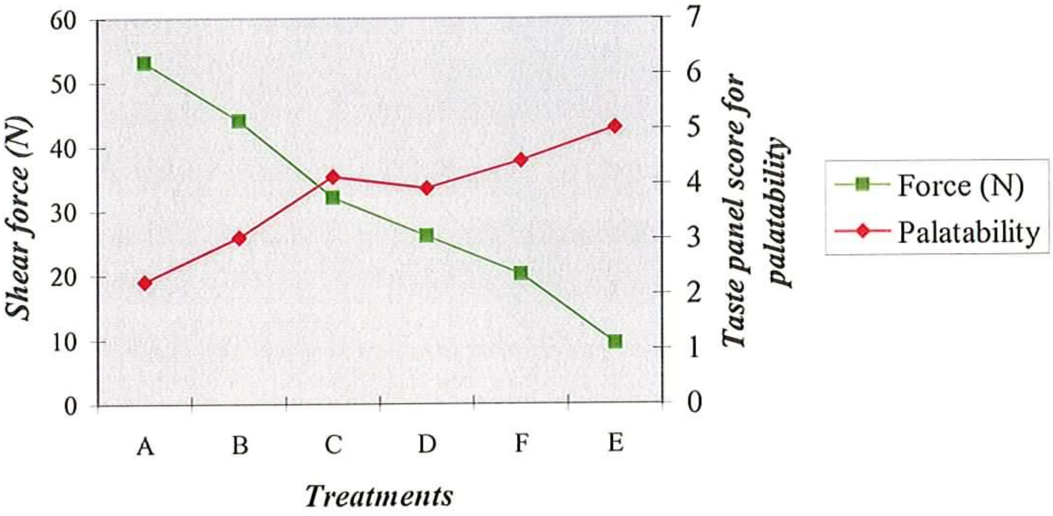


Figure 3.32: Relationship between work to fracture and palatability

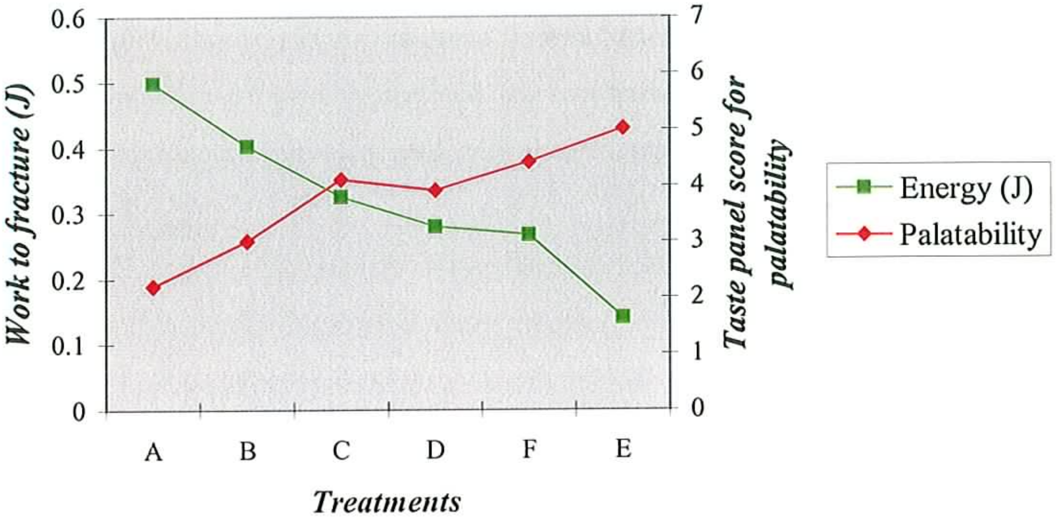
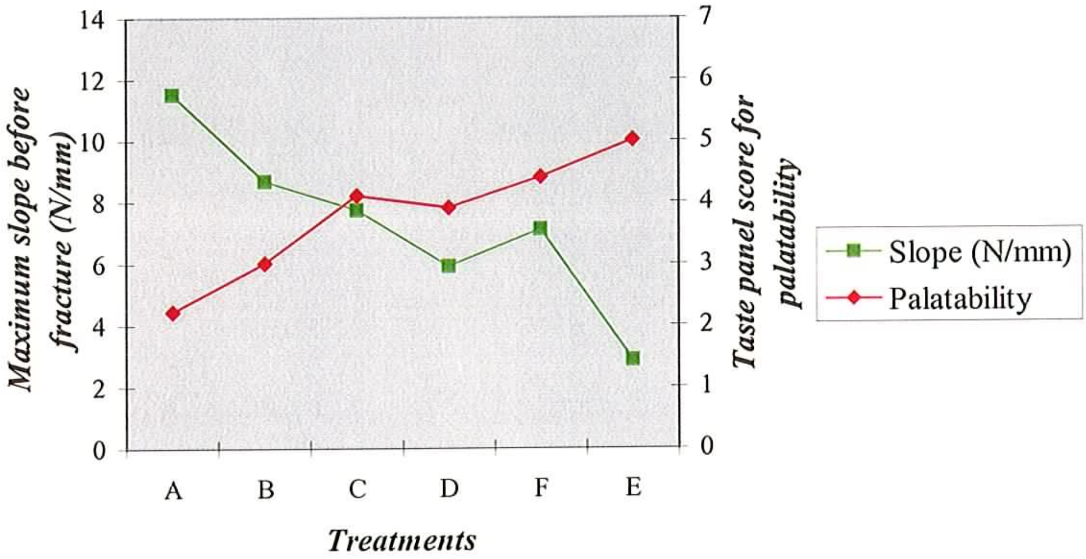


Figure 3.33: Relationship between maximum slope before fracture and palatability



In summary, all three instrumental parameters, shear force, work to fracture and maximum slope before fracture, give a good indication of the level of hardness of a potato. Shear force and work to fracture can be used to determine the denseness of a product. To a certain extent these parameters can give an indication of the palatability of a potato product although a more extensive sensory trial would be necessary in order to establish a range in some instrumental unit that would indicate the level of edibility.

Conclusions

This study was carried out to investigate the effects of low temperature blanching on the firmness of whole processed new potatoes and to determine whether the enzyme, pectin methyl esterase (PME), a naturally occurring enzyme in fruits and vegetables, plays a role in improving the firmness of whole new potatoes, following a pre-blanching, then processing. Two varieties of new potato were used for blanching, Maris peer, from Portugal and Nicola, from England. Potatoes were blanched whole at temperatures of 60, 65, 70, 75, 80, 90 and 100°C and texture was measured by puncture testing using an Instron Universal Testing Machine.

Results showed that blanching temperatures can be divided into three groups with respect to their effect on the texture of whole new potatoes. Temperatures of 60, 65, 70 and 75°C could be classed as low blanching temperatures having negligible effect on texture. The extent of change in texture at these temperatures was of the magnitude of only 8 N for Nicola and 3 N for Maris peer from raw to the end of the blanching period, which represents an insignificant change in texture ($P > 0.05$). A blanching temperature of 80°C represented an intermediate temperature resulting in approximately 55% loss of firmness, with its softening effect lying between that of the low temperature group and that of the higher temperature group of 90 and 100°C. These two temperatures caused rapid softening of the potato tissue. The most rapid rate of texture degradation was seen at 100°C. At both 90°C and 100°C there were two phases of softening observed. For 100°C there was a rapid softening phase from 0 – 25 min, with texture degradation rates (k) of 0.137 and 0.118 min^{-1}, and a slower phase from 25 – 40 min, with k values of 0.0297 and 0.037 min^{-1}, for Maris peer and Nicola varieties respectively. At 90°C, the first phase was from 0 – 40 min and 0 – 35 min and the second phase was from 40 – 60 min and 35 – 60 min for Maris peer and Nicola varieties respectively. The k values at 90°C were lower than those for 100°C.

Blanching at 100°C for 25 min or more results in approximately 97% loss of firmness compared to the raw product. Application of the Arrhenius equation to the data from the blanching experiments revealed that the blanching process is temperature dependent for the temperatures of 80, 90 and 100°C. Activation energies of 137.06 and 95.68 KJ mol^{-1} for these temperatures were calculated for Maris peer and Nicola respectively.

It was observed that both potato varieties behaved nearly identical at each blanching temperature. This agrees with results obtained for compositional analysis of these potato varieties, where no significant difference was found between the two cultivars based on tests for starch, reducing sugar, moisture and ash content.

The optimum activity of PME (2.92 μmol/min/g) was found at a blanching temperature of 65°C for 15 min. The enzyme was rapidly inactivated after 15 min at 75°C and after 5 min at 80 and 90°C. The effect of blanching temperature on the activity of PME was found to be significant ($P < 0.05$) with a significant difference between the activity at 65°C and all the other blanching temperatures used i.e. 75, 80 and 90°C ($P < 0.05$).

There was no significant difference between the firmness (measured as maximum shear force (kN)) of potatoes blanched at 65°C and 75°C ($P > 0.05$) despite there being a difference in PME activity at these temperatures. However, after processing at temperatures of 95°C and 100°C the firming effect of using low blanching temperatures became evident. There was a significant difference between the firmness of potatoes blanched at 65°C then processed and those blanched at 75°C then processed, for both processing temperatures. This implies that the structure of potatoes blanched at 65°C was sufficiently reinforced to be able to better withstand the thermal effect of the high temperatures compared to those blanched at 75°C. This may be related to the PME activity at 65°C and 75°C, however, further work would be necessary to verify this.

Although there was no significant difference between the firmness of potatoes blanched at 65°C or 75°C then processed at 100°C, and potatoes processed at 100°C with no pre-treatment ($P > 0.05$), the degree of sloughing and disintegration of potatoes pre-blanched then processed was considerably less than those given a single high temperature processing treatment, particularly when blanched at 65°C. This means that potatoes blanched at low temperatures prior to processing retain their more structural integrity than those processed without a pre-treatment and so are more suitable for further processing.

Analysing the data from the processing experiments, where potatoes were blanched at 65°C or 75°C then processed at both 95 and 100°C, using parameters defined by Moreira *et al.* (1994), gave a clear picture of the effect on firmness of these blanching and processing treatments, both separately and combined. It was concluded from the results of these calculations that a blanching temperature of 65°C followed by processing at 100°C gave the best result in terms of preventing texture degradation when compared to the texture loss that would have occurred had there been no blanching step. The overall treatment that gave the firmest product (highest shear force values) was a blanching step at 65°C followed by processing at 95°C.

Instrumental parameters of work to fracture (J) and maximum slope before fracture (N/mm) calculated from the force vs. displacement curve produced by the Instron Software showed that using a low temperature pre-treatment in combination with a high processing temperature increases the energy required to fracture the product and makes it more elastic thereby strengthening the potato and making it less breakable and more suitable for further processing.

Sensory analysis was carried out to determine if there was a difference perceived between the texture of potatoes that received a blanching treatment before processing and those that were processed with no blanching treatment. In addition, sensory testing allowed the correlation of instrumental parameters of shear force, work to fracture and maximum slope before fracture with sensory parameters for potatoes subjected to a range of treatments. There were six treatments in total, four of which involved a pre-blanch at 65°C followed by processing at either 95°C or 100°C, and two which involved only a processing step at 95°C and 100°C. Panellists did not like the potatoes that had been pre-blanched, stating that they tasted too hard or undercooked, but preferred those potatoes that had been given a treatment similar to conventional cooking of potatoes. However, potatoes that were pre-blanched retained their structure and moistness and so would be ideal for further processing. Instrumental parameters of maximum shear force, work to fracture and maximum slope before fracture correlated well with hardness ($R^2 > 0.86$) and denseness ($R^2 > 0.81$) but not with moistness ($R^2 = 0.46$, 0.52, 0.51 respectively). These instrumental parameters could be used as indicators of the hardness and denseness of a potato product and with further work it might be possible to utilise them in measurements of levels of palatability or edibility of potatoes.

In summary, potatoes that receive a low temperature blanching treatment exhibit reduced sloughing and disintegration. They maintain their structural integrity during processing. Therefore, a pre-blanch at low temperatures, particularly a temperature of 65°C, prior to processing produces a firmer potato that has a better appearance, holds its shape and that would be suitable for further processing if required.

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