Effects of Pretreatment and Micronization on the Cookability and Chemical Components of Green and Yellow Field Peas

BY

Ruth Toews

A Thesis
Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Food Science
University of Manitoba
Winnipeg, MB

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree of Master of Science

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ACKNOWLEDGMENTS

I would like to thank Dr. Susan Arntfield for her guidance and encouragement. I gratefully acknowledge the assistance of Aniko Bernatsky for her help with the micronizing and chemical analyses, Donna Ryland for her help with the texture and sensory tests, and Dr. Stephan Cenkowski and Crystal Cinq-Mars for their help with the hydration rate experiment.

I am thankful for the funding I received through the University of Manitoba Graduate Fellowship (Duff Roblin Fellowship) and the William B. Malchy Graduate Fellowship. Financial support was provided by NSERC, Centra Gas, SaskEnergy and InfraReady Products Incorporated.

Finally, I would like to thank my parents, Ernie and Alice, and my sisters, Helen and Emily, for their support and encouragement.

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LIST OF ABBREVIATIONS

ANF	Anti Nutritional Factors
CF	Compression Force
EDTA	Ethylene Diamine Tetra Acetic Acid
F	Firmness
Gal	Galactose
HM	High-Methoxylated
IDF	Insoluble Dietary Fibre
IR	Infrared
LM	Low-Methoxylated
Raf	Raffinose
RF	Residual Fraction
S	Sedimentation Coefficient
SDF	Soluble Dietary Fibre
Sta	Stachyose
Suc	Sucrose
TDF	Total Dietary Fibre
Ver	Verbascose

ABSTRACT

Micronization, a processing technique using infrared radiation to partially cook tempered food products, is an alternative method from the traditional soaking and cooking or canning methods of processing legumes. This study had three objectives: to optimize the collecting temperature of micronized green and yellow peas; to optimize their tempering level and time; and to determine suitable tempering solutions from those listed in the literature. These objectives were evaluated in terms of their ability to decrease subsequent cooking times through changes in seed components, and to reduce anti nutritional levels. Sample texture, based on a set cooking time, was compared to the maximum acceptable texture measurement (compression force (CF) = 125 N; firmness (F) = 292 Nmm) determined by an expert panel. Samples with texture values less than this limit would not require the full cooking time. Based on the texture results, the optimal collecting temperatures were 80-85°C for green peas and 92.5-97.5°C for yellow peas, and that both should be tempered for 6 h to 30% moisture. Tempering solutions containing mixtures of sodium salts (low concentration: 0.2% sodium bicarbonate, 0.1% sodium carbonate, 0.1% sodium phosphate dihydrate; high concentration: 1.5% sodium bicarbonate, 0.5% sodium carbonate, 1.0% sodium tripolyphosphate, 2.5% sodium chloride) gave the lowest texture values of micronized green and yellow peas after cooking for 75 (green peas) and 60 (yellow peas) minutes. Other solutions (2% sodium tripolyphosphate; 1% citric acid and 2%

ascorbic acid) also gave suitable texture results; however, detrimental colour changes occurred. Water-soluble pectin had significant ($P<0.05$) negative correlations with the CF and F for both green and yellow peas (CF: $R^2 = -0.5553$ and -0.6954 respectively; F: $R^2 = -0.5300$ and -0.5830 respectively), indicating that it is a good indicator of acceptable texture levels. Other dietary fibre components may also be involved in the softening process. Distilled water gave the largest reductions in anti nutritional levels, but low concentrations of sodium salts also gave favourable results. Therefore, micronized green and yellow peas should be tempered for 6 h to 30% moisture with a solution containing sodium salts and collected at 80-85°C and 92.5-97.5°C, respectively to reduce the cooking time and anti nutritional levels.

1.0 INTRODUCTION

In Canada, field pea production accounted for 70% of the 1999 total Canadian pulse production (FAO, 1999). This translated to 15% of the world's production of field peas (FAO, 1999; Skyrpetz, 2000). Higher quality Canadian field peas are used for human consumption, either in Canada or other parts of the world (Gane, 1985; Wright, 1985; Agriculture and Agri-Food Canada, 2000). They are consumed as canned, rehydrated or split field peas (Drake and Muehlbauer, 1985; Black *et al.*, 1998a). Research has shown that variables, such as environmental and agronomic conditions, can affect the properties and quality of peas (Bakr and Gawish. 1992; El-Tabey Shehata, 1992).

Typically, a pretreatment step is used to shorten later canning and cooking times. Soaking is the preferred pretreatment for traditional methods, such as cooking, canning and dehulling, while tempering is preferred for micronizing, an application of high intensity infrared (IR) heat. Soaking refers to immersing peas in excess media; tempering refers to adding a specific amount of media so that peas reach a specific moisture level at the end of the pretreatment time (Arntfield *et al.*, 1997; Scanlon *et al.*, 1998). Water alone has been used as the pretreatment in some studies (Sefa-Dedeh *et al.*, 1978; Kon, 1979; Anzaldula-Morales *et al.*, 1996), while various solutions have been used in other studies. These solutions include disodium ethylene diamine tetra acetic acid (EDTA) (Estévez *et al.*, 1991; Aguilera and Rivera, 1992), calcium chloride (Ros and Rincón, 1991), citric acid (McCurdy

et al., 1983), sodium bicarbonate (Buckle and Sambudi, 1990; de León *et al.*, 1992; Vidal-Valverde *et al.*, 1992b; Black *et al.*, 1998b), sodium tripolyphosphate (Black *et al.*, 1998b; Scanlon *et al.*, 1998), sodium chloride (Ros and Rincón, 1991; Black *et al.*, 1998b), and combinations of sodium salts (Iyer *et al.*, 1980; Black *et al.*, 1998b).

During pretreatment, water or solutions are incorporated into the seed, resulting in hydration of protein and starch granules and rearrangement of the ions within the seed. Thus, when the seeds are heated, proteins are denatured and swollen starch granules are gelatinized.

Micronization, a dry heat processing technique, opens a new area of field pea processing. It uses IR radiation (λ = 1.8-3.4 μm) to partially cook the food. IR rays are emitted from ceramic heaters, transmitted through the air and absorbed by the seed. This energy excites the constituent molecules on the outer surface and causes them to vibrate (Rusnak *et al.*, 1980; McCurdy, 1992; Sakai and Hanzawa, 1994; Sarantinos and Black, 1996). This heat is conducted into the surrounding tissues, which then cooks the food (Kouzeh-Kanani *et al.*, 1981; Driscoll, 1992; Sakai and Hanzawa, 1994). Water vapor is released, which dries the food (Drake and Muehlbauer, 1985; Igbasan and Guenter, 1996). Thus, the micronized food is a dried, partially cooked product.

This process differs from the traditional thermal pulse processing methods. In traditional thermal processes, such as cooking and canning, heat is slowly transferred to the food surface by convection, which is dependent on the surrounding environment (Sakai and Hanzawa, 1994; Abe and Afzal, 1997). With IR rays, energy is not released until the rays penetrate absorbent surfaces. Thus, IR heating is dependent on the food composition and

equipment properties (Sarantinos and Black, 1992; Sakai and Hanzawa, 1994; Fasina *et al.*, 1997). Traditional thermal processing methods also have high energy and time requirements. Pretreatments alone may take from 12-24 hours and cooking requires an additional few hours (Kon, 1979; Drake and Muehlbauer, 1985; Buckle and Sambudi, 1990). During cooking and canning, high temperature processing is required, which leads to high energy costs for both home-cooked and industrially processed field peas. While IR heating has similar pretreatment times, it has much shorter processing times. McCurdy (1992) reported processing times of 40-60 s for peas, while Kouzeh-Kanani *et al.* (1981) have reported processing times of 60-80 s for soybeans. Final cooking times are also reduced. For example, cooking times of traditionally processed lentils may take from 80-150 min (Black *et al.*, 1998b), but with micronization it is reduced to 10-15 min (Arntfield *et al.*, 1997).

Other advantages have also been found. They include the following: destruction of trypsin inhibitors in soybeans (Kouzeh-Kanani *et al.*, 1981; Chubb, 1982) and inactivation of myrosinase in canola (Abe and Afzal, 1997); increased digestibility of soy milk (Metussin *et al.*, 1992); and decreased microbial load (Blenford, 1980; Driscoll, 1992; Sakai and Hanzawa, 1994).

Until now, micronization has been used to dry, thaw, roast and pasteurize foods (Kouzeh-Kanani *et al.*, 1981; Sakai and Hanzawa, 1994). By capitalizing on the unique properties of this technique to improve the cooking times, pulses may become more attractive for both domestic and export markets. Currently, little research is available that

looks at the micronizing parameters required to produce dry peas stable at normal storage conditions with faster cooking times.

The first objective of this research was to optimize the collecting temperature of the green and yellow field peas processed by micronization. Evaluating the residual moisture content, the degree of starch gelatinization and the cooked texture was used to monitor this optimization. The average surface temperature at the end of micronizing was used as the collecting temperature of the sample. The second objective was to use distilled water to optimize the tempering conditions, specifically tempering time and level. This was monitored by measuring the residual moisture level, the cooked texture, and the presence of the anti nutritional factor, phytic acid. Starch gelatinization, soluble protein and pectin fraction levels were measured to determine their influence on the cooked texture. The final objective was to determine suitable tempering solutions based on examples found in the literature. The suitability of each solution was evaluated by measuring the residual moisture, ash, colour, cooked texture and anti nutritional factors, such as phenolic compounds, phytic acid and α-galactosides. Starch gelatinization, soluble protein, dietary fibre and pectin fraction levels were measured to determine whether they influenced the cooked texture.

2.0 LITERATURE REVIEW

2.1 Background

Field or dry peas (*Pisum sativum*) are classified as legumes or pulses. As such, they are defined as the edible seeds from pod-bearing plants. Other legumes include lentils, cowpeas, soybeans and a range of beans.

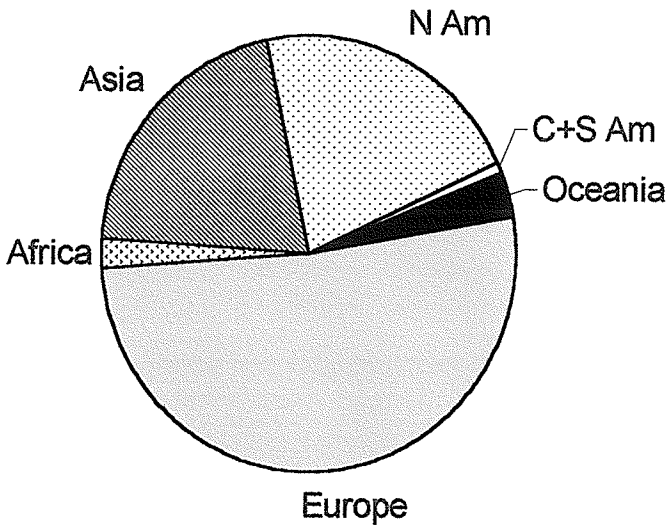
Peas can be grouped into three main categories. The vining pea, also known as the garden pea, is harvested when the sugar content is high. It is used fresh or immediately canned or frozen (Snoad, 1985; Bouwman, 1991; Deshpande and Adsule, 1998). The forage pea, as the name implies, is used for animal feed. The whole plant is harvested when the pea reaches the flat pod stage (Snoad, 1985; Bouwman, 1991). The third group of peas, called dry, harvest or field peas, are used for both feed and food. Higher quality yellow and green types are produced for human consumption (Bouwman, 1991). As food, they are sold for home use, canning, and protein and starch extraction (Snoad, 1985; Wright, 1985; Deshpande and Adsule, 1998). For this research, yellow and green types of the dried peas were used.

2.1.1 Production and Consumption of Field Peas

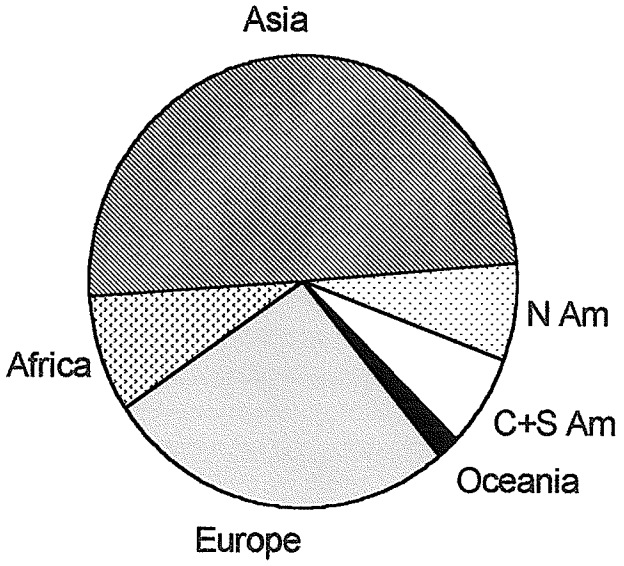
In 1999, 59 million metric tonnes of pulses were produced around the world (FAO, 1999). Of this, 12 million metric tonnes were dried peas (FAO, 1999). Canada produced

2.25 million metric tonnes, 1.4 million of which were yellow and 0.7 million were green (Skrypetz, 2000). Figure 1 shows the production and food distribution of dry peas across the six major land regions: Africa, Asia, Central and South America, Europe, North America and Oceania. From this figure we can see that North America produces 20% of the world's field peas, but it only uses 7% as food. The remaining peas are used for animal feed or they are exported (Bouwman, 1991; Skyrpetz, 2000).

Although Europe is responsible for half the world's production of dry peas, most is used for animal feed (Grosjean and Gatel, 1989). Asia uses most of its dry pea crop for human consumption and is a major importer of Canadian dry peas (Skyrpetz, 2000). In total, 65% of peas are consumed in developing countries (Jones and Boulter, 1983; Uzogara *et al.*, 1990). As with all types of legumes, peas are high in protein. Thus, they are incorporated into the diet because animal foods are unavailable, too expensive, or not readily accepted (Deshpande *et al.*, 1990; Uzogara *et al.*, 1990; Joseph *et al.*, 1993). Peas are also a good source of carbohydrates, B complex vitamins, minerals and dietary fibre (Kadam *et al.*, 1989; Marzo *et al.*, 1997). However, before field peas can be consumed, they must be processed. Whether they are processed at home or in industry, peas are subjected to pretreatment and cooking steps. The pretreatment may be a tempering or soaking step. Both the pretreatment and cooking steps affect the final textural quality of peas (Janicki *et al.*, 1992). Tempering or soaking is used to soften peas so that the cooking time is shorter. Cooking increases their tenderness to produce a level acceptable to the consumer (Wright, 1985).



A. Production of Field Peas



B. Food Distribution of Field Peas

Figure 1. The production (A) and food distribution (B) of field peas in Africa, Asia, Central and South American, Europe, North America and Oceania (FAO, 1999).

2.1.2 SEED STRUCTURE

Mature legumes seeds have three predominant components: embryo axis, seed coat or hull and cotyledons. The embryo axis and seed coat make up only 1-2% and 8-15% of the total seed weight, respectively. The embryo axis is rich in nutrients, but since it constitutes such a small portion of the whole seed, it does not contribute to the overall food value (Kadam *et al.*, 1989).

The seed coat, made up of cellulose, hemicellulose, lignin, pectin and calcium, is poor in nutrients except calcium (Kadam *et al.*, 1989). Therefore, removing it does not have a large effect on the overall food value. The seed coat protects the embryo and cotyledons, and its permeability influences the seed's rate of water absorption (Kadam *et al.*, 1989; Stanley *et al.*, 1989). In a study by Ali-Khan (1993), the hull percentage of six registered field peas cultivars was evaluated over three years and in two locations. It was found that environmental conditions affected the hull percentage differently for each cultivar. Reichert and Ehiwe (1987) found similar results when 20 cultivars of field peas were grown at 6 locations. Powell (1989) found that the rate of water absorption was also affected by the seed coat colour. In Powell's experiment, coloured seed coats absorbed water more slowly than white seed coats. Powell (1989) determined that the tight-fitting coloured seed coat hampered the movement of water into the seed.

Cotyledons make up 84-90% of the seed and have the largest, balanced food value of the whole seed. Storage parenchyma cells, 70-100 μm in diameter, make up the cotyledons structure. Starch granules are the most abundant components inside all parenchyma cells, and are embedded in a protein matrix. This matrix is more prominent in

the outer parenchyma layers, while starch granules are more prominent in the centre (Kadam *et al.*, 1989; Joseph *et al.*, 1993; Liu, 1995). Each parenchyma cell has a distinct cell wall and middle lamella, the common boundary layer (Rockland and Jones, 1974; Liu, 1995).

2.2 Composition of Field Peas

The chemical composition of peas is dependant on genotypic, phenotypic, agronomic and environmental factors (Cawood, 1987; Gueguen and Barbot, 1988; Kadam *et al.*, 1989; Fenwick, 1991; Murcia and Rincón, 1992; Marzo *et al.*, 1997; Baniel *et al.*, 1998). For example, field pea storage proteins are encoded by numerous genes and subjected to various post-translational modifications (Higgins, 1984; Boulter *et al.*, 1987; Müntz, 1989). External supplies of nutrients can affect the types of storage proteins produced (Higgins, 1984; Randall *et al.*, 1989). The position of the pea within the pod, the pod's location on the plant, the smoothness of the pea and the size of the pea also influence its protein content and composition (Leterme, 1989; Bertholdsson, 1990; Murcia and Rincón, 1992). Starch granules are also heterogeneous components of field peas. Each granule differs in its fine structure and properties (Reddy *et al.*, 1989). Thus, biochemical variability has a large impact on the characteristics and properties of field peas.

2.2.1 CARBOHYDRATES

Carbohydrates, a large fraction within the field pea, range from 29.3% to 58.5% (Table 1) (Reddy *et al.*, 1989; Deshpande and Damodaran, 1990). They can be divided into soluble sugars, starch and pectin.

Table 1. Chemical composition of field peas

Constituent	Amount (%)	Reference
Carbohydrate	29.3-58.5	Deshpande and Damodaran, 1990 Reddy *et al.*, 1989
Sugars	3.1-8.7	Bastianelli *et al.*, 1998 Reddy *et al.*, 1989
Starch	24.0-48.6	Kadam *et al.*, 1989 Otto *et al.*, 1997
Dietary Fibre	18.7-27.6	Igbasan *et al.*, 1997 Otto *et al.*, 1997 Zdunczyk *et al.*, 1997
Protein	17.7-32.9	Bastianelli *et al.*, 1998 Kadam *et al.*, 1989 Marzo *et al.*, 1997
Lipid	0.7-3.2	Bastianelli *et al.*, 1998 Deshpande and Damodaran, 1990 Otto *et al.*, 1997
Ash	2.4-4.0	Bastianelli *et al.*, 1998 Deshpande and Damodaran, 1990 Igbasan *et al.*, 1997
Phytic Acid	0.6-1.3	Zdunczyk *et al.*, 1997
Polyphenols	<0.1-4.1	Igbasan *et al.*, 1997
Protease Inhibitors	1.3-7.6 U/mg	Leterme *et al.*, 1989 Zdunczyk *et al.*, 1997
Oligosaccharides	4.2-7.6	Kadam *et al.*, 1989 Reddy *et al.*, 1984 Zdunczyk *et al.*, 1997

2.2.1.1 Soluble Sugars. Soluble sugars in peas include the reducing sugars, such as glucose and fructose, as well as oligosaccharides in the raffinose series, namely, raffinose, stachyose and verbascose. Soluble sugars account for 4-15% of the total carbohydrate content (Reddy *et al.*, 1984). Simple sugars are used mainly as building blocks for larger polysaccharides or as attachments to proteins and lipids; thus, mature seeds contain only minor amounts. The raffinose sugars, making up 30-80% of the soluble sugars (Reddy *et al.*, 1984), are only digested by anaerobic microorganisms living in the colon. Often this leads to abdominal discomfort and gas production (Kuo *et al.*, 1988). These oligosaccharides are further discussed in section 2.2.5: Anti Nutritional Factors.

2.2.1.2 Starch. Starch, the predominant carbohydrate in field peas (Table 1), is embedded in the cotyledon's protein matrix in the form of granules (Kadam *et al.*, 1989; Joseph *et al.*, 1993; Liu, 1995). As mentioned before, each starch granule has its own unique structure and properties (Kadam *et al.*, 1989; Deshpande and Damodaran, 1990). Inside each starch granule are two glucose polymers: amylose, an essentially linear polysaccharide of α(1-4)glucose linkages; and amylopectin, a branched polysaccharide of α(1-4, 1-6) glucose linkages. These two glucose polymers form crystalline and amorphous regions within the starch granule that can be seen in polarized light (Bogracheva *et al.*, 1998). Amylose is primarily responsible for the gelatinization temperature and pasting properties of starch, which is important during the cooking step of field pea processing (Reddy *et al.*, 1989; Deshpande and Damodaran, 1990; Bogracheva *et al.*, 1998).

When starch granules are heated in the presence of water, the crystalline regions begin to melt and the glucose polymers hydrate and swell. Thus, the molecular order within

the granule is disrupted. This is called starch gelatinization (Reddy *et al.*, 1989; Deshpande and Damodaran, 1990; Fujimura and Kugimiya, 1994; Bogracheva *et al.*, 1998). Fujimura and Kugimiya (1994) studied the gelatinization of isolated and *in situ* kidney bean starch. They found that gelatinization of *in situ* starches was suppressed when compared to isolated starches due to limited water and space availability. Thus, the degree of starch gelatinization is an important parameter for determining the extent of cooking in legumes.

2.2.1.3 Pectin. Pectin is a polygalactuonic acid interrupted by esterified regions, or rhamnose or xylose units (Talbott and Ray, 1992). It is found in the seed coat and in the cell walls, middle lamellar region and intercellular layers of cotyledons. Pectin is involved in maintaining seed structure integrity by associating with other intercellular components and other pectin molecules (Uzogara, 1990; Talbott and Ray, 1992). The pectin found in peas can be divided into three main fractions: water soluble fraction, ethylene diamine tetra acetic acid (EDTA) soluble fraction and residual fraction. The water soluble fraction contains polygalacturonic acid highly esterified with methyl groups (> 50 %); thus, it is also referred to as high-methoxylated (HM) pectin. Low-methoxylated (LM) pectin is soluble in EDTA, and as the name implies, it has only a few regions of esterification (<50%). In this fraction, pectin salts of calcium and magnesium are found. The residual fraction (RF) contains pectin salts not soluble in EDTA and protopectin, a water insoluble parent pectic substance (Dietz and Rouse, 1953; Kon, 1968; BeMiller and Whistler, 1996).

During soaking and cooking steps, HM pectins leach out of the seed (Uzogara *et al.*, 1990; Liu *et al.*, 1993). Pectin leaching is enhanced when sodium salts are in the soaking media. Sodium ions displace the divalent cations in the LM and RF pectin fractions, and

thus increase the solubility of pectin and the breakdown of intercellular spaces (Liu *et al.*, 1993). When calcium or other divalent cations are present in the media or when they are released from degraded phytic acid, ionic cross-links between pectin molecules are increased. Therefore, the intercellular structure is strengthened and prevented from breaking down (Talbot and Ray, 1992). This may be one of the steps in producing the hard-to-cook phenomenon in legumes.

2.2.2 Dietary Fibre

Dietary fibre is defined as the lignin and plant polysaccharides remaining after human digestion of plant materials (Bennink, 1994). Its quantification is dependant on the analytical method used. The major components are cellulose, hemicellulose, pectin and lignin. These components provide structure and support to cells (Hincks and Stanley, 1987). Approximately 80% of the seed coat is comprised of dietary fibre; thus, removal of the seed coat significantly decreases the total dietary fibre in legumes (Kadam *et al.*, 1989). Lignin is a 3D polymer consisting of approximately 40 phenol units with strong intramolecular bonds (Bennink, 1994). It is covalently linked with hemicellulose and may bind calcium in aqueous solutions (Torre *et al.*, 1992). Cellulose, a β(1-4)linked glucose polymer, is the main source of strength and rigidity for cell walls. When heat is applied, its solubility increases. Therefore, it can be softened during cooking (Potter and Hotchkiss, 1995). Hemicellulose is a heterogeneous polysaccharide that consists of a xylose, mannose, or galactose backbone with arabinose, galactose or urnonic acids as side chains. It is soluble

in dilute alkali, not water, and it covalently binds with lignin to form a matrix that encompasses the cellulose (Buxton *et al.*, 1987; Bennink, 1994).

2.2.3 PROTEIN

Protein levels in peas range from 17.7-32.9% (Table 1), with the largest concentration found in the outer portion of the seed (Kadam *et al.*, 1989; Bora *et al.*, 1994; Kosson *et al.*, 1994; Marzo *et al.*, 1997). Most of the proteins in peas are considered to be storage proteins (Bora *et al.*, 1994), which are those proteins synthesized into membrane-bound protein bodies or organelles during seed development. In general, legume storage proteins account for >5% of the extractable total seed protein and can be hydrolyzed during germination and early growth as a reduced nitrogen source (Deshpande and Damodaran, 1990). Because they act as a nitrogen reserve, they contain high levels of asparagine (11.4-12.0 g/16 g N), glutamine (16.3-17.3 g/16 g N) and arginine (8.3-9.9 g/16 g N) amino acids (Deshpande and Damodaran, 1990; Igbasan and Guenter, 1996; Igbasan *et al.*, 1997). However, as with other legumes, field pea protein is deficient in sulphur containing amino acids: methionine (0.9-1.2 g /16 g N) and cystine (1.2-1.7 g/16 g N) (Deshpande and Damodaran, 1990; Igbasan and Guenter, 1996; Zdunczyk *et al.*, 1997).

Gueguen and Barbot (1988) found that the concentration of amino acids in the protein of peas is a function of the amino acid composition of storage proteins, of which albumins and globulins are the main types (Bora, *et al.*, 1994; Igbasan *et al.*, 1997). Albumins, soluble in water, are metabolic proteins, such as protease inhibitors. These inhibitors (discussed further in section 2.2.5 Anti Nutritional Factors) reduce the nutritive

value of peas if they are not denatured during processing (Bhatty, 1988; Deshpande and Damodaran, 1990). The globulin storage proteins, extracted in saline solutions, can be subdivided into legumin (10.5-13.0 S) and vicilin (7-9 S) based on their sedimentation (S) coefficients (Deshpande and Damodaran, 1990; Bora *et al.*, 1994; Igbasan *et al.*, 1997). These globulins are found in the ratio of (legumin:vicilin) 0.2-1.5 (Deshpande and Damodaran, 1990).

As alluded to earlier, storage proteins are localized in protein bodies, which also contain phytic acid salts, cations and hydrolytic enzymes (Liu, 1995). These bodies form an amorphous protein matrix, within which starch granules are located (Kadam *et al.*, 1989; Liu, 1995). During heat processing, proteins undergo structural changes, so that the protein molecule unfolds and hydrophobic sites are exposed. This decreases their solubility and may result in their aggregation (Nakai and Li-Chen, 1989; Zheng *et al.*, 1998). The extent of denaturation is dependant on the initial moisture level, heating temperature and heating time (Zheng *et al.*, 1998). Partially denatured proteins may improve their digestibility, provided large aggregates are not formed (Damodaran, 1996). Changes in pH and the addition of salts also influence the extent of denaturation (Damodaran, 1996; Zheng *et al.*, 1998).

2.2.4 Lipid and Ash

Most legumes have a lipid content of 1-2%, except those also classified as oilseeds, such as peanuts and soybeans (Kadam *et al.*, 1989). The lipid content of field peas (Table 1) is reported to be in this range (Deshpande and Damodaran, 1990; Daveby *et al.*, 1993; Bastianelli *et al.*, 1998). Bastianelli *et al.* (1998) found that this value varied with the type

of field pea used, where wrinkled peas have the highest (3.17±0.51%) and coloured peas the least (1.76±0.19%). Kosson *et al.* (1994) reported that the distribution of lipids varies with cultivar, location, climate, season and environmental conditions. Similar to protein, the outer 10% of the cotyledon has the greatest proportion of lipid (Kosson *et al.*, 1994). As with other legumes, the main fatty acids are linoleic (50.15-58.9%) and oleic (15.36-26.1%) (Kosson *et al.*, 1994; Bastianelli *et al.*, 1998).

The ash or mineral content of peas ranges from 2.4-4.0% (Table 1) (Deshpande and Damodaran, 1990; Bastianelli *et al.*, 1998). Phosphorus, stored as phytate, is found in the largest amount (Igbasan *et al.*, 1997; Kadam *et al.*, 1989). Peas are reported to be good sources of calcium, iron, magnesium and copper (Deshpande and Damodaran, 1990).

2.2.5 Anti Nutritional Factors (ANF)

Peas and other legumes have toxic components that affect metabolic processes and thus decrease their nutritive value to both humans and animals. ANF levels in peas are variable and lower than levels in other legumes (Bond, 1993; Zdunczyk, 1997). ANF typically found in peas include the following: phytic acid, polyphenols, protease inhibitors and α-galactosides (raffinose sugars).

2.2.5.1 Polyphenols. Polyphenols are only found in peas with coloured flowers (Grosjean and Gatel, 1989; Bastianelli, *et al.*, 1998). Specifically, they are predominantly found in the seed coat (Savage, 1989). These compounds are involved in disease resistance for seeds (Bajaj and Dhillon, 1988; Marzo *et al.*, 1997). When they are present, polyphenols may impart an astringent taste, which lowers consumption of peas. They also inhibit protein

digestibility by forming stable cross-links with proteins, which alter the tertiary protein structure (Sosulski, 1979; Amory and Schubert, 1987; Bjerg, *et al.*, 1989). During the detoxification process *in vivo*, polyphenols are methylated, which reduces the methionine content of peas (Savage, 1989). Polyphenolic content can be reduced by soaking alone (35-42% reduction after 6 hours), soaking and dehulling (59-68% reduction after soaking for 12 h) and ordinary cooking (8-9% reduction) (Bishnoi, *et al.*, 1994). These compounds have also been implicated in the hard-to-cook phenomenon (Stanley and Aguilera, 1985). Polyphenols are thought to migrate into the cotyledons where they form insoluble macromolecules in cell walls. Thus restricted water penetration and cell separation hinder the softening process during cooking.

2.2.5.2 Phytic Acid. As mentioned before, phytate or phytic acid is found in the protein matrix (Carnovale, *et al.*, 1988; West *et al.*, 1994) of legumes where it is a chelating agent for cations, such as potassium, calcium and magnesium, and a storage place for phosphorus (Greenwood, 1989; Reddy, *et al.*, 1989). Reduction in mineral availability is the main nutritional consequence of phytic acid in the food source (Carnovale, *et al.*, 1988). It can also bind with proteolytic enzymes and thus lower the Protein Efficiency Ratio of peas (Kumar and Kapoor, 1983; Deshpande and Cheryan, 1984). The phytic acid content of dry peas varies with variety, growing conditions and irrigation conditions (Reddy, *et al.*, 1989; Marzo, *et al.*, 1997). Bishnoi *et al.* (1994) reported significant differences in the phytic acid content of all field and vegetable peas tested. Phytic acid content decreases during soaking through leaching (Uzogara *et al.*, 1990; Bishnoi *et al.*, 1994). Bishnoi *et al.* (1994) reported 4-5% loss of phytic acid after just 6 hours, while greater losses were observed for longer

soaking times. Savage (1989) found that phytic acid content also decreased after cooking. Many authors have proposed that decomposition of phytic acid is one factor leading to the hard-to-cook phenomenon (Kon and Sanshuck, 1981; Moscoso *et al.*, 1984; Aguilera and Stanley, 1985; Hentges *et al.*, 1991; Liu, 1995). These authors propose that with the hydrolysis of phytate by phytase, released calcium ions form cross-links between pectin chains in the middle lamella. Thus, the middle lamella is not able to break down during cooking (Liu *et al.*, 1993; Hulse, 1994; Liu, 1995).

2.2.5.3 Protease Inhibitors. Protease inhibitors present in the cotyledons of peas include inhibitors of trypsin, chymotrypsin and amylase. These inhibitors prevent the *in vivo* enzymes, trypsin, chymotrypsin and amylase, from adequately metabolizing the protein and starch in peas (Savage, 1989). Inhibitor activity varies with cultivar: wrinkled peas have less activity than smooth peas (Valdebouze *et al.*, 1980); and spring peas have less activity than winter peas (Valdebouze *et al.*, 1980; Leterme *et al.*, 1989). Although field peas have approximately 10% of the trypsin inhibitor activity of soybeans (Valdebouze, *et al.*, 1980; Bjerg, 1989), they have a much higher chymotrypsin inhibitor activity than field beans (Griffiths, 1984). Amylase inhibitor activity does not pose a serious problem because field peas have low levels and the activity is readily denatured at 100°C (Savage, 1989). Like all proteins, protease inhibitors can be denatured with high temperatures (>100°C) and changing pH (Saini, 1989a; Savage, 1989). However, the extent of heat denaturation is dependant on the temperature, duration of heating, moisture content and type of heat (Saini, 1989a).

2.2.5.4 α-Galactosides. Alpha-galactosides, also known as the raffinose sugars, are comprised of raffinose, stachyose, verbascose and ajugose. Essentially, these sugars just differ in the number of galactosyl moieties attached to a sucrose primer. As the seed matures and ripens, galactinol is attached to sucrose via an α(1→4) galactosidic linkage to produce raffinose and *myo*-inositol. Galactinol is then attached to raffinose to produce stachyose and *myo*-inositol, and then it is attached to stachyose to produce verbascose and *myo*-inositol (Amuti and Pollard, 1977; Kandler and Hopf, 1980; Lowell and Kuo, 1989). Ajugose is the largest α-galactoside with 4 galactosyl moieties. As this progression implies, verbascose and ajugose are the last oligomers deposited in the seed (Saini, 1989b).

In the seed, these raffinose sugars are used as an energy source for the germinating seed. However, humans are unable to metabolize these oligomers in the small intestine because they do not have the enzyme α-galactosidase. Therefore, these oligomers pass into the colon where the natural flora use them for energy. Carbon dioxide, hydrogen and methane are released into the colon, which can lead to flatulence, diarrhoea, nausea, cramps and discomfort (Sosulski *et al.*, 1982; Jood *et al.*, 1985; Phillips and Abbey, 1989; Saini, 1989b).

Many researchers have developed methods for reducing the α-galactoside content in legumes. These methods include a combination of the following: extrusion (Jood *et al.*, 1986), soaking in various solutions (Akinyele and Akinlosotu, 1991; Jood *et al.*, 1985; Jood *et al.*, 1996), dehulling (Akinyele and Akinlosotu, 1991), fermenting (Akinyele and Akinlosotu, 1991), autoclaving (Jood *et al.*, 1995) and germinating (Jood *et al.*, 1985).

2.3 Processing of Field Peas

Typically, field pea processing involves pretreatment and cooking steps. For canning, the pretreatment step consists of soaking and sometimes blanching (McCurdy *et al.*, 1983; Drake and Muehlbauer, 1985; Wang *et al.*, 1988; Ros and Rincón, 1990), while for micronization, the pretreatment step is tempering (Tyler and Karoutis, 1993; Arntfield *et al.*, 1997). After the pretreatment, the peas are cooked in a thermal or infrared process.

2.3.1 CANNING

2.3.1.1 Soaking and Tempering. The first step in many legume processing methods is to increase the moisture content, which makes them more tender and thus reduces subsequent processing times. Most often, this is done by soaking, that is, using excess soaking media to saturate the seed (Scanlon, *et al.*, 1998). Tempering, that is using a specific amount of tempering media to increase the moisture content to a specific level, is also used (Arntfield *et al.*, 1997). Typically, it takes 6-18 hours for the solution to fully penetrate into the seed (Kon, 1979; Deshpande *et al.*, 1989; Buckle and Sambudi, 1990; Deshpande and Damodaran, 1990).

Sefa-Dedah *et al.*, (1978) tested the effect of soaking time on water absorption rate in cowpeas. After 1, 3, 6, 12, 18 and 24 hours, cowpeas soaked at 25°C in water were removed for water absorption tests. They found that water was absorbed in 3 distinct stages. In the first stage (0-6 hours), water was rapidly absorbed by the seed, which was dependant on the initial moisture content and the outer structures of the cowpea. Thanos (1998) suggested that the rapid initial uptake is due to the filling of capillaries on the surface

of the seed coat. During the second stage, the water absorption rate slows, and it levels off during the third stage.

Soaking or tempering time is also dependant on the temperature (Kon, 1979; Iyer *et al.*, 1980; Hung, *et al.*, 1993), and for tempering, the target moisture level also controls the time required to reach equilibrium (Tyler and Karoutis, 1993). For example, in the study by Tyler and Karoutis (1993), peas tempered to 40% moisture reached equilibrium after 7 hours at 65°C, but at 25°C, it took more than 12 hours. When peas were tempered to 20% moisture at 35°C, they reached equilibrium after 4 hours.

Researchers have found that the type of soaking/tempering media used has a large impact on the end result (Buckle and Sambudi, 1990; Akinyele and Akinlosotu, 1991; Estévez *et al.*, 1991; Vidal-Valverde *et al.*, 1992b). Solutions ranging from distilled water to individual salts to dilute acids to salt mixtures have all been used (Iyer *et al.*, 1980; Al-Nouri and Siddiqi, 1982; McCurdy *et al.*, 1983; Drake and Muelhbauer, 1985; Black *et al.*, 1998b; Scanlon *et al.*, 1998). Various salts have been traditionally added to the soaking/tempering solution as a way to improve the final texture and nutritional properties. These salts include disodium EDTA (Estévez *et al.*, 1991; Aguilera and Rivera, 1992), sodium bicarbonate (Buckle and Sambudi, 1990; de León *et al.*, 1992; Vidal-Valverde *et al.*, 1992b; Black *et al.*, 1998b), sodium tripolyphosphate (Black *et al.*, 1998b; Scanlon *et al.*, 1998), sodium chloride (Ros and Rincón, 1991; Black *et al.*, 1998b) and calcium chloride (Drake and Muehlbauer, 1985). Iyer et al. (1980) observed lower water absorption rates for legumes soaked in acidic solutions, such as 0.1 to 1% citric, malic and tartaric acid. At higher concentrations of acid, they found that permeability of the seed coat decreased.

Generally, it has been found that adding sodium salts to water or soaking in alkaline solutions increases the water absorption rate of legumes. Deshpande *et al.* (1989) suggested an alkali soaking solution favourably alters the permeability of cell membranes.

It is thought that the micropyle and hilum, two small openings in the hull, and seed coat, each play a role in the seed's water absorption/dehyration mechanism. These structural features are dependant on variety. Deshpande and Cheryan (1986) showed that initially, the water absorption rate was controlled by the hilum and micropyle. Only after soaking for 30 to 60 minutes did the seed coat impact the water absorption rate. When Tang and Sokhansanj (1993) looked at the drying of lentils, they found that at moisture levels greater than 15%, the seed coat controlled the drying rate, while at moisture levels less than 15%, the hilum controlled the dehydration. Sefa-Dedeh *et al.* (1978) suggested that cowpeas with thick seed coats absorb water slower than those with thin seed coats. Others have observed that the seed size influences the water absorption rate, such that smaller seeds absorb water faster (Erskine *et al.*, 1991; Hung *et al.*, 1993). Once water penetrates the seed, other factors influence the absorption rate, such as the type of protein, and the amount of amylose in starch granules (Deshpande *et al.*, 1989). The rigid protein matrix associated with dry legumes swells during soaking due to the hydration of protein bodies. This loosens the starch granules embedded in the matrix and allows them to swell (Liu, 1995). Vidal-Valverde, *et al.* (1992b) reported structural changes in the proteins and starches after soaking that are similar to changes during germination, while Akinyele and Akinlosotu (1991) reported that fermentation, as seen by the foaming that occurs, takes place in the soaking solution.

Unlike tempering, soaking results in the loss of water soluble components from legumes, such as pectin, amino acids, calcium, magnesium, reducing sugars, total phosphorus, tannins, phytate, and oligosaccharides (Kon, 1979; Iyer *et al.*, 1989; Uzogara *et al.*, 1990; Buckle and Sambudi, 1990; Akinyele and Akinlosotu, 1991; Estévez *et al.*, 1991). Various researchers have found that soaking at elevated temperatures results in greater solute loss, but that over time, the rate decreases (Kon, 1979; Iyer, *et al.,* 1980). Others (Silva *et al.*, 1981; Varriano-Marston and Jackson, 1981; Uzogara *et al.*, 1990) have reported solubilization, and thus leaching out, of pectin when monovalent ions, such as sodium and potassium, were in the soaking solution. This agrees with the findings of Bakr and Gawish (1992), who reported greater solute loss in 2% NaCl soaking solution than with distilled water.

2.3.1.2 Cooking. Cooking is the process by which legumes are softened to a level acceptable to the consumer. This may or may not be preceded by a soaking or tempering step. Legume cookability refers to the condition by which they achieve an acceptable consumer tenderness (Iyer *et al.*, 1989). Legumes may be cooked at atmospheric pressure and temperature or at high pressure and temperature combinations. As with soaking and tempering, the final cooked product is influenced by cooking media, cooking time, cooking temperature and cell components. Thus far, no consensus has been reached for a standard method of cooking legumes. During the canning process, whole legumes are used, which increases the cooking time. Traditionally legumes require 1-2 additional hours of cooking after they are soaked to reach the desired tenderness. Techniques have been developed to shorten cooking times, such as using legumes split into cotyledons or using quick cooking

methods (Labuza *et al.*, 1972; Rockland and Jones, 1974; Al-Nouri and Siddiqi, 1982; Iyer *et al.*, 1989).

During the cooking process several chemical and physical changes occur in legumes. First, the intercellular matrix of the middle lamella is loosened so that individual cells are separated. This is characterized by water entering the seed, which causes increased mobility and solubilization of enzymes and substrates. These enzymes begin to break down intercellular components and thus release cations, thereby increasing the solubility of intercellular components (Uzogara *et al.*, 1990). As water hydrates individual cells and heat is applied, starch granules are gelatinized and proteins are denatured (Rockland and Jones, 1974; Uzogara *et al.*, 1990). When legumes are hydrated by soaking or tempering before cooking, the process just described is sped up. Leaching of solubilized components also occurs during cooking (Rincón *et al.*, 1990; Uzogara, 1990).

As with soaking or tempering, legumes are cooked in a wide range of media: water, calcium chloride and sodium salts (Rockland and Metzler, 1967; Rockland and Jones, 1974; Uzogara *et al.*, 1990; de León *et al.*, 1992). Uzogara *et al.* (1990) cooked cowpeas at 100°C for 35 minutes in distilled water, local tap water (high in calcium) and 0.1% (w/v) solutions of calcium chloride, magnesium chloride and sodium bicarbonate. Softness was measured with a needle penetrometer, where large penetration distances indicated softer cowpeas. These researchers found that sodium bicarbonate increased cowpea softness, loss of pectic substances and leached solids, while calcium chloride had the opposite effect. They suggested that the sodium ions enhanced pectin β-elimination reactions. These reactions occur in near neutral mediums at elevated temperatures. During β-elimination, pectin

degrades to lower molecular weight compounds by breaking down glycosidic bonds at adjacent carboxymethyl groups. Uzogara *et al.* (1990) suggested that lower molecular weight compounds are able to leach out, which lowers the structural integrity of the cells. Therefore, a softer texture is measured.

De León *et al.* (1992) suggested that an ionic interchange mechanism could be involved when legumes are soaked and cooked in salt solutions. For their experiment, they soaked black beans in salt solutions with different ratios of monovalent (Na^+ and K^+) to divalent (Ca^{2+} and Mg^{2+}) ions, based on a 4.30 ratio for fresh black beans. Cooking was done using either the same salt solution or water. They found that cooking times required to reach a soft texture for both cooking solutions decreased with higher monovalent concentrations, and hypothesized that sodium ions migrates into cells, while magnesium and potassium ions migrate out. As a result, water absorption increases and heat transfer between bean cotyledons and salt solutions improve.

In a study by Anzaldúa-Morales *et al.* (1996), the effects of cooking chick peas, lentils, broad beans, pinto beans, white beans and black beans from 0 to 300 min at four different temperatures (80-95°C) was investigated. This experiment was done 1500 m above sea level, which corresponds to water boiling at 95°C. These legumes were soaked in distilled water at 25°C for 8 hours and then cooked. Puncture force was measured as the force required to completely penetrate the seed. Therefore, softer textures required less force. Generally, these legumes softened faster at higher temperatures. At all temperatures, the legumes underwent a rapid softening rate followed by a slower softening rate as time

progressed. Therefore, the best cooking time is the inflection point between the two softening rates.

As eluded to earlier, quick cooking methods have been developed for legumes (Rockland and Metzler, 1967; Rockland and Jones, 1974; Iyer *et al.*, 1980; Al-Nouri and Siddiqi, 1982). Generally, a vacuum treatment (Hydravac process) is applied intermittently for 30 to 60 minutes in an inorganic salt solution. After this, the legumes are soaked for 6 hours in the same solution, followed by rinsing and drying. The salt solution contains a mixture of sodium chloride, sodium tripolyphosphate, sodium bicarbonate and sodium carbonate, the actual concentration of which depends on the legume and later processing steps (Al-Nouri and Siddiqi, 1982). This process is a faster method because the salt solution infuses through the hilum and other seed coat openings, which plasticizes the seed coat and causes it to expand to its maximum dimensions within a few minutes. The cotyledons are thus surrounded by the salt solution which causes them to quickly hydrate and fill the seed coat. Therefore, a softer texture is obtained faster than during normal cooking.

2.3.2 MICRONIZATION

2.3.2.1 Description of Technique. Micronization is a dry heat process by which infrared (IR) radiation is used to expose food to heat for a short time (Rusnak *et al.*, 1980; Kouzeh-Kanani *et al.*, 1984; Sarantinos and Black, 1996; Zheng *et al.*, 1998). While the food material is exposed to IR radiation, it travels along a vibrating conveyor. This ensures that the food surface has uniform exposure to IR radiation and that heat damage is

minimized (Blenford, 1980; Fasina *et al.*, 1997). Micronizing is an efficient way to heat food as heat is generated only when IR rays interact with matter and is not lost to the air.

IR radiation has wavelengths from 0.75 μm to 1000 μm, which can be further divided into three groups: near IR (0.75-1.4 μm), mid-IR (1.4-3 μm) and far-IR (3-1000 μm) (Sakai and Hanzawa, 1994; Fasina *et al.*, 1997). Micronizing equipment uses IR radiation at the 1.8-3.4 μm range, which is generated by a tungsten filament in a quartz element or by gas-fired ceramic burners (Blenford, 1980; Rusnak *et al.*, 1980; Sakai and Hanzawa, 1994; Cenkowski and Sosulski, 1998). After IR radiation is released, it is transmitted through the air to the food at a rate dependant on the temperature differences between the source and food (Sakai and Hanzawa, 1994). When IR radiation encounters the food, most of it is absorbed at a uniform rate. This is an efficient way to heat foods as IR radiation is not lost during the transmittance through the air; rather, it interacts with the food molecules to generate heat. Inside the food, the IR rays cause the water, protein and starch molecules to vibrate, which causes an increase in the food temperature. This uniform heating cooks the entire food particle to the same level (Kouzeh-Kanani *et al.*, 1981; Driscoll, 1992; McCurdy, 1992; Sakai and Hanzawa, 1994).

The intensity of IR rays influences the processing temperature to which food is exposed. Controlling the temperature of the IR source and the distance between the product and the rays can control the intensity of the IR rays (Blenford, 1980; Driscoll, 1992). The temperature reached by the product is also influenced by the time of exposure to the IR source. Thus, this process can also be controlled.

During the micronization process, water vapour is released, soluble protein level decreases and starch is gelatinized (Croka and Wagner, 1975; Kouzeh-Kanani, *et al.*, 1984; South and Rose, 1993; Igbasan and Guenter, 1996).

2.3.2.2 Applications of Micronization. Micronization has been used for improving the value of animal feed, such as pulses (Chubb, 1982; Metussin *et al.*, 1992; Igbasan and Guenter, 1996) and grains (McCurdy, 1992; Abe and Afzal, 1997). Kouzeh-Kanani *et al.* (1984) found that the percentage of gelatinized starch in micronized corn increased with higher temperatures. This was also seen by Croka and Wagner (1975) when they micronized sorghum. Croka and Wagner (1975) found that micronization increased the susceptibility of sorghum starch to enzymatic degradation, which then increased the availability of starch. Savage and Clark (1988) found an improvement in the digestibility of nitrogen in micronized brown sorghum. Igbasan and Guenter (1996) found that the true amino acid availability and true metabolizable energy increased for micronized peas ($P \leq 0.01$), although the solubility of proteins was reduced. Zheng *et al.* (1998) also found that proteins were denatured through micronization. They suggested that hydrophobic aggregation was the primary result of the denatured storage proteins. In these studies mentioned, micronization has been used solely to improve the nutritional value. Other advantages have also been found. They include the following: lower energy requirements for milling, cooking, splitting and canning (Fasina *et al.*, 1997); reduction in ANF for chickpeas (Sarantinos and Black, 1996), soybeans (Chubb, 1982), and canola (Abe and Afzal, 1997); changes in water absorption (Campbell *et al.*, 1999; Scanlon *et al.*, 1999); lower processing costs (Chubb, 1982); reduced lentil cooking time (Arntfield *et al.*, 1997); and decreased microbial load (Blenford,

1980; Driscoll, 1992; Sakai and Hanzawa, 1994). Until now, this processing technique has been used mainly for drying, thawing, roasting and pasteurizing in food applications (Kouzeh-Kanani, *et al.*, 1981; Sakai and Hanzawa, 1994).

2.4 Quality Measurements of Field Peas

Field peas, like all other foods, must meet certain criteria before they are acceptable for human consumption. Colour, texture and flavour are the most important quality characteristics for human food (Lund, 1982; Cawood, 1987). Both colour and texture or cooking quality may be measured using subjective and objective methods, but flavour can only be measured with subjective methods. As the work done in this thesis deals only with colour and texture, flavour quality measurements will not be discussed.

2.4.1 Colour

Colour is a major quality attribute of field peas, as it is used to establish their market value and to determine their use as food or feed (Gubbels, 1977; Mazza and Oomah, 1994; Periago *et al.*, 1996). Seeds can only be up to 2% bleached before they are no longer classified as Canada Grade No. 1 (Canadian Grain Commission, 1991). Bleaching results when seed moisture is greater than 20%. It can also result from soil and environmental conditions (Gubbles, 1977; 1980; Mazza and Oomah, 1994). Colour can also change during processing of legumes (Iyer *et al.*, 1980; McCurdy *et al.*, 1983; Bouwman, 1991).

The green- and yellowness of field peas can be assessed subjectively as part of sensory tests or objectively with colour measuring systems. Over the years, many colour measuring systems have been developed (Hunter, 1975; Little, 1976; Hunt, 1991). In pea

processing, colourimeters marketed with L, a, b display and spectrophotometers are the most common colour measuring systems used. Colourimeters calculate the chromatic dimensions of colour (Hunter, 1975). The "L" value calculated by the system correlates to lightness, the "a" value correlates to redness (+) or greenness (-), and the "b" value correlates to yellowness (+) or blueness (-). Spectrophotometers measure the wavelength distributions of light reflected from or transmitted through a sample (Hunter, 1975).

Ros and Rincón (1991) used a HunterLab Colourmeter, standardized with a white tile, to measure the colour of their garden peas. Gubbels (1977) and Mazza and Oomah (1994) also used this system to estimate the colour of field peas by standardizing first with a green tile. McCurdy *et al.* (1983) used a HunterLab Colour Difference meter, and an Agtron reflectance spectrophotometer for their experiments. Drake and Muehlbauer (1985) used the Agtron reflectance spectrophotometer to measure the colour of green and yellow field peas.

2.4.2 Texture Measurements of Heat Processed Peas

After peas are cooked or canned, their textural quality is determined using subjective and/or objective methods. Generally, the quality of cooked or canned peas is determined by either a set textural response or a set processing time, after which the texture may be measured. The variety of methods used to evaluate the texture make it difficult to determine the appropriate processing conditions and to compare results (Gubbels, 1980; Lund, 1982; Ramcharran and Walker, 1985; Hung and Thompson, 1989; Van Loey *et al.*, 1995; Black

et al., 1998a; Arntfield *et al.*, 2000). As mentioned earlier, a standard method determining legume "doneness" has not been established.

Subjective methods of determining the cooking quality of legumes range from using untrained or trained panelists to squeezing them between two flat rigid surfaces (El-Tabey Shehata, 1992). Al-Nouri and Siddiqi (1982) used 50 untrained panelists to evaluate the organoleptic properties of broad beans. However, typically, panelists evaluate the doneness of cooked legumes. The cooking time is determined when the majority of panelists perceive it to be cooked (Muneta, 1964).

Jones and Boulter (1983) and Bishnoi *et al.* (1994) determined the cooking time for black beans and peas, respectively by squeezing them between the index finger and thumb. When the cotyledons yielded to only slight pressure, they were considered cooked. Black *et al.* (1998b) also used this method to determine the cooking time for 20 varieties of field peas cooked in various solutions. Mills *et al.* (1994) used a similar approach in determining the cooking time of field peas and white beans. However, in the latter experiment, the cooking time was determined when the opaque core of 9/10 seeds disappeared. These researchers found this to be less subjective than the finger-pressing method.

Whenever subjective methods are used, the analysts assess the textural quality through well-established procedures. However, correlating these responses to physical and chemical measurements or objective techniques is not always possible (Lund, 1982). Black *et al.* (1998a) tested the correlation between the cooking time determined by the finger-pressing method and the cooked force determined by instrumental measurements of 61 varieties of field peas. They found that the measurements made with a texture analyzer were

significantly correlated ($R^2 = 0.75$; $P<0.001$) to the results obtained by finger-pressing. Others (Rockland and Metzler, 1967; Scanlon *et al.*, 1998) have used the results from trained sensory panelists to show a positive correlation with instrumental measurements for bean and lentil texture evaluations.

The instruments and methods used to evaluate the cooking quality or texture of peas can be broadly divided into three categories: puncture/penetration tests, shear press tests and compression/extrusion devices (Voisey and Nonnecke, 1973; El-Tabey Shehata, 1992). Pea tenderometers (Rincón *et al.*, 1990; Ros and Rincón, 1991; Periago *et al.*, 1996), maturometers, penetrometers and the single pea puncture method (Hung and Thompson, 1989) are used to measure the tenderness of individual garden peas; thus, they will not be discussed here.

Puncture/penetration tests generally involve a plunger penetrating into the seed(s) at a specific crosshead speed. Anzaldúa-Morales *et al.* (1996) used a texture analyzer with a 1 or 2 mm diameter cylindrical punch at crosshead speed of 5 mm/s to measure the complete puncture force of white, pinto and black beans, chickpeas, lentil and broad beans. They presented their results as the average of 40 seeds. Others have also used a cylindrical punch to measure bean hardness. Experimental conditions for these experiments ranged from a 2.5 mm (3/32 in) diameter punch with crosshead speed of 30 cm/min and 500 replicate samples (Moscoso *et al.*, 1984) to a 3.2 mm (1/8 in) diameter punch with crosshead speed of 30 cm/min and 100 replicate samples (Paredes-López *et al.*, 1989) to a 1.6 mm diameter probe with crosshead speed of 1 cm/min and 20 replicate samples (Stanley *et al.*, 1989).

The Mattson bean cooker and modifications thereof use legume penetration to measure cooking time. Generally, seeds sit in the cooker indentations with plungers resting on top of them. The cooking time of legume seeds is determined when a specific number of seeds are softened. This is measured by counting the number of plungers that have penetrated their seed (Mattson, 1946; Kon and Sanshuck, 1981). Researchers have used various combinations of the number of softened seed to the number to total seeds. For example, in the work by de León *et al.* (1992), 100 out of 100 black beans needed to be softened before the cooking time was determined. Paredes-López *et al.* (1989) determined the cooking time when 17 out of 25 beans were soft, while Martín-Cabrejas *et al.* (1997) and Hentges *et al.* (1990; 1991) required only 25 out of 50 seeds to be soft.

The Kramer shear press is the most common instrument used to measure the shearing force of cooked dry legumes. This instrument uses a linear motion from a hydraulic ram to push 10 blades through a sample in a slotted container. It has been used on cooked beans, lima beans, lentils, soybeans and field peas (Rockland and Metzler, 1967; Quast and da Silva, 1977; Iyer *et al.*, 1980; McCurdy *et al.*, 1983; Drake and Muehlbauer, 1985; Bhatty, 1990; Liu *et al.*, 1992; Tuan and Phillips, 1992).

The third category of instruments measuring legume tenderness are the compression/extrusion devices (Sefa-Dedeh, *et al.*, 1978; Iyer *et al.*, 1980; Drake and Muehlbauer, 1985; Liu *et al.*, 1992a; 1992b; Sarantinos and Black, 1996; Scanlon *et al.*, 1998; Arntfield, *et al.*, 2000). In these methods, a legume sample is placed in a container with a bars or rods at the bottom. The container is pushed up toward the piston or the piston moves down into the container by a motorized screw drive. Samples may or may not

be completely compressed within the container. The force applied on the piston from the sample is recorded (Voisey and Nonnecke, 1973). Garcia-Vela *et al.* (1991) measured the texture of 30 g bean samples using a crosshead speed of 100 mm/min and a load cell of 5 kN, while Tuan and Phillips (1992) measured 50g of cooked cowpeas using a crosshead speed of 50 mm/min and a 500 kg load cell. Stanley *et al.* (1989) also used this method to measure the texture of 30 g of common beans, while Black *et al.* (1998a) only compressed a single layer of cooked pea seeds to 50 % of their height.

MATERIALS AND METHODS

3.1 Materials

Green and yellow field peas (*Pisum sativum*) from the 1998 crop year were purchased from Roy Legumex, Ltd. St. Jean-Baptiste, MB. They were stored at 4°C in a 80 L closed container (Trimeld Rubbermaid®). All experiments were done in duplicate unless otherwise stated. When the spectrophotometer (Pharmacia Biotech Ultra Spec 2000) was used to quantify results, two replicates for each duplicate were prepared. The cuvette used for these experiments was 10 mm optical glass (Hellma, Fisher). Table 2 lists the chemicals used for tempering and used in all chemical analyses.

3.2 Methods

3.2.1 TEMPERING

The formula used to calculate the amount of tempering solution (Arntfield *et al.*, 1997; Scanlon, *et al.*, 1998) is as follows:

$$\begin{matrix}\text{Tempering} \\ \text{Solution } (kg)\end{matrix} = \frac{\text{weight of peas}(kg) * (\text{tempering level}(\%) - \text{initial moisture}(\%))}{100 - \text{tempering level } (\%)} \quad (1)$$

Five kilograms of peas divided into two equal portions were tempered to a specific moisture content for a specific time in closed 18.5 L Rubbermaid® containers. In the preliminary studies, the peas were tempered with distilled water to 20%, 25%, 30% and 35%

Table 2. Chemicals used to temper yellow and green peas and used in chemical analyses

	Chemicals
Sigma Chemical Co.	2(N-morpholino)ethanesulfonic acid (MES) tris(hydroxymethyl)aminomethane (TRIS) Celite Phytic Acid Tannic Acid 5-sulphosalisylic acid m-hydroxybiphenyl anhydrogalacturonic acid Folin Ciocalteau Reagent Dietary Fibre Kit Glucose Sucrose Fructose Stachyose Raffinose *Rhizopus* glucoamylase
Fisher Scientific International Inc.	Acetone, reagent grade Ferric chloride HCl NaOH, molecular biology grade Disodium EDTA, reagent grade Sodium chloride, lab grade Sodium tripolyphosphate, laboratory grade Auto-type Kjeltabs
Mallinckrodt Chemical	Sodium borate, analytical reagent Sodium carbonate, analytical reagent Sodium citrate dihydrate, analytical reagent Sodium phosphate dihydrate, analytical reagent Calcium Chloride, analytical reagent
Pierce (Illinois)	RBS 35 detergent concentrate Coomassie® Protein Assay Reagent Kit Bovine serum albumin
Glass Microfibre Filters (England)	Whatman GF/C 125 mm filter
Megazyme International Ireland Inc. (Wicklow, Ireland)	Verbascose

moisture for six and 20 hours. The peas were shaken every hour (6 h tempering) or 10 times (20 hour tempering). In the subsequent study, the peas were tempered to 30% moisture for 6 hours with various solutions (Table 3). The peas were shaken every hour for 15 s.

3.2.2 MICRONIZATION

A pilot scale, gas-fired micronizer (Micronizing Company, UK) (Figure 2) equipped with 4 ceramic IR burners set 17 cm above the vibrating conveyor was used to process the tempered peas. Peas were poured into the hopper and fed in a single layer onto the vibrating conveyor via a vibrating feeder. A warm-up sample of peas was run through the micronizer until they reached an average surface temperature greater than 80°C. The surface temperature was measured using an IR thermometer (Cole-Palmer Instrument Co., Illinois). At that point the divided tempered samples were mixed together and added to the hopper. The slope of the vibrating bed and flow rate were adjusted to collect the peas at specific temperatures. Peas were collected in a plastic pail, at which point the average surface temperature was measured. Based on preliminary testing, green peas were collected at 80-85°C, 85-90°C, 90-95°C and 95-100°C, while yellow peas were collected at 90-95°C, 95-100°C and 100-105°C. In all succeeding studies, green peas were collected at an average surface temperature ranging from 80-85°C and yellow peas were collected at an average surface temperature ranging from 92.5-97.5°C. The micronized peas were then cooled at ambient conditions to room temperature in an open 11.3 L Rubbermaid® container. Once the peas were cooled, random samples were taken for quality and chemical measurements.

Table 3. Solutions used to temper green and yellow peas before micronization

Tempering Solution	Reference
distilled water	Aguilera and Rivera, 1992 Akinyele and Akinlosotu, 1991 Anzaldúa-Morales *et al.*, 1996
150 ppm disodium EDTA	Aguilera and Rivera, 1992 Estévez *et al.*, 1991
0.06% sodium carbonate + 0.2% sodium bicarbonate	Scanlon *et al.*, 1998
2% sodium tripolyphosphate	Black *et al.*, 1998b Scanlon *et al.*, 1998
2% sodium chloride	Black *et al.*, 1998b Ros and Rincón, 1991
1% citric acid + 2% ascorbic acid	Iyer, *et al.*, 1980 Scanlon, *et al.*, 1998
0.5% calcium chloride	Drake and Muehlbauer, 1985 McCurdy *et al.* 1983
2% sodium tripolyphosphate; washed with 10 L distilled water	
0.2% sodium bicarbonate + 0.1% sodium carbonate + 0.1% sodium phosphate dihydrate	Al-Nouri and Siddiqi, 1982
2.5% sodium chloride + 0.5% sodium carbonate + 1.5% sodium bicarbonate + 1.0% sodium tripolyphosphate	Iyer *et al.*, 1980

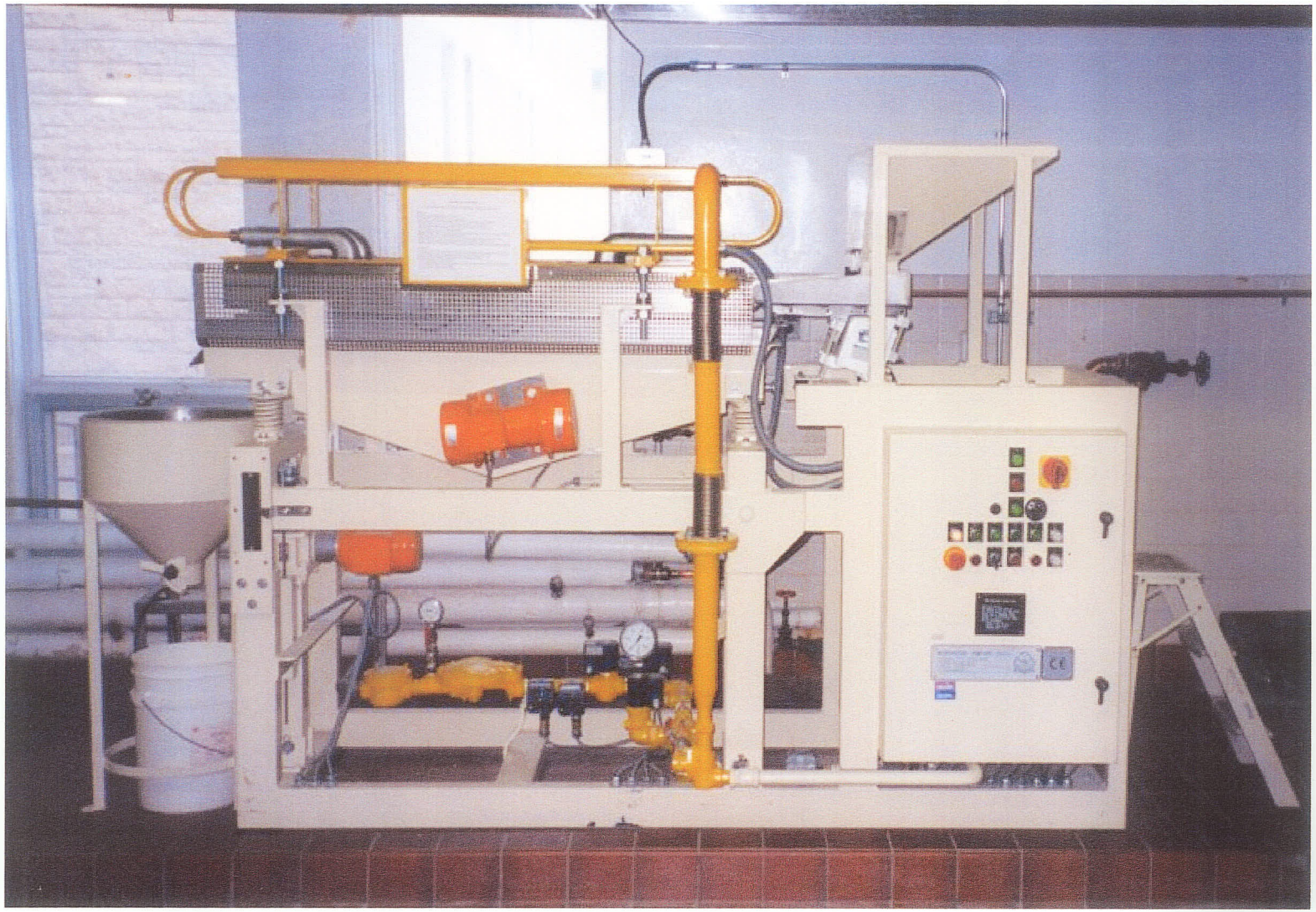


Figure 2. The pilot scale, gas-fired micronizer (Micronizing Company, UK) used in these experiments.

3.2.3 COOKING

Peas (50 g) were cooked in 750 mL distilled water on a gas stove. Both the peas and water were added to a 1.5 L Pyrex pot with lid and brought to a full boil at maximum heat. Once a full boil was reached, timing began and the heat was reduced to a simmer, such that the water was kept at a boiling temperature for the entire cooking time. Initially, all peas were cooked for 90 minutes. After cooking curves were done, where peas were cooked from 15-90 minutes at 15 minute intervals, the cooking time was reduced. Green peas were then cooked for 75 min, while yellow peas were cooked for 60 min. Once the peas were cooked, they were drained for one minute and then cooled for 30 minutes before being sealed in a 140 mL container. Texture measurements were taken within 3 hours of cooking.

3.2.4 TEXTURE

At least 3 replications of 10±0.02 g samples were compressed to 100% of their height using the Lloyd Materials Testing Machine Model L1000R (Lloyd Instruments Ltd., UK) equipped with a 1000 N load cell, and a 10 cm^2 Ottawa Texture Measuring System wire extrusion cell with an 8-bar extrusion grid (Voisey, 1970). A crosshead speed of 60 mm/min was used. The parameters measured for texture analysis were maximum compression force (CF; N), which was the peak force used to compress the peas, and firmness (F; Nmm), which was the slope of the load-deformation curve.

3.2.5 EXPERT PANEL

3.2.5.1 Green Peas. Raw green peas were prepared by rinsing 300 g for 1 min with 500 mL of distilled water. They were then cooked in 9.5 L stainless steel pots with 4.5 L

distilled water for 65, 75, 85, 95 and 105 min. When each pot of peas had cooked for the appropriate time, the peas were drained for 1 min and then sealed in 750 g opaque containers. Within 3 h of cooking, the texture of the peas was determined according to the parameters listed in section 3.2.4 Texture. Fifteen minutes before the 6 panelists arrived, 20 g of sample was weighed into 125 mL Styrofoam cups labeled with 3-digit random numbers. Each panelist received a tray containing the 5 green pea samples placed in a random order. Room temperature water was provided to rinse between each sample. At the beginning of the session, the panelists determined that the peas should have a uniform, soft texture suitable for soup. Panelists were asked to individually evaluate the force required to bite through each sample and the way the samples were perceived in the mouth throughout the chewing process just prior to swallowing. They were then asked to write down their observations. A copy of the ballot is provided in Appendix 1. When this was completed, the panelists discussed their observations and chose three samples that met the criteria. Each panelist then received the same three samples labeled with different 3-digit random numbers and asked to again choose the sample best fitting the criteria.

3.2.5.2 Yellow Peas. Raw yellow peas were soaked overnight in a 1:3 pea to distilled water ratio because it was found that this reduced the variability between peas. The peas were then cooked for 15, 20, 25, 30, 35 and 40 minutes with distilled water in 9.5 L stainless steel pots. Once the peas were cooked, the procedure described for the green peas (section 3.2.5.1 Green Peas) was followed. Eight panelists participated in this panel.

3.2.6 Colour Evaluation

Colour was evaluated on whole raw and micronized peas using a HunterLab Color/Difference Meter (Hunter Associated Laboratory Inc.; McLean, Virginia). The instrument was calibrated using a standard white tile (L = 92.37, a = -1.2, b = 0.5). Three readings were made on each 200 g sample. The colour was expressed as average Hunter L, a, b values, where L is brightness, +a redness, -a greenness, +b yellowness and -b blueness.

3.2.7 Hydration Rate

Ten whole peas were weighed individually and then soaked in a beaker with 100 mL distilled water. Timing began when the peas were added. Every 30 min for the initial 6.5 h and for a total of 15 h, the timer was stopped and the peas removed with a scoopula. Peas were quickly blotted dry on a paper towel and weighed. Once the peas returned to the beaker with water, timing resumed. The peas were removed, weighed and returned until a constant weight was established.

3.2.8 Grinding

A Thomas Wiley Cutting Mill (Philadelphia, PA) broke 50 g of whole peas into smaller pieces using a screen size of 10. The pieces were then ground using a Cyclotec 1093 Sample Mill (Techator; Hoganän, Sweden) so that the flour passed through a 1 mm mesh screen. The ground samples were used for all chemical analyses. They were stored at -18°C in a 175 g opaque container with lid and warmed to room temperature prior to use.

3.2.9 Moisture

Moisture was determined using AOAC method 930.15. Aluminum weighing dishes with handles (Fisher Scientific) were used.

3.2.10 Crude Fat

Crude fat was determined with Soxhlet method (AACC method 30-25, 1995).

3.2.11 Ash

The ash content was determined using the AACC method 08-12 (1995).

3.2.12 Gelatinized Starch Determination

The degree of gelatinized starch was measured using the methods from Chaing and Johnson (1977) and Arntfield *et al.* (1997). Glucose was used as the standard.

3.2.13 Soluble Protein

Soluble protein was determined according to the method from Arntfield *et al.* (1997), using bovine serum albumin as the standard.

3.2.14 Dietary Fibre

Soluble (SDF), insoluble (IDF) and total (TDF) dietary fibre was determined using the AACC method 32-07 (1995) using the total dietary fibre assay kit (Sigma Chemicals). RBS 35 detergent concentrate, 30 mL in 1 L water, was used instead of the micro-cleaning solution. The micro-Kjeldahl method (AOAC method 42.023; N x 6.25) was used to

determine the protein content. Auto-type Kjeltabs were the catalysts used during the digestion.

3.2.15 PECTIN

High-methoxylated (HM) or water soluble pectin, low-methoxylated (LM) or EDTA soluble pectin and residual fraction (RF) pectin were quantified using a method developed from McComb and McCready (1952), Dietz and Rouse (1953), Blumenkrantz and Asboe-Hanson (1973) and Hentges *et al.* (1991). A 2.5 g sample was mixed with 20 mL of 95% ethanol. After sitting for 10 min at room temperature, it was centrifuged at 12000 rpm for 10 min and the supernatant discarded. This was repeated 2 more times. The pellet was vacuum dried overnight at 55°C and kept in a desiccator until needed.

The dried pellet was dissolved in 20 mL of 60% ethanol and heated for 10 min at 85°C. The cooled mixture was centrifuged at 3000 rpm for 10 min and the supernatant discarded. The precipitate was mixed with 20 mL of distilled water and then sat at room temperature for 10 min before centrifuging for 10 min at 3000 rpm. The supernatant was decanted into a 50 mL volumetric flask. The extraction of HM pectin with water was then repeated using 20 mL of distilled water, centrifuging and decanting into the same volumetric flask. Two and a half millilitres of 1N NaOH was added to the flask before it was diluted to volume and mixed. The water soluble fraction stood at least 15 min at room temperature before the colorimetric procedure was started.

The residue from the water soluble fraction was then mixed with 20 mL of 0.5% disodium EDTA. It sat at room temperature for 10 min before centrifuging for 10 min at

3000 rpm. The supernatant was decanted into a 50 mL volumetric flask. The extraction of LM pectin with the EDTA solution was then repeated using 20 mL of 0.5% disodium EDTA, centrifuging and decanting into the same volumetric flask. Two and a half millilitres of 1N NaOH was added to the flask before it was diluted to volume and mixed. The EDTA soluble fraction stood at least 15 min at room temperature before the colorimetric procedure was started.

The residue from the EDTA soluble fraction was then mixed with 20 mL of 0.05 N NaOH. It sat at room temperature for 15 min before centrifuging for 10 min at 3000 rpm. The supernatant was decanted into a 200 mL volumetric flask and then diluted to volume.

The standard stock solution was prepared according to Dietz and Rouse (1953) using anhydrogalacturonic acid. Three millilitres of 0.0125 M sodium borate/H_2SO_4 were added to 0.5 mL of the standard solutions and each sample extraction. A corresponding blank was prepared for each sample extraction. The mixture was then mixed, boiled for 5 min and cooled. To the blanks, 50 µL of 0.5% NaOH was added, while to the standard solutions and sample readings, 50 µL of 0.15% m-hydroxybiphenyl/0.5% NaOH was added. After sitting for 20 min, the absorbance was read at 520 nm. The spectrophotometer was zeroed by a mixture of 0.5 mL distilled water, 3 mL sodium borate/H_2SO_4 and 50 µL of 0.5% NaOH.

3.2.16 Phenolic Determination

This method was compiled from Swain and Hillis (1959), Goldstein and Swain (1963), Schanderl (1970) and Dorrell (1976). Phenolic compounds were extracted from raw

and micronized peas by refluxing 0.1 g samples in a 250 mL round bottom flask with 12.5 mL 80% ethanol pH 4.0 for 30 min. The flask contents were then centrifuged for 5 min at 2000 rpm. The supernatant was then diluted to 25 mL. A blank, consisting of refluxed 80% ethanol (pH 4.0), was also included.

For the determination, 0.5 mL of supernatant was diluted to 7 mL in a 10 mL graduated test tube and mixed. Lowry Reagent (0.5mL) was then added. After sitting for 3 min, 1 mL of saturated sodium carbonate was added. The volume was then brought up to the 10 mL mark and the solution sat for 1 h. The resulting colour was measured at 746 nm. Tannic acid was used as the standard.

3.2.17 Phytic Acid

The method by Latta and Eskin (1980) was used to determine the phytic acid content. The extracted phytic acid was diluted to 5x its volume.

3.2.18 α-Galactoside Determination using HPLC

The HPLC procedure used to determine the oligosaccharide content of field peas was taken from Bach Knudsen and Li (1991). Minor modifications were made.

Duplicate samples (500 mg) were extracted with 10 mL 50% ethanol (Johansen *et al.*, 1996) containing 1 mg/mL *myo*-inositol as the internal standard. The sugars were extracted with continuous mixing for 1 h at room temperature. The extracted material was then centrifuged for 15 min at 2000 rpm. An aliquot of 3-4 mL of supernatant was filtered through a Sep-Pak® C_{18} cartridge (Waters, Massachusetts) prewetted with 2 mL ethanol and 5 mL distilled water. The first 3 mL of eluate was collected and further filtered though

a Cameo 3N syringe filter (MSI Westboro, Massachusetts). From this, 0.5 mL was drawn, to which 0.5 mL 95% ethanol was added to precipitate any remaining soluble protein and polysaccharides. After vortexing, this mixture stood for 30 min at -18°C and then was centrifuged for 20 min at 3000 rpm. The clear supernatant was transferred to an 8 mL glass vial with screw cap lid and dried at 50°C under N_2. Prior to HPLC analysis, the sugars were redissolved in 0.5 mL of 0.005 M Na_2SO_4.

A Waters Associates system (Mississauga, ON) consisting of a chromatography pump, R401 differential refractometer detector, Waters QA-1™ data system integrator with built-in plotter (chart speed at 0.5 mm/min), model U6K injector valve and an Aminex HPX-87N (300 x 7.8 mm) resin-based column in the sodium form (Bio-Rad, Richmond, CA) was used. The mobile phase was 0.005 M Na_2SO_4 and the flow rate was 0.5 mL/min. The column temperature was kept constant at 83°C by means of a Temperature Control Unit model III. Sample volume was 20 µL.

The individual sugars were identified by their retention times compared to those of standard sugars (verbascose, stachyose, raffinose, sucrose, glucose, fructose and galactose). The sugars were quantitated according to the height of the peak instead of area, as height obtained better repeatability of analysis. Initially, *myo*-inositol was used as an internal standard, but it eluted at the same time as arabinose and raw samples were found to have *myo*-inositol/arabinose. Therefore, external standards were used. Quantities of standard solutions (1 mg/mL) ranging from 5 to 25 µL were injected.

RESULTS AND DISCUSSION

4.1 Composition and Properties of Raw Green and Yellow Peas

The chemical composition of raw green and yellow peas is shown in Table 4. These values were used as a comparison for the micronized samples. Green peas had larger soluble protein, fat, IDF and SDF amounts than yellow peas. They both had similar pectin and TDF values. For both green and yellow peas, the soluble protein (25.07% for green and 22.81% for yellow), fat (1.81% for green and 1.64% for yellow), phytic acid (1.09% for green and 1.36% for yellow) and ash (2.38% for green and 2.91% for yellow) content were similar to values found in the literature (Deshpande and Damodaran, 1990; Zdunczyk *et al.*, 1997; Bastianelli *et al.*, 1998). Small amounts of gelatinized starch were found in the raw sample. This may be from the breakdown of the starch molecule from the alkali hydrolysis during the analysis. The largest pectin fraction found in raw peas (RF) is composed of protopectin and pectin salts not soluble in EDTA, while a smaller pectin fraction (HM) is soluble in water. Similarly, the majority of dietary fibre is in the insoluble form for both green and yellow peas. The TDF found in the peas is similar to literature values (Igbasan *et al.*, 1997; Otto *et al.*, 1997; Bastianelli *et al.*, 1998).

As expected, galactose was not detected in either green or yellow raw peas (Reddy *et al.*, 1984). Stachyose was the predominant oligosaccharide, followed by verbascose, sucrose and raffinose. This pattern is similar to that observed by Reddy *et al.* (1984) and

Table 4. The chemical composition [1], texture and colour characteristics [1] of raw green and yellow field peas

	Green Peas	Yellow Peas
% Gelatinized Starch (DM)	6.78 ± 0.21	7.19 ± 1.75
% Soluble Protein (DM)	25.07 ± 1.54	22.81 ± 0.02
% Fat (DM)	1.81 ± 0.14	1.64 ± 0.09
% Phytic Acid (DM)	1.09 ± 0.05	1.36 ± 0.00
% High Methoxylated Pectin (DM)	0.069 ± 0.011	0.061 ± 0.000
% Low Methoxylated Pectin (DM)	0.011 ± 0.001	0.007 ± 0.006
% Residual Pectin (DM)	0.471 ± 0.059	0.427 ± 0.007
% Ash (DM)	2.38 ± 0.01	2.91 ± 0.05
% Insoluble Dietary Fibre (DM)	22.01 ± 0.14	21.03 ± 0.43
% Soluble Dietary Fibre (DM)	0.74 ± 0.04	0.30 ± 0.20
% Total Dietary Fibre (DM)	22.27 ± 0.24	22.14 ± 0.09
% Verbascose (DM)	1.504 ± 0.085	1.509 ± 0.057
% Stachyose (DM)	2.664 ± 0.226	2.786 ± 0.112
% Raffinose (DM)	0.750 ± 0.055	0.937 ± 0.147
% Sucrose (DM)	1.485 ± 0.076	1.328 ± 0.051
% Galactose (DM)	0.000 ± 0.000	0.000 ± 0.000
Compression Force (N) [2]	187.3 ± 22.5	120.3 ± 11.4
Firmness (Nmm) [2]	444.4 ± 32.4	231.4 ± 7.1
Hunter Colorimeter L	47.6 ± 0.17	55.2 ± 0.09
a	-3.8 ±0.05	3.1 ± 0.05
b	11.3 ± 0.05	14.5 ± 0.02

[1] mean ± standard deviation

[2] Peas were cooked for 90 min without soaking

Zdunczyk *et al.* (1997). Reddy *et al.* (1984) found verbascose (2.2-4.2%) and sucrose (2.3-4.2%) values to be higher than those in Table 4 (green peas: 1.504 and 1.485% respectively; yellow peas: 1.509 and 1.328% respectively), while Zdunczyk *et al.* (1997) found stachyose (2.25%) to be lower than those in Table 4 (green peas = 2.664%; yellow peas = 2.786%). Saini (1989b) found verbascose (2.2%)to be the predominant α-galactoside followed by stachyose (1.9%).

Quality characteristics, compression force, firmness and colour, are also shown in Table 4. Yellow peas required a lower CF value than the green peas. Similarly, the raw yellow peas had lower firmness values than the green peas. While the peas were cooking, the yellow peas started falling apart faster than the green peas. This led to fewer cooked whole peas and more empty seed coats during the texture analysis of yellow peas. This could account for the softer texture.

4.2 Expert Panel Findings

Table 5 lists the ideal textural characteristics for cooked green and yellow peas suitable for use in soups as determined by the expert panel. The panel decided that the cooked peas should be somewhat firm with smooth and cohesive interiors and non-leathery seed coats. A summary of the comments by the panelists for the first round of 5 cooking times is found in Table 6 (green peas) and Table 7 (yellow peas). A summary of the comments by the panelists for the second round of testing is found in Table 8 (green peas) and Table 9 (yellow peas). Detailed comments by each panelists can be found in the Appendices 2 (green peas) and 3 (yellow peas).

Table 5. The ideal textural characteristics of optimally cooked green and yellow peas suitable for use in soups as determined by an expert panel

Ideal Textural Characteristics
yields smoothly with continuous bite through; interior smooth, not gritty or grainy; chewiness and certain degree of cohesiveness; some firmness, not break down quickly; still whole peas; integrity of skin but not tough;

Many panelists found that the variability within each sample of green peas (Table 6) made it very difficult to determine the sample with optimal textural characteristics. As an example, the sample cooked for 105 min (CF = 97.4 N; F = 205.5 Nmm) was found to be overcooked (i.e. peas were soft and mushy), but some firm seeds were still found in this sample. Figure 3 shows the gradual reduction of CF (Figure 3A) and F (Figure 3B) applied to green peas cooked for longer times. Because of the high variability within each sample near the cook point, the cooking curve does not level off to indicate the shortest time to reach a soft texture.

Table 8 lists the comments given by the panelists for the recoded and reevaluated samples cooked for 85, 95, and 105 min (CF = 236.2, 187.8 and 97.4 N respectively; F = 630.8, 432.3 and 205.5 Nmm respectively). Based on the comments for the second round of testing for green peas, the sample cooked for 105 min was too long. Again, the high variability within these samples made it difficult to determine the sample with the best textural characteristics. The panel recommended that for future tests, the peas should be soaked before cooking. This was done for the yellow peas. These peas exhibited much less variability within each sample than the green peas (Appendix 2 and 3).

Table 6. A summary of the comments for the green peas cooked for 65, 75, 85, 95 and 105 minutes

Cook Time (min)	Comments
65	hard, tough, crunchy, too firm
75	smooth breakdown; small percentage of leathery peas; firm, chewy
85	fractures into fragments, hard, crunchy; seed coat separates and remains after the rest is swallowed
95	variable - some are very hard, others soft; breaks down easily; many seed coats remaining
105	softness very variable from pea to pea; mushy peas, many empty seed coats; some peas are fractured into grainy bits;

Table 7. A summary of the comments for the yellow peas cooked for 20, 25, 30, 35 and 40 minutes

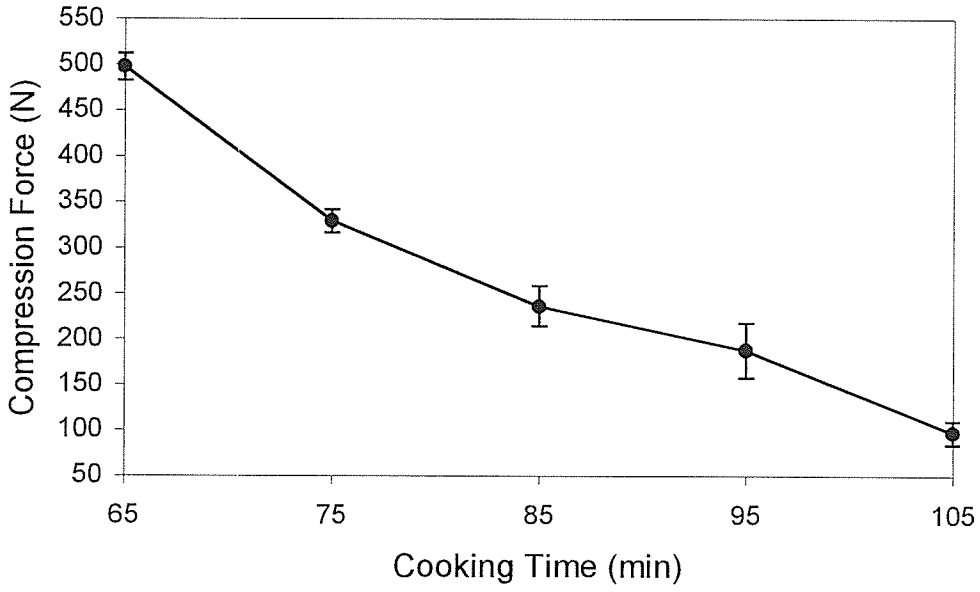
Cook Time (min)	Comments
20	crunchy, hard, not cooked; seed coats are tough
25	seed coat separates and is tough, but chewable; odd gritty pea in sample; peas break down quickly and smoothly
30	firm, but not hard; integrity of pea is good, good smooth breakdown; slightly chewy seed coats
35	soft interior disintegrates rapidly, low cohesiveness; seed coats more evident; smooth interior
40	many broken down pieces in sample and many empty seed coats; overcooked, very watery, mushy;

Table 8. A summary of the comments for the second round of testing - three samples of yellow peas cooked for 85, 95 and 105 min

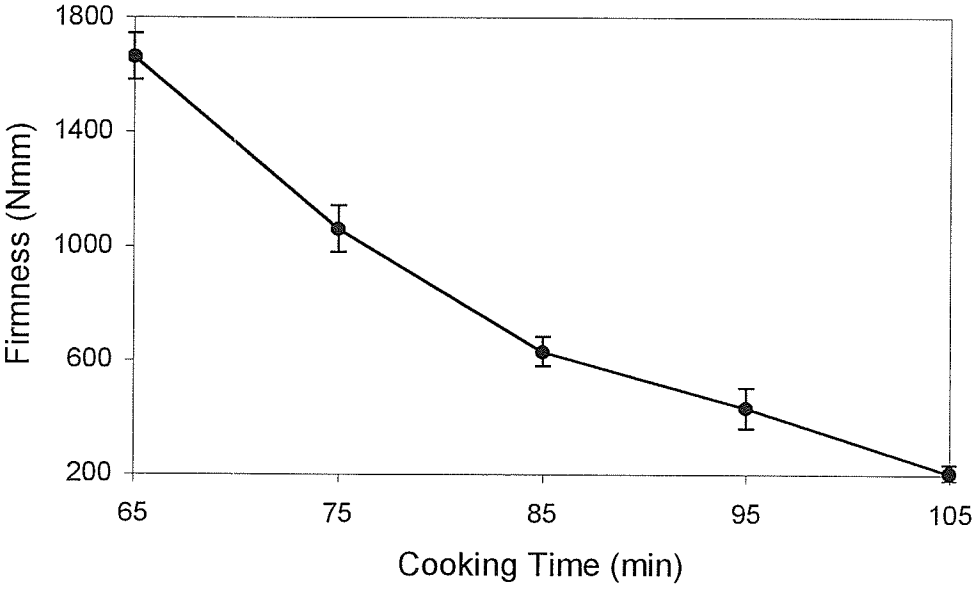
Cook Time (min)	Comments
85	too hard; variable hardness perceived within the sample; seed coat not perceived
95	some firmness with most peas, some too soft; seed coat is more detectable
105	too soft and watery; highly variable hardness perceived within the sample; tough and chewy seed coat

Table 9. A summary of the comments for the second round of testing - two samples of yellow peas cooked for 30 and 35 min

Cook Time (min)	Comments
30	inconsistent hardness within sample; seed coat breaks down fairly well; firmer, more chewy than other sample (cooked for 35 min); smooth breakdown of interior
35	overcooked; tough seed coat, many empty seed coats; grainy and watery interior



A. Compression Force of Green Peas



B. Firmness of Green Peas

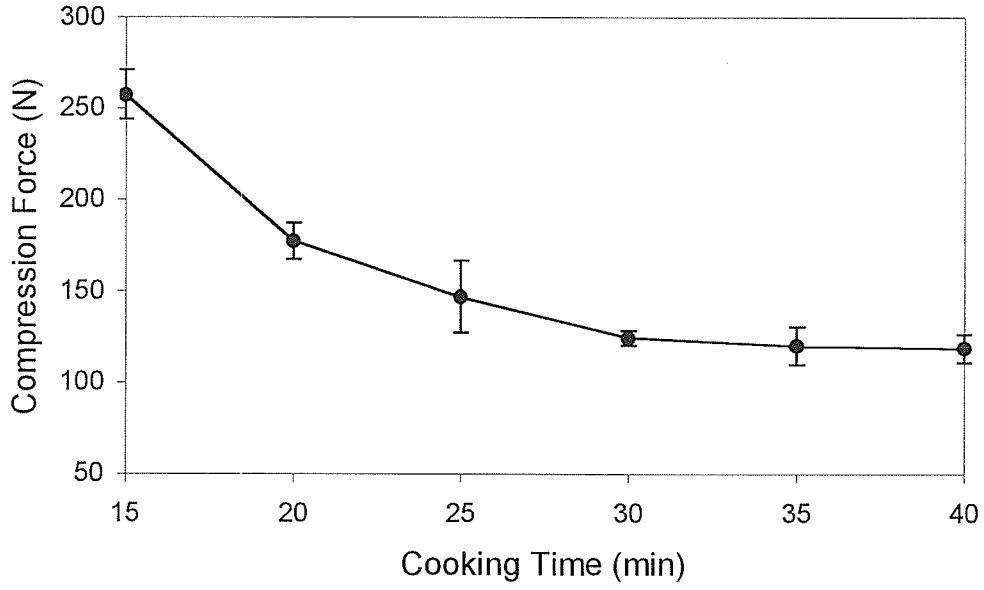
Figure 3. The compression force (A) and firmness (B) cooking curves of raw green peas. The green peas were cooked for 65, 75, 85, 95 and 105 min prior to texture analysis. Standard deviation is indicated by the error bars.

Panelists found that yellow peas cooked for 40 min (CF = 118.5 N; F = 270.5 Nmm) were too soft and had many empty seed coats (Table 7). The samples cooked for 20 and 25 min (CF = 177.2 and 146.7 N respectively; F = 454.9 and 323.5 Nmm respectively) were still too firm. Therefore, the samples cooked for 30 and 35 minutes (CF = 124.4 and 120.1 N respectively; F = 292.0 and 258.5 Nmm respectively) were recoded and reevaluated (Table 9). The majority of the panelists thought that the sample cooked for 30 minutes best fit the ideal textural characteristics. This was confirmed with the cooking curves (Figure 4). Thus, it was determined that a compression force of 125 N and firmness value of 292 Nmm would be the maximum acceptable instrumental measurement for both green and yellow peas to infer optimal cooking.

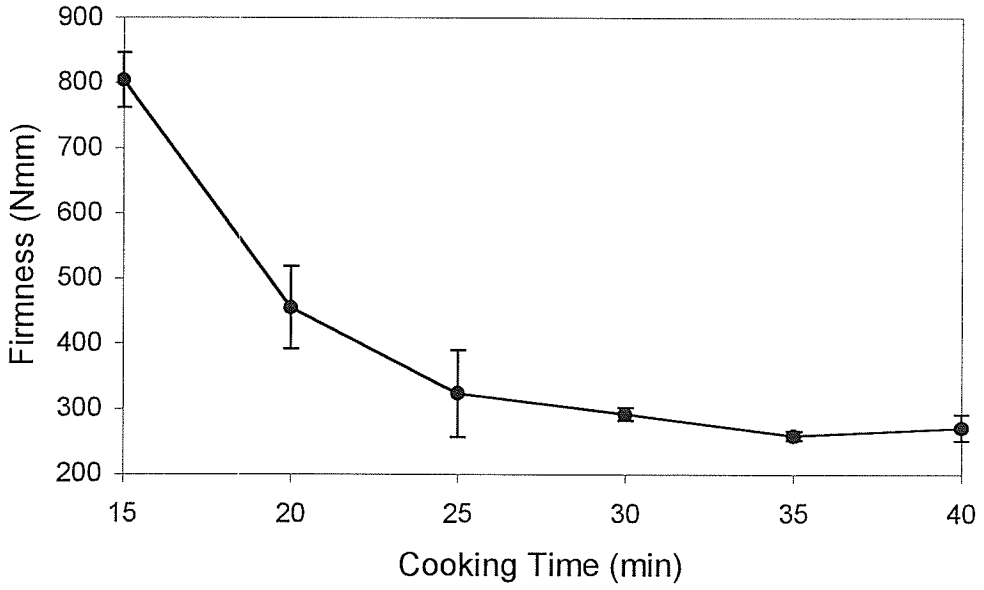
4.3 Optimizing Collecting Temperatures of Micronized Green and Yellow Peas

After the characteristics of the raw peas were determined, the collecting temperature of green and yellow peas was optimized using a fixed tempering level (25% moisture using distilled water) and time (20 h). Collecting both green and yellow peas at higher surface temperatures resulted in lower final moisture levels (Table 10). This results from longer exposure to IR radiation, which leads to greater internal heating and thus more moisture loss (McCurdy, 1992; Arntfield *et al.*, 1997). The moisture levels reached by all samples (green peas: 15.77-21.79%; yellow peas: 18.31-19.38%) are considered to be too high for extended storage.

Figure 5 shows the effect the collecting temperature had on both the degree of gelatinized starch and CF for the green (Figure 5A) and yellow (Figure 5B) peas. Firmness

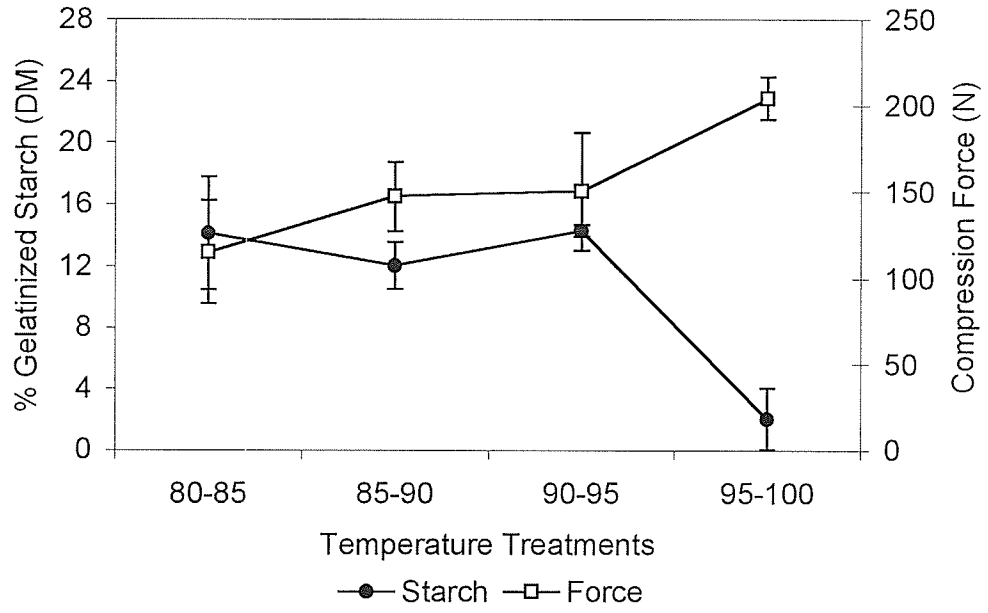


A. Compression Force of Yellow Peas

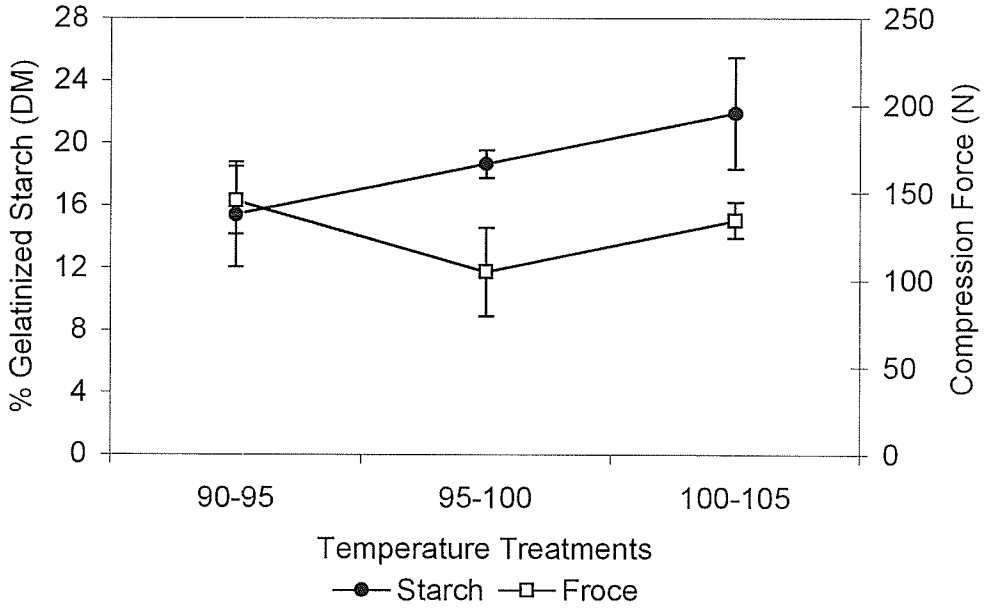


B. Firmness of Yellow Peas

Figure 4. The compression force (A) and firmness (B) cooking curves of raw yellow peas. The yellow peas were soaked for 20 h prior to cooking for 20, 25, 30, 35 and 40 min and texture analysis. Standard deviation is indicated by the error bars.



A. Green Peas



B. Yellow Peas

Figure 5. The degree of starch gelatinization and the compression force for micronized green (A) and yellow (B) peas tempered for 20 h to 25% moisture with distilled water and collected at various temperatures. The compression force was measured after cooking peas for 90 min. Standard deviation is indicated by the error bars.

values were strongly correlated ($P<0.01$) with CF (green peas: $R^2 = 0.9955$; yellow peas: $R^2 = 0.9854$), and thus are not shown. No significant differences were seen among the degree of gelatinized starch values of green and yellow peas, and among the CF values of yellow peas.

Table 10. Residual Moisture [1] of Micronized Green and Yellow Peas Tempered for 20 h to 25% Moisture with Distilled Water and Collected at Various Temperatures

Green Peas [2]	Moisture (%) [3]	Yellow Peas [4]	Moisture (%) [3]
G8085	21.79 ± 0.03	Y9095	19.38 ± 0.08
G8590	18.70 ± 0.04	Y9500	19.33 ± 0.04
G9095	20.33 ± 0.02	Y0005	18.31 ± 0.01
G9500	15.77 ± 0.00		

[1] mean ± standard deviation
[2] Green peas were collected at 80-85°C (G8085), 85-90°C (G8590), 90-95°C (G9095) and 95-100°C (G9500)
[3] different letters in the same column indicate significant difference ($P \leq 0.05$)
[4] Yellow peas were collected at 90-95°C (Y9095), 95-100°C (Y9500) and 100-105°C (Y0005)

As green peas were collected at higher temperatures, the moisture and degree of starch gelatinization decreased, and the CF increased. Perhaps these peas were dried too quickly so that the starch was unable to fully gelatinize. For the green peas, a significant ($P<0.05$) positive correlation was found between the residual moisture and gelatinized starch level ($R^2 = 0.7266$), while significant ($P<0.05$) negative correlations were found between the CF and residual moisture level ($R^2 = -0.8556$) and the CF and gelatinized starch level ($R^2 = -0.7845$). For future micronization experiments, it was decided that the green peas would be collected at 80-85°C since the CF (113.7 N) was below 125 N, the F (235.1 Nmm) was

below 292 Nmm. This temperature range also had the highest degree of gelatinized starch (14.13%).

Collecting yellow peas at various temperatures did not significantly change the degree of gelatinized starch and the CF (Figure 5B). However, as the collecting temperature increased, the degree of gelatinized starch also increased (15.41% at 90-95°C, 18.66% at 95-100°C and 21.90% at 100-105°C). When the yellow peas were collected at surface temperatures of 100-105°C, popping noises were heard during the micronization process and some micronized peas were burnt. Therefore, for future micronization experiments, it was decided that the yellow peas would be collected at surface temperatures between 92.5°C and 97.5°C. At this surface temperature range, the CF (120.1 N) averaged below 125 N and the F (237.2 Nmm) averaged below 292 Nmm.

4.4 Optimizing Tempering Level and Time for Micronized Green and Yellow Peas

After the collecting temperature was optimized for green (80-85°C) and yellow (93.5-97.5°C) peas, the tempering level and time needed to be optimized. Four tempering levels (20, 25, 30 and 35%) and two tempering times (6 and 20 h) were evaluated. Micronized samples with CF and F values less than 125 N and 292 Nmm, respectively had the optimal texture results. Gelatinized starch, soluble protein and pectin were measured to determine which contributed to the micronized texture. Reductions in phytic acid, an ANF, were also measured. Cooking curves were done for samples with CF and F below 125 N and 292 Nmm, respectively.

4.4.1 RESIDUAL MOISTURE

The tempering level, tempering time and their interaction have effects on the residual moisture level of green and yellow peas (Tables 11 and 12). Generally, it was found that micronization only reduced the moisture by a maximum of 12%. This was higher than the 7% reduction for green field peas found by Zheng *et al* (1998). Perhaps during the cooling period after micronization these peas lost moisture through sweating. Sarantinos & Black (1996) were concerned over the microbial safety of micronized chick peas with residual moisture levels higher than the presoaking moisture level. The high moisture levels of peas tempered to >25% moisture and then micronized (15.57%-28.44% green; 15.33%-27.78% yellow) are considered to be too high for extended storage.

Table 11. Residual Moisture [1] of Green Peas Tempered for 6 and 20 h to 20%, 25%, 30% and 35% Moisture with Distilled Water and Micronized to 80-85°C [2, 3]

Tempering Level (%)	% Moisture (Tempered 6 h)	% Moisture (Tempered 20 h)
20	13.30 ± 0.00 [1 d]	13.06 ± 0.79 [1 d]
25	16.38 ± 0.00 [1 c]	15.57 ± 0.02 [2 c]
30	20.37 ± 0.05 [1 b]	19.68 ± 0.02 [2 b]
35	24.51 ± 0.02 [2 a]	28.44 ± 0.01 [1 a]

[1] mean ± standard deviation
[2] different numbers in the same row indicate significant difference ($P < 0.05$)
[3] different letters in the same column indicate significant difference ($P < 0.05$)

The residual moisture level for green peas (Table 11) tempered for 6 h increased at a lower rate with higher tempering levels than green peas tempered for 20 h. When green peas tempered to higher moisture levels were micronized, it took longer for the peas to reach the optimum collecting temperature, perhaps due to the cooling effect of the released water

vapour. As a way to increase the collecting temperature, the slope of the vibrating bed was adjusted in such a way as to hold the peas in the IR radiation for a longer time. Thus, the green peas were collected at the desired temperature range.

When the tempering level was 20, 25 and 30%, the residual moisture level was higher for green peas tempered for 6 h than for 20 h. However, when green peas were tempered to 35%, the residual moisture level was higher after 20 h of tempering compared to 6 h. Perhaps when the green peas were tempered to 35% moisture for 6 h, water did not have enough time to fully penetrate into the seed. Therefore, during micronization, the water, which was close to the surface, was easier to evaporate. When a longer tempering time was used (20 h), the water absorbed by the green peas tempered to 35% moisture had more time to migrate into the seed; thus, it was harder to remove during micronization. At this high tempering level, the green peas needed to be held for a longer time before the optimum collecting temperature was reached. Perhaps, a case-hardening effect prevented moisture evaporation from within the seeds. Thus, the outer surface of the peas reached the optimum collecting temperature, but the moisture could not be evaporated.

The residual moisture levels for yellow peas (Table 12) also increases with increasing tempering level and with longer tempering time. At lower tempering levels (20 and 25%), the residual moisture levels were the same for yellow peas tempered for 6 or 20 h. When yellow peas were tempered to higher moisture levels (30 and 35%), those tempered for 20 h had higher residual moisture levels. Again, this may be related to better moisture equilibrium within the seed or case-hardening of the outer seed surface, which lessened water evaporation during micronization.

Table 12. Residual Moisture [1] of Yellow Peas Tempered for 6 and 20 h to 20%, 25%, 30% and 35% Moisture with Distilled Water and Micronized to 92.5-97.5°C [2, 3]

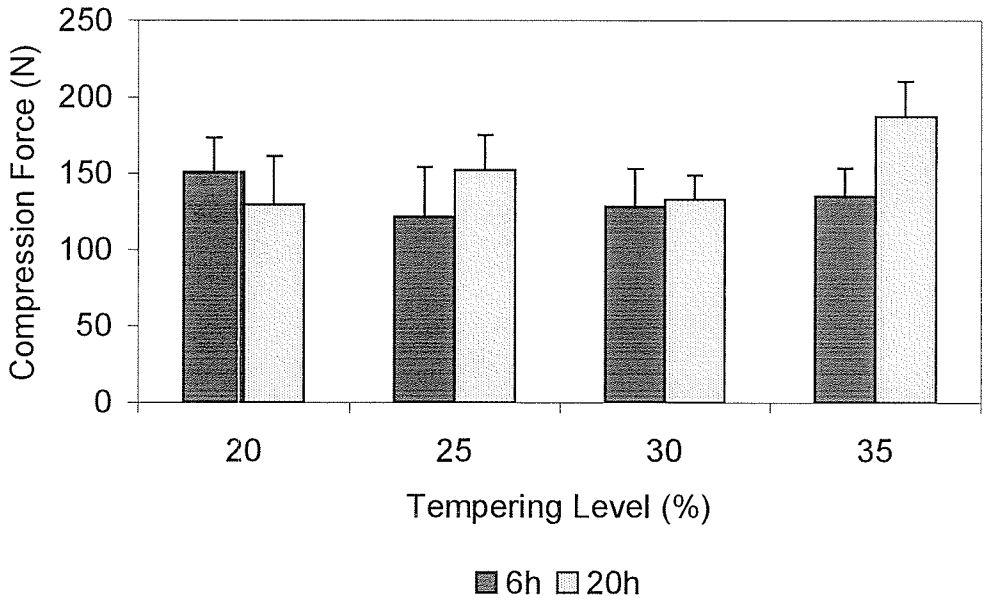
Tempering Level	% Moisture (Tempered 6 h)	% Moisture (Tempered 20 h)
20%	13.69 ± 0.01 [1 d]	14.06 ± 0.76 [1 c]
25%	15.33 ± 0.01 [1 c]	15.35 ± 0.08 [1 c]
30%	18.87 ± 0.05 [2 b]	19.55 ± 0.04 [1 b]
35%	23.48 ± 0.08 [2 a]	27.78 ± 0.05 [1 a]

[1] mean ± standard deviation
[2] different numbers in the same row indicate significant difference ($P < 0.05$)
[3] different letters in the same column indicate significant difference ($P < 0.05$)

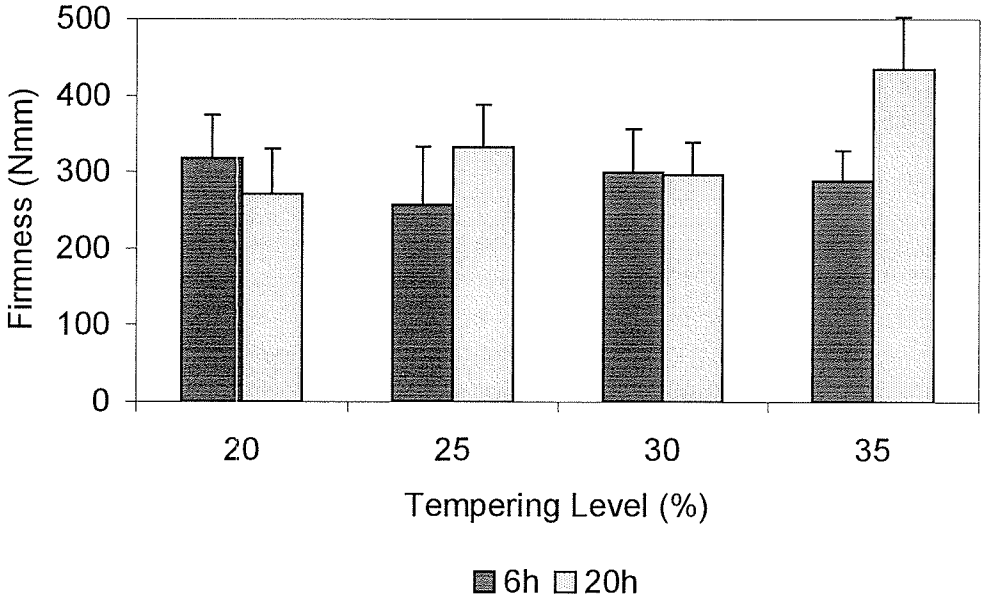
4.4.2 TEXTURE

The CF (Figure 6A) and F (Figure 6B) values for green peas did not show significant differences among the tempering levels and times. However, all micronized green peas had a lower CF and F than the raw (CF = 187.3 N; F = 444.4 Nmm). This clearly shows that micronized green peas need shorter cooking times than the raw. It is interesting to note that green peas tempered to 35% for 20 h had the highest CF (187.1 N) and F (435.1 Nmm) values. This may result from case hardening of the peas during micronization.

For yellow peas (Figure 7), all firmness values (161.2-278.3 Nmm) were below 292 Nmm and CF values (69.3-140.0 N) were around or below 125 N. These CF and F values (125 N and 292 Nmm, respectively) are the maximum acceptable texture measurements as determined by an expert panel. The texture scores for yellow peas were significantly different for the tempering level only. The texture values clearly show that micronized yellow peas can be cooked for less than 90 min. Thus, the minimum tempering level to

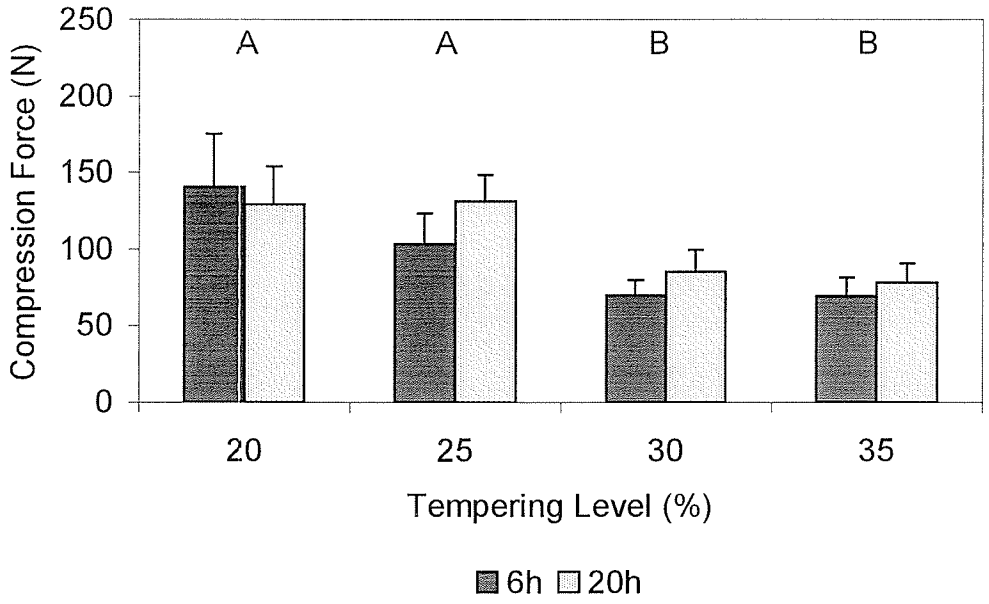


A. Compression Force of Green Peas

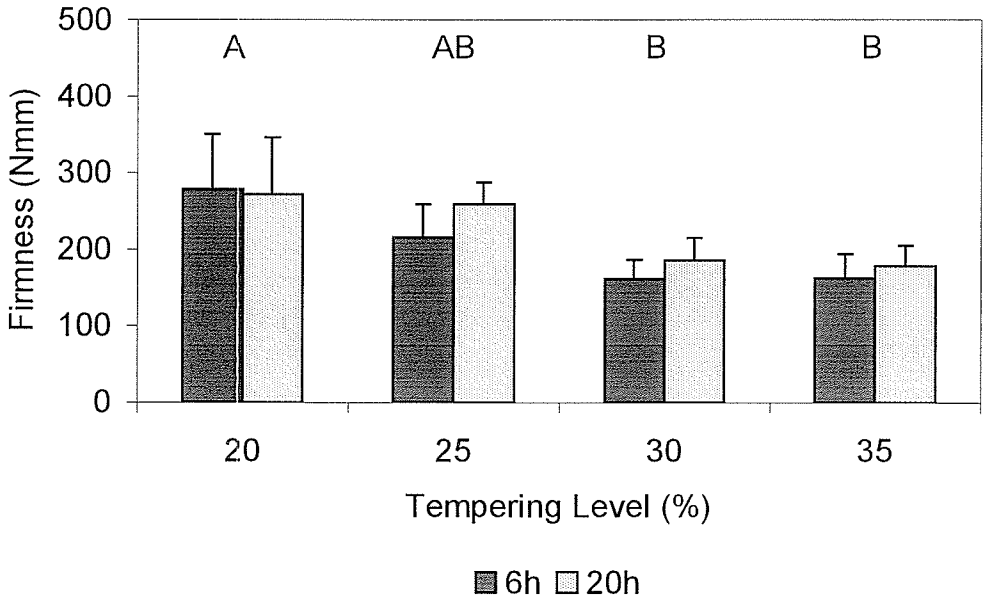


B. Firmness of Green Peas

Figure 6. The compression force (A) and firmness (B) for micronized green peas tempered for 6 and 20 h to 20, 25, 30 and 35% moisture with distilled water. Green peas were cooked for 90 min before texture analysis. No significant differences were found for tempering level or time. Standard deviation is indicated by the error bars.



A. Compression Force of Yellow Peas

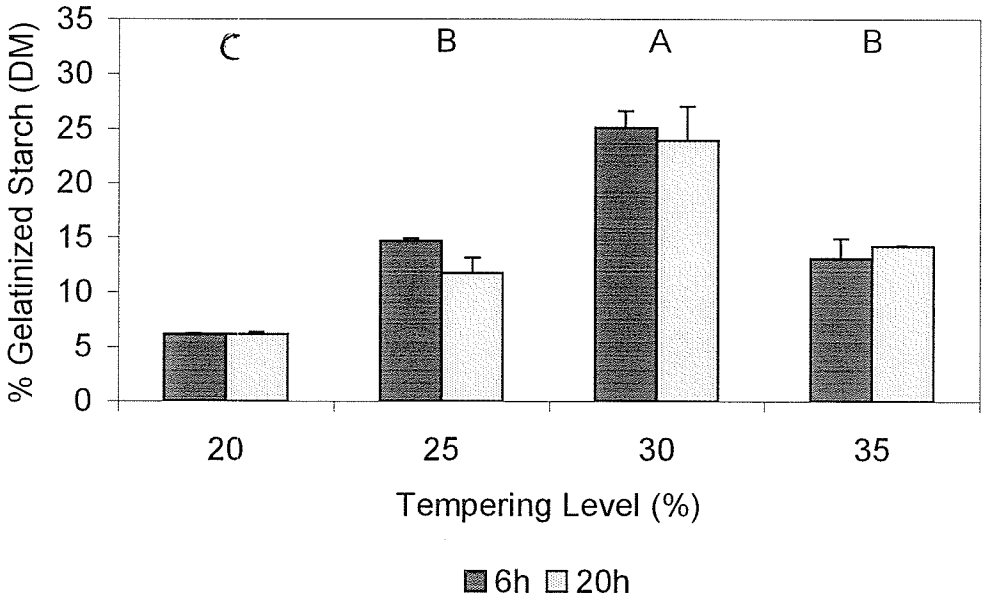


B. Firmness of Yellow Peas

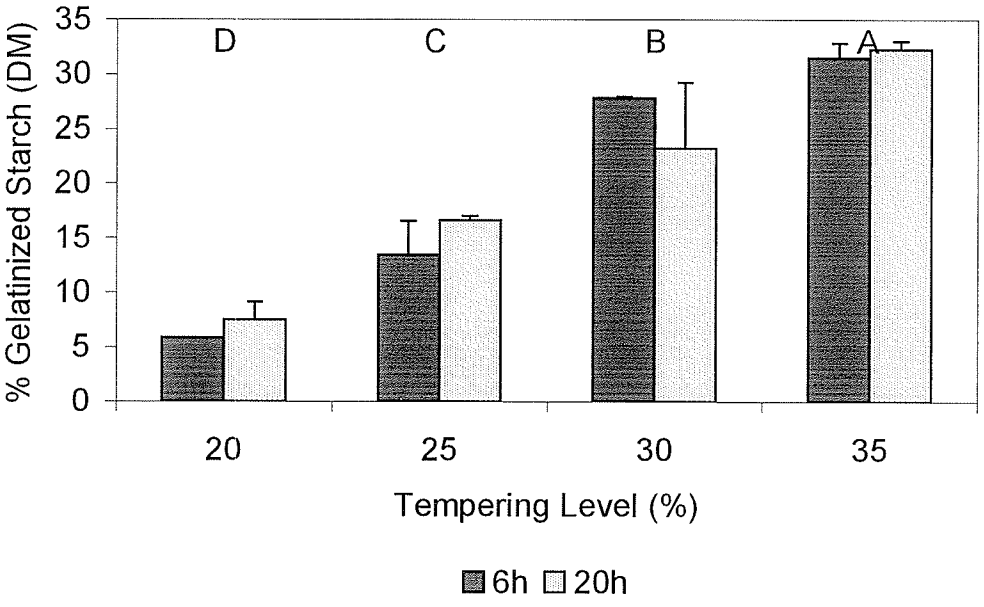
Figure 7. The compression force (A) and firmness (B) for micronized yellow peas tempered for 6 and 20 h to 20, 25, 30 and 35% moisture with distilled water. Yellow peas were cooked for 90 minutes before texture analysis. Different capital letters above the tempering levels indicate significant differences ($P<0.05$). Standard deviation is indicated by the error bars.

shorten cooking times is 20%. However, yellow peas tempered to 20% moisture have CF (134.5 N) and F (275.1 Nmm) higher than the raw values (CF = 120.3 N; F = 231.4 Nmm). Micronized chick peas also had higher texture scores than the raw (Sarantinos and Black, 1996). These authors reported that the seeds hardened during micronization. These yellow peas and chick peas were tempered to 20 and 17% respectively and had residual moisture levels between 12.4 and 14.5%. Perhaps when these samples were micronized, they were kept in the IR radiation too long. Thus, after all the free water was evaporated, the outer layers became hard (Sarantinos and Black, 1996). Thus, to have shorter cooking times than the raw, micronized yellow peas collected at 92.5-97.5°C needed to be tempered to at least 25% moisture.

4.4.2.1 Gelatinized Starch. Figure 8 shows the effect the tempering level and time had on the degree of gelatinized starch for green (Figure 8A) and yellow (Figure 8B) peas. For both green and yellow peas, only the tempering level had a significant effect on the degree of gelatinized starch. Tempering green and yellow peas to 20% moisture gave gelatinized starch levels similar to that of raw peas (6.78% green; 7.19% yellow). Tempering to 35% moisture gave yellow peas the highest gelatinized starch level (31.07-32.05%), while tempering to 30% moisture gave the highest gelatinized starch level for micronized green peas (23.89-25.08%). Increasing the tempering level to 35% moisture for green peas decreased the degree of gelatinized starch. Perhaps for green peas collected at 80-85°C, significant evaporative cooling at the 35% tempering level prevented the requisite time-temperature-moisture conditions necessary for starch gelatinization, whereas for yellow peas at 92.5-97.5°C, sufficient thermal energy was present to gelatinize the starch. Also,



A. Green Peas



B. Yellow Peas

Figure 8. The degree of gelatinized starch for micronized green (A) and yellow (B) peas tempered for 6 and 20 h to 20, 25, 30 and 35% moisture with distilled water. Tempering time was not significant for both green and yellow micronized peas. Different captial letters above the tempering levels indicate significant differences ($P<0.05$). Standard deviation is indicated by the error bars.

case hardening may have prevented starch from fully gelatinizing because IR radiation could not fully penetrate into the seed centre and thus, granule swelling was restricted (Sarantinos and Black, 1996).

As mentioned before, the firmness value for green peas tempered to 35% moisture for 20 h spiked to 435.1 Nmm, which indicates a firmer seed. The degree of gelatinized starch for green and yellow peas is significantly correlated (Tables 13 and 14) with the residual moisture level ($R^2 = 0.9727$ and $R^2 = 0.9102$ respectively). Yellow peas also had significant ($P<0.05$) negative correlations between gelatinized starch and CF ($R^2 = -0.8118$), and gelatinized starch and F ($R^2 = -0.7610$). This shows that high levels of gelatinized starch for micronized yellow peas are associated with low texture values. Thus, both are indicative of shorter cooking times.

Both green and yellow ground pea samples tempered to 35% moisture became moldy before the soluble protein, pectin fraction and phytic acid determinations could be completed. Thus, tempering peas to 35% moisture was not a suitable tempering condition for further micronization experiments.

4.4.2.2 Soluble Protein. As with the texture values, the soluble protein of green peas (14.25-15.33%) did not show significant differences among the tempering levels and times (Figure 9A). However, micronization did reduce the soluble protein level by approximately 40% from the raw green pea level (25.07% soluble protein). Others have also reported reduced protein solubility after micronization: 30-70% reduction for peas by McCurdy (1992); 30% reduction for soybeans by Metussin *et al.* (1992); and 50% reduction for wheat and barley by South & Ross (1993). Zheng *et al.* (1998) found that the reduction

Table 13. Correlation values [1] among the tempering conditions and chemical composition values of green peas (n = 12)

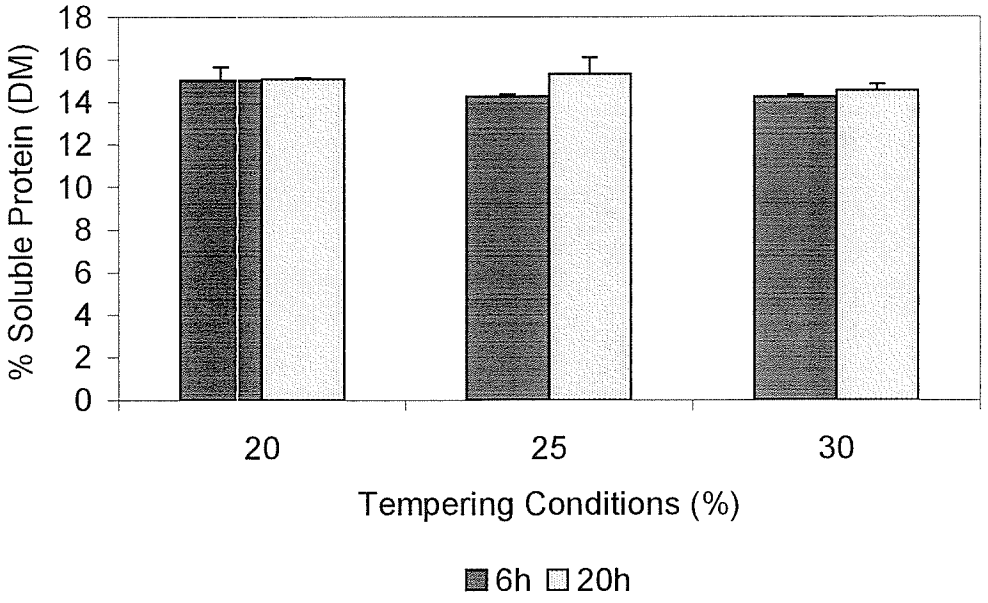
	Residual Moisture	RF Pectin	LM Pectin	Gelatinized Starch
Tempering Level	0.9817	-0.8990	0.6026	0.9652
Gelatinized Starch	0.9727	-0.9245	0.6320	
LM Pectin	0.6263	-0.6581		
RF Pectin	-0.9294			
Phytic Acid			0.7206	

[1] All values listed are significant at $P<0.05$.

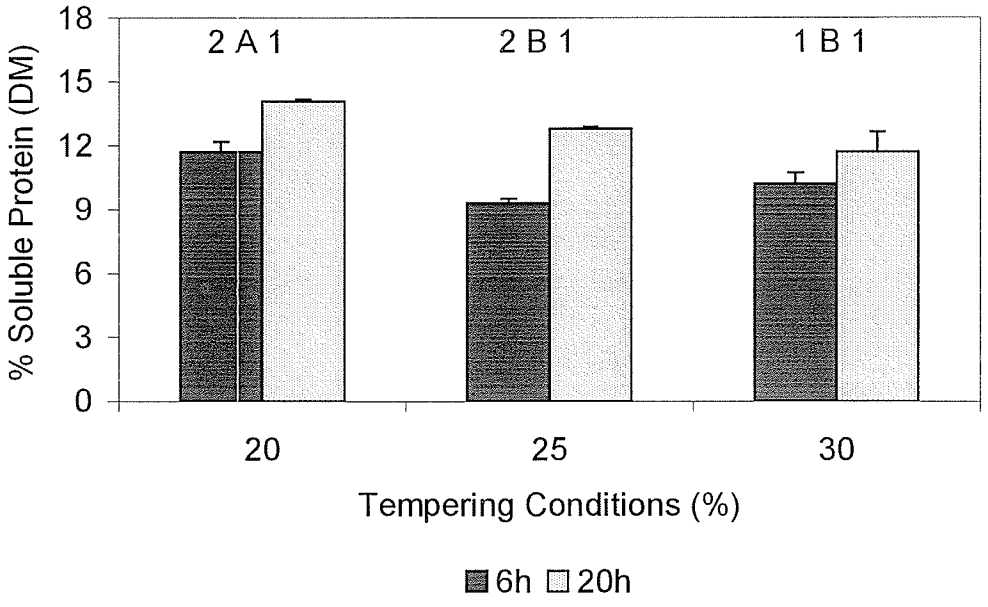
Table 14. Correlation values [1] among the tempering conditions, texture values and chemical composition values of yellow peas (n = 12)

	Residual Moisture	RF Pectin	F	CF	LM Pectin	Gelatinized Starch	Soluble Protein
Tempering Level	0.9540	-0.7958	-0.7352	-0.7820	0.8886	0.9592	
Gelatinized Starch	0.9102	-0.8154	-0.7061	-0.7522	0.9310		
LM Pectin	0.8719	-0.8046	-0.7382	-0.8027			
CF	-0.8118	0.5910	0.9782				
F	-0.7620						
RF Pectin	-0.7238						
Tempering Time							0.7464

[1] All values listed are significant at $P<0.05$



A. Green Peas



B. Yellow Peas

Figure 9. The soluble protein level of micronized green (A) and yellow (B) peas tempered for 6 and 20 h to 20, 25 and 30% moisture with distilled water. No effect of tempering time and level was found for green peas. An overall effect, but no interaction, of the tempering time and level was found for yellow peas. Different capital letters above the tempering levels indicate significant differences ($P<0.05$). Different numbers above the tempering times indicate significant differences ($P<0.05$). Standard deviation is indicated by the error bars.

in soluble protein was related to high initial seed moisture levels, high micronizing temperatures and long heating times. Since green peas were collected at a relatively low temperature range of 80-85°C, the soluble protein level did not show the influence of tempering level and heating time.

The soluble protein of yellow peas (Figure 9B), on the other hand, was significantly affected by the tempering level and time. Generally, the soluble protein level was reduced by 40-60% after micronization. Greater reductions occurred with yellow peas tempered for 6 h than for those tempered for 20 h and for yellow peas tempered to 25 or 30% moisture than 20% moisture. These results concur with those from Zheng *et al.* (1998). Higher moisture levels gave greater reductions in soluble protein by increasing the protein solubility during tempering, and thus exposing more protein to IR radiation, which caused them to denature. Legume proteins are more concentrated near the outer surface of the seeds. Thus, seeds with greater moisture in this area would have lower protein solubility after micronization. Arntfield *et al.* (1997) found that the protein solubility of micronized lentils was correlated with their texture values. Although this was not the case for yellow peas, both the soluble protein and texture values were reduced at higher tempering levels.

4.4.2.3 Pectin. Table 15 shows the HM (Table 15A), LM (Table 15B) and RF (Table 15C) pectin values for micronized green peas. Generally, with higher tempering levels, the total pectin level decreases. The total pectin level decreased faster when the micronized green peas were tempered for 6 h than for 20 h. Also, those tempered to >25% moisture (0.377-0.483%) or for 20 h (0.432-0.534%) had lower total pectin levels than the pectin level for raw peas (0.551%).

Table 15. High-methoxylated (A), low-methoxylated (B) and residual fraction (C) pectin measurements [1] of green micronized field peas tempered for 6 and 20 h and to 20, 25 and 30% moisture with distilled water [2, 3]

A. High-Methoxylated Pectin Values

Tempering Level	% HM Pectin (Tempered 6 h)	% HM Pectin (Tempered 20 h)
20%	0.104 ± 0.008 [1 a]	0.072 ± 0.003 [2 ab]
25%	0.057 ± 0.012 [1 b]	0.054 ± 0.000 [1 b]
30%	0.059 ± 0.001 [1 b]	0.080 ± 0.013 [1 a]

B. Low-Methoxylated Pectin Values

Tempering Level	% LM Pectin (Tempered 6 h)	% LM Pectin (Tempered 20 h)
20%	0.012 ± 0.002 [2 b]	0.030 ± 0.000 [1 a]
25%	0.025 ± 0.003 [1 ab]	0.014 ± 0.000 [2 b]
30%	0.040 ± 0.009 [1 a]	0.043 ± 0.008 [1 a]

C. Residual Fraction of Pectin Values

Tempering Level	% RF Pectin (Tempered 6 h)	% RF Pectin (Tempered 20 h)
20%	0.482 ± 0.019 [1 a]	0.432 ± 0.002 [1 a]
25%	0.401 ± 0.024 [1 b]	0.414 ± 0.018 [1 a]
30%	0.278 ± 0.004 [2 c]	0.309 ± 0.003 [1 b]

[1] mean ± standard deviation
[2] different numbers in the same row indicate significant differences ($P < 0.05$)
[3] different letters in the same column indicate significant differences ($P < 0.05$)

HM pectin of the micronized green peas was lower than the raw (0.069%) for samples tempered for 6 h to 25 and 30% and for 20 h to 30% (0.057, 0.059, 0.054% respectively), and it was higher for samples tempered for 6 h to 20% and for 20 h to 20 and 30% (0.104, 0.072, 0.080% respectively). LM pectin of the micronized green peas was higher than the raw peas (0.011%). Samples tempered for 6 h had higher LM values as the moisture was increased, while samples tempered for 20 h had higher values at tempering levels of 20 and 30%. RF pectin was lower than the raw (0.471%) for all micronized green peas except those tempered for 6 h to 20% (0.482%). A significant ($P<0.05$) negative correlation (Table 13) was calculated between LM and RF pectin fractions. This shows that some RF pectin, which is composed of protopectin and insoluble pectic salts, is converted to LM pectin, which is composed of pectin salts of calcium and magnesium. These two pectin fractions are also significantly correlated with the degree of gelatinized starch (LM: $R^2 = 0.6320$ and RF: $R^2 = -0.9245$ respectively). LM pectin has a significant correlation with the residual moisture level. This indicates that the more moisture is available within the seed, the better able starch granules are to swell and subsequently to gelatinize because the intercellular spaces have lost some of their rigidity through conversion of RF to LM pectin.

These results are a bit unusual in that many researchers have reported greater pectin solubility after heat treatment (Lee *et al.*, 1979; Uzogara *et al.*, 1990; Ben-Shalom *et al.*, 1992). Perhaps during the tempering and micronization process, greater amounts of HM pectin were demethylated and hydrolyzed into smaller components that may not have been detected using this assay. Similarly this may have contributed to the large decrease in RF pectin after tempering for 6 h to 30% moisture. Various researchers have reported that the

increase in pectin solubility leads to shorter cooking times (Kon, 1968; Wang *et al.*, 1988; Vidal-Valverde *et al.* 1992b). This was not the case here.

Table 16 shows the HM (Table 16A), LM (Table 16B) and RF (Table 16C) pectin values for micronized yellow peas tempered for 6 and 20 h to 20, 25 and 30% moisture. The higher total pectin amounts occurred for samples tempered for 20 h to 20% moisture (0.521%) and the lowest for samples tempered for 20 h to 25% moisture (0.476%).

All HM pectin values for the micronized yellow peas are higher than that for raw yellow peas (0.061% HM pectin). This agrees with the results from Kon (1968) and Wang *et al.* (1988). Yellow peas tempered for 20 h to 20, 25 and 30% moisture gave a significant reduction in HM pectin. Although, the level of HM pectin tempered for 6 h was higher at higher tempering levels, this was not found to be significant. Differences between HM pectin tempered for 6 and 20 h were also not significant. All LM pectin values for the micronized yellow peas were higher than that for the raw peas (0.007% LM pectin) and increased significantly as the tempering level increased. A significant interaction between tempering level and time occurred for yellow peas tempered to 30% moisture (6 h: LM = 0.058%; 20 h: LM = 0.038%). RF pectin decreased with increasing tempering levels (6 h: RF = 0.399-0.351%; 20 h: RF = 0.414-0.374%) and all values were lower than that for raw peas (0.477%). The results for RF pectin also show a significant interaction between tempering level and time.

As with the green peas, a significant ($P<0.05$) negative correlation (Table 14) was calculated between the LM and RF pectin fractions. This shows that some RF pectin, which is composed of protopectin and insoluble pectic salts, is probably converted to LM pectin.

Table 16. High-methoxylated (A), low-methoxylated (B) and residual fraction (C) pectin measurements [1] of yellow micronized field peas tempered for 6 and 20 h and to 20, 25, 30, and 35% moisture with distilled water [2, 3]

A. High-Methoxylated Pectin Values

Tempering Level	% HM Pectin (Tempered 6 h)	% HM Pectin (Tempered 20 h)
20%	0.063 ± 0.017 [1 a]	0.090 ± 0.004 [1 a]
25%	0.077 ± 0.007 [1 a]	0.082 ± 0.004 [1 ab]
30%	0.080 ± 0.002 [1 a]	0.073 ± 0.003 [1 b]

B. Low-Methoxylated Pectin Values

Tempering Level	% LM Pectin (Tempered 6 h)	% LM Pectin (Tempered 20 h)
20%	0.016 ± 0.000 [1 c]	0.017 ± 0.002 [1 c]
25%	0.026 ± 0.001 [1 b]	0.026 ± 0.001 [1 b]
30%	0.058 ± 0.002 [1 a]	0.038 ± 0.002 [2 a]

C. Residual Fraction of Pectin Values

Tempering Level	% RF Pectin (Tempered 6 h)	% RF Pectin (Tempered 20 h)
20%	0.399 ± 0.007 [1 a]	0.414 ± 0.002 [1 a]
25%	0.399 ± 0.003 [1 a]	0.368 ± 0.006 [2 b]
30%	0.351 ± 0.007 [1 b]	0.374 ± 0.020 [1 b]

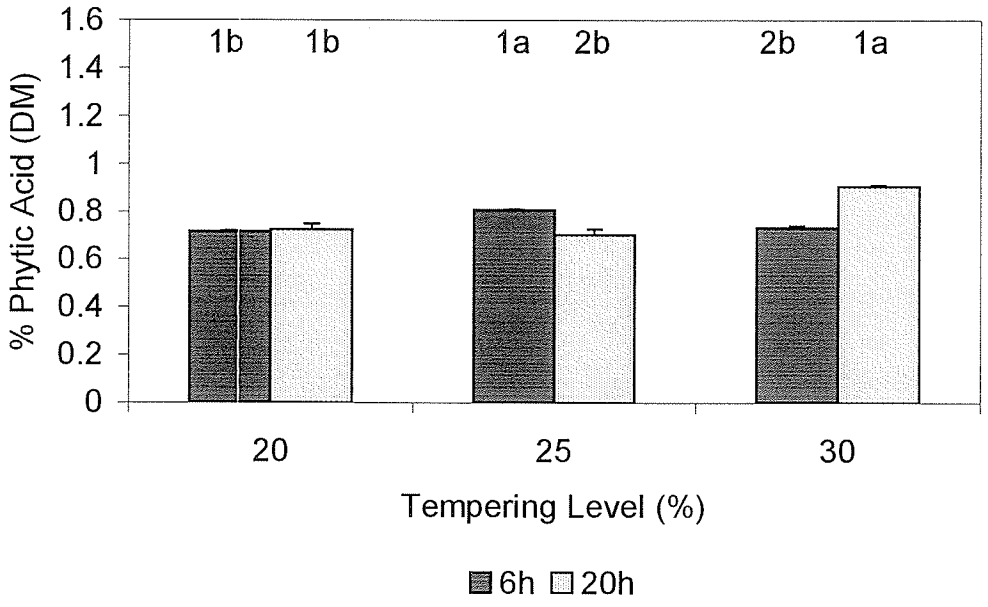
[1] mean ± standard deviation
[2] different numbers in the same row indicate significant differences ($P < 0.05$)
[3] different letters in the same column indicate significant differences ($P < 0.05$)

These two pectin fractions have significant ($P<0.05$) correlations with the residual moisture, the degree of gelatinized starch and CF (LM: $R^2 = 0.8719$, 0.9310 and -0.8027; RF: $R^2 =$ -0.7238, -0.8154 and 0.5910 respectively). LM pectin of yellow peas is also significantly correlated with F ($R^2 = -0.7382$). These correlations suggest that high levels of available moisture within the seed are better able to reduce the rigidity in the intercellular spaces by increasing the LM pectin fraction and lowering the RF pectin, which then leads to greater starch gelatinization and shorter cooking times through reduced texture values.

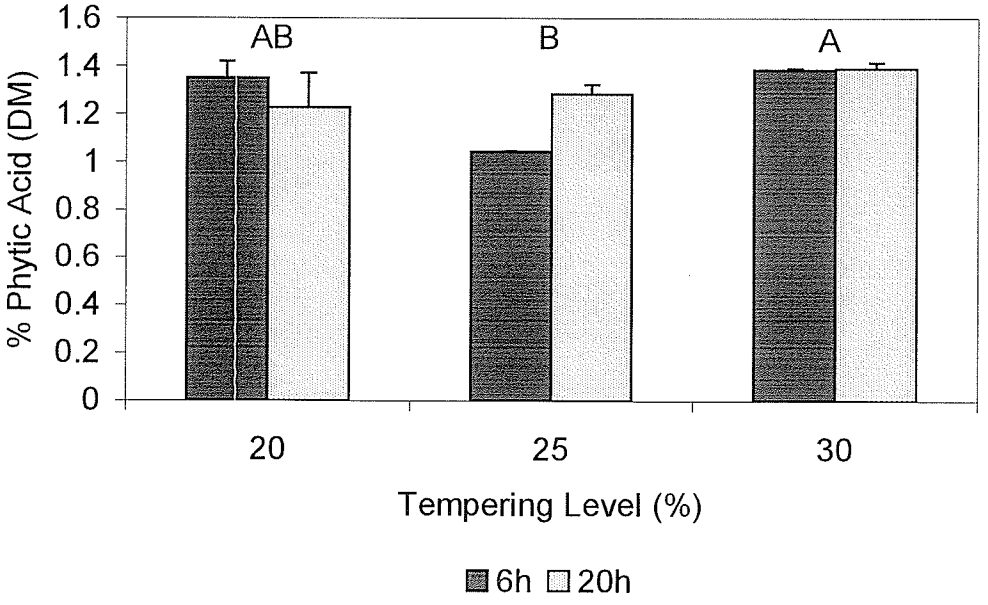
4.4.3 Phytic Acid

As mentioned before, phytic acid is an ANF that chelates cations such as calcium and magnesium (Greenwood, 1989; West *et al.*, 1994). Because phytic acid is fairly heat stable, its levels in peas can only be reduced through leaching into surrounding media or through enzymatic hydrolysis (Reddy *et al.*, 1989a; Estévez *et al.*, 1991; Bishnoi *et al.*, 1994). Tempering, which does not use excess moisture, allows metabolic processes similar to germination and fermentation to occur (Akinyele and Akinlosotu, 1991; Vidal-Valverde *et al.*, 1992b). Thus, cations are released into the cells when phytic acid is hydrolyzed by phytase during tempering (Liu *et al.*, 1993; Hulse, 1994).

The interaction between tempering level and time on phytic acid was significant for micronized green peas (Figure 10A), while only the tempering level affected the phytic acid content of yellow peas (Figure 10B). Also, all micronized green peas had phytic acid levels lower than the raw (1.09%) and micronized yellow peas had phytic acid levels less than or equal to the raw value (1.36%). Interestingly, the phytic acid level of green peas was



A. Green Peas



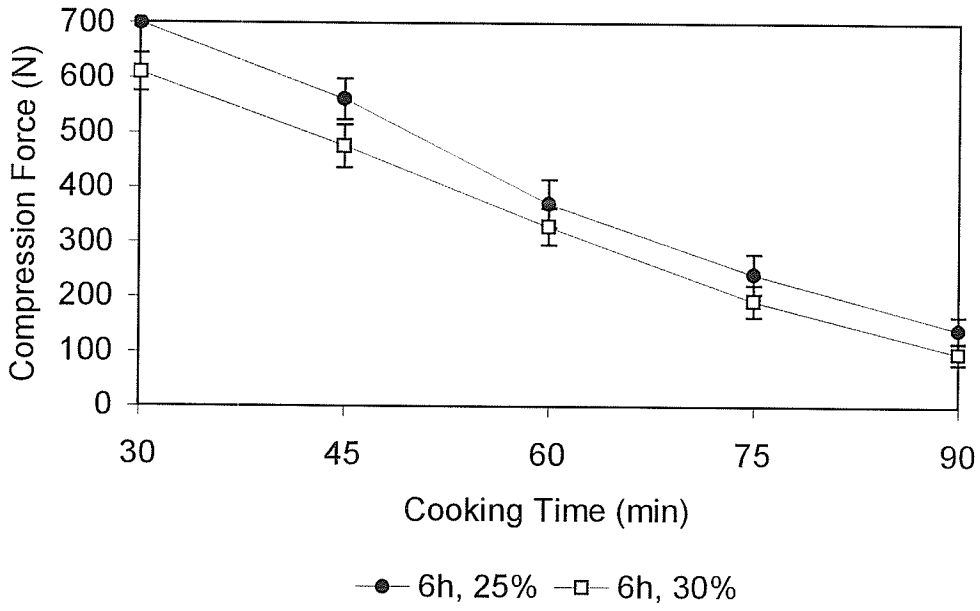
B. Yellow Peas

Figure 10. The phytic acid in micronized green (A) and yellow (B) peas tempered for 6 and 20 h to 20, 25 and 30% moisture with distilled water. The interaction of tempering level and time was significant for green peas; the tempering level was significant for yellow peas. Different letters above the tempering levels indicate significant differences ($P<0.05$). Different numbers above the tempering times indicate significant differences ($P<0.05$). Standard deviation is indicated by the error bars.

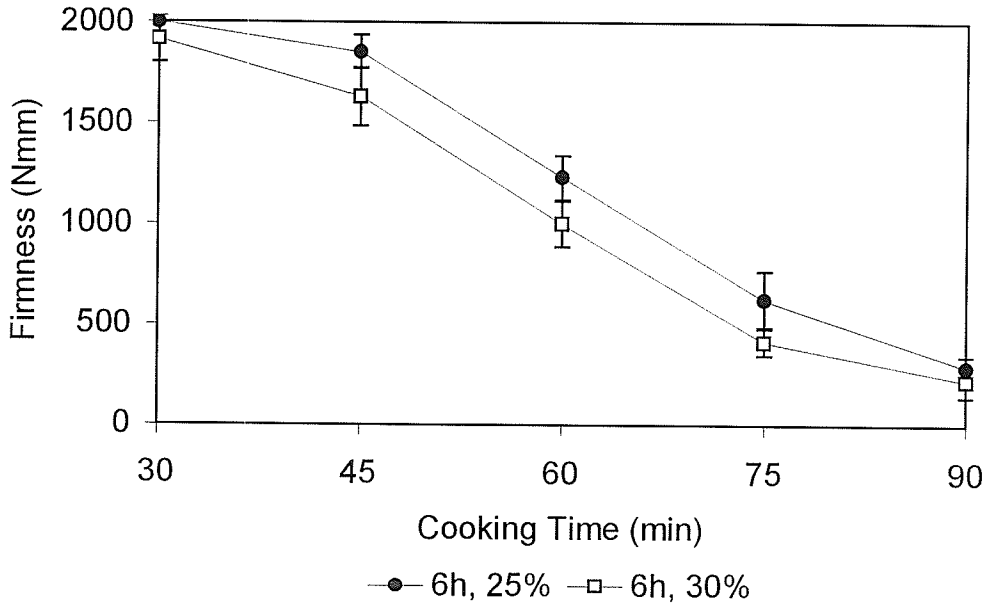
reduced more than that for yellow peas (green peas: 17-36% reduction; yellow peas: 0-23% reduction). Perhaps, the phytic acid in green peas is more accessible than it is for yellow peas, or the collecting temperature for yellow peas denatured more phytase than for green peas. The highest phytic acid level, i.e. smallest phytic acid reduction, for micronized green peas occurred after tempering for 6 h to 30%, while that for yellow peas occurred after tempering to 30%, regardless of tempering time. Perhaps because of the high tempering level and the long time required to reach the collecting temperature, these samples were exposed to more IR radiation, which caused more phytase to be denatured. For green peas, phytic acid was significantly ($P<0.05$) correlated (Table 13) with LM pectin. Perhaps, the released cations are incorporated into the insoluble pectic salts of RF pectin. This then enhances the conversion of RF to LM pectin, which leads to the positive correlation between LM pectin and phytic acid.

4.4.4 Cooking Curves for Peas Tempered for 6 h to 25 and 30% Moisture

As a result of the chemical analyses and texture evaluation, cooking curves of micronized green (Figure 11) and yellow (Figure 12) peas were done. Micronized peas tempered for 6 h at 25% and 30% moisture were chosen. At these pretreatment conditions, green peas had higher gelatinized starch (Figure 6A) and LM pectin (Table 15B), and a greater reduction in soluble protein (Figure 9A) and RF pectin (Table 15C). Although these factors did not translate into significant reductions in texture (Figure 7), lower CF and F were seen compared to tempering for 20 h and to 20% moisture. Micronized yellow peas also had higher gelatinized starch (Figure 6B), HM pectin (Table 16A) and LM pectin (Table

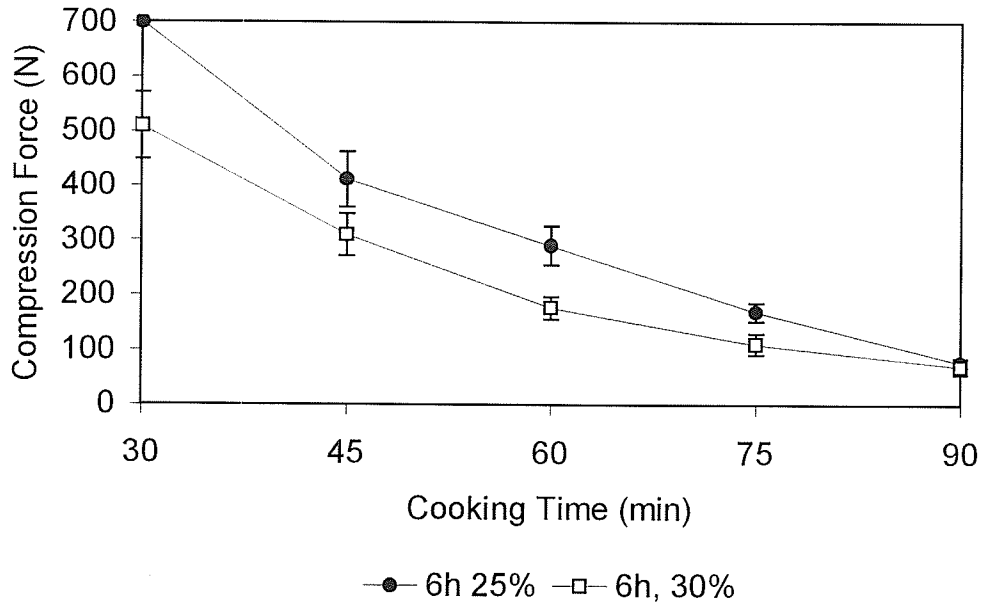


A. Compression Force Cooking Curve

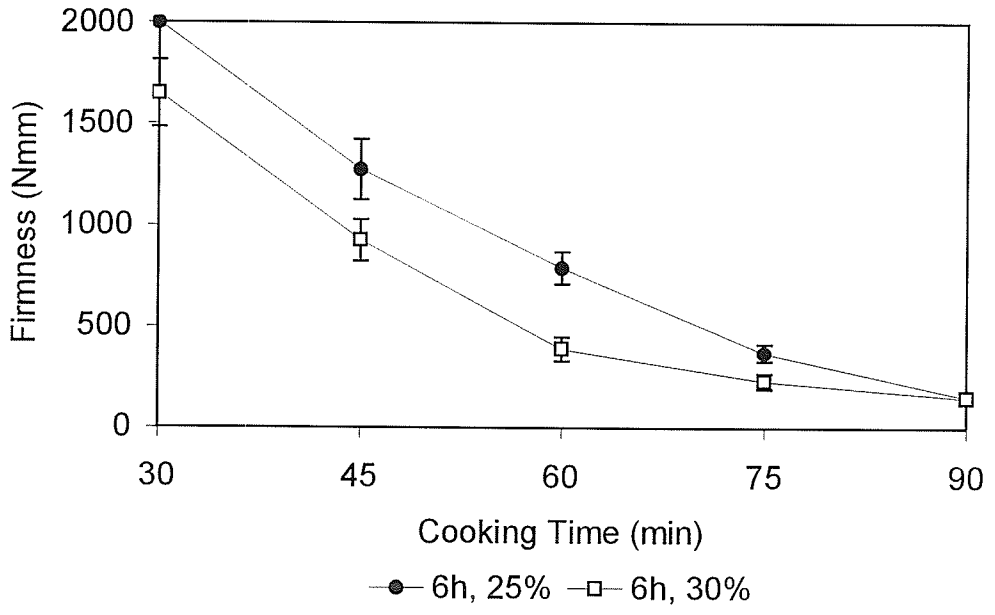


B. Firmness Cooking Curve

Figure 11. Compression force (A) and firmness (B) cooking curves for micronized green peas tempered for 6 h to 25 and 30% moisture with distilled water. Standard deviation is indicated by the error bars.



A. Compression Force Cooking Curve



B. Firmness Cooking Curve

Figure 12. Compression force (A) and firmness (B) cooking curves for micronized yellow peas tempered for 6 h to 25 and 30% moisture with distilled water. Standard deviation is indicated by the error bars.

16B), and a greater reduction in soluble protein (Figure 9B) and RF pectin (Table 16C). The combination of these results translated into lower CF and F values compared to yellow peas tempered for 20 h and to 20% moisture.

In the cooking curves for micronized green and yellow peas (Figures 11 and 12), the 30% tempering level had lower CF and F results for the entire cooking time. The F cooking curve for micronized green peas tempered to 30% moisture (Figure 11B) shows that after 75 min of cooking, the texture leveled off (413.2 Nmm). The cooking curve was considered to be leveled off after the inflection point between the cooking rates. This rate change is not as apparent in the CF cooking curve nor in the cooking curves for micronizing green peas tempered to 25% moisture. As mentioned earlier, the expert panel did not conclusively find a maximum acceptable texture measurement for green peas. Therefore, the cooking time at which the texture of peas tempered to 30% moisture began to level off, i.e. 75 min, was chosen for cooking future micronized green peas. Both the CF and F cooking curves of micronized yellow peas show the texture leveling off after 60 min of cooking. This corresponds to a CF of 176.4 N and a F of 387.7 Nmm. Although these CF and F values are higher than the maximum acceptable determined by the expert panel (CF = 125 N; F = 292 Nmm), it was decided that a cooking time of 60 min would be used for future micronized peas. This is because 60 min appears to be the critical time for yellow pea softening.

4.4.5 THEORETICAL SEED MOISTURE DISTRIBUTION

Because of concerns over the water distribution within the seed after tempering to 30% moisture for 6 h, a study was done to see whether moisture equilibrium could be reached in raw green and yellow peas after tempering to the chosen parameters. Equations describing the drying of a single sphere were used to calculated the moisture at three points within the seed: the centre, the midpoint between the centre and surface; and the surface (Pabis *et al.*, 1998). However, before we could do this, several assumptions were made: the pea was considered to be a perfect sphere; initially, before tempering, moisture content was uniformly distributed throughout the pea; during tempering, moisture on the surface of the peas was always available; and the moisture was uniformly absorbed and diffused in individual layers throughout the seed. Thus, the hydration of the peas was not affected by the seed coat, the seed constituents and the chemical composition. Not everyone agrees with these assumptions (Tang and Sokansanj, 1993), but they are tenable for the purpose of measuring the theoretical moisture distribution within the pea.

The average moisture ratio of the whole pea at a given time θ can be determined as (Pabis *et al.*, 1998):

$$MR(\theta) = \frac{M(\theta) - M_{\Omega}}{M_{\omega} - M_{\Omega}} \qquad (2)$$

where MR(θ) is the moisture ratio at a specific time, decimal
M(θ) is the moisture at time θ (%)
M_e is the equilibrium moisture content (%)
M_o is the initial moisture content (%)

For a spherical object, this moisture ratio can be described as a function of a Fourier number (Pabis, *et al.*, 1998):

$$MR(0) = \frac{6}{\pi^{\theta}} \sum_{n=1}^{\infty} \frac{1}{n^{\theta}} \exp(-n^{0}\pi^{0} Fo_{\gamma}) \qquad (3)$$

where Fo_m is the Fourier number for mass transfer [$Fo_m = (D_m\theta)/R^2$], non-dimensional
D_m is the diffusion coefficient (m^2/min)
R is the radius of a sphere (m)

Equation 3 can be simplified to one term because the diffusion effect after the first two hours, not the initial effect, is desired. Thus, simplifying equation 3 and substituting the Fourier number, the moisture ratio can be described as:

$$MR(\theta) = \frac{6}{\pi^{\theta}} \exp(-\pi^{\theta} \frac{D_{\gamma}\theta}{R^{\theta}}) \qquad (4)$$

From the above equation, a diffusion coefficient is determined, which is needed for determining the theoretical moisture content at a specific time (θ) along the sphere radius:

$$D_{\gamma} = \frac{-R^{\theta}}{\pi^{\theta}\theta} \ln(\frac{MR(\theta)\pi^{\theta}}{6}) \qquad (5)$$

Thus, the diffusion coefficient can be calculated based on results found in Appendix 4. The measured average moisture increase was used in this equation. It was also assumed that over time, the absorbed moisture was not lost to the surroundings. The initial moisture used in these calculations for green peas was 13.9% and for yellow peas was 12.4%.

Figure 13A shows that as the moisture content changes, the diffusion coefficient also changes. However, because the peas are not a homogeneous product or a perfect sphere, and that equation 4 was simplified to one term (equation 5), this variation was expected.

Once the diffusion coefficient was calculated, similar equations were used to determine the theoretical moisture content distribution along the sphere radius at time θ. Thus, equation 6 gives the theoretical moisture ratio at a specific point along the sphere radius and at a specific time (Pabis *et al.*, 1998):

$$MR(r,\theta) = \frac{2R}{\pi r}\sum_{n=1}^{\infty}(-1)^{\varphi+\Theta}\left(\frac{\sin(\frac{\varphi\pi'}{\psi})}{n}\right)\exp\left(-n^{\theta}\pi^{\theta}\frac{D_r\theta}{R^{\theta}}\right) \qquad (6)$$

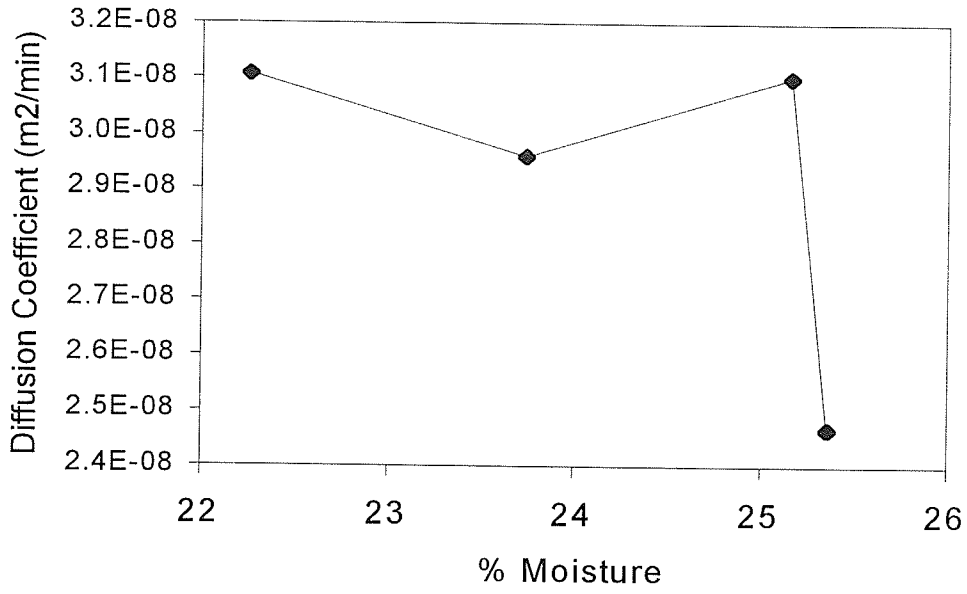
where MR(r,θ) is the moisture ratio at a specific location and time, decimal
r is the specified radius (m)
R is the radius of the sphere (m)
θ is the time (min)
D_m is the diffusion coefficient (m^2/min)

Again, as the initial couple terms of absorption can be ignored, equation 6 can be simplified to one term to give equation 7:

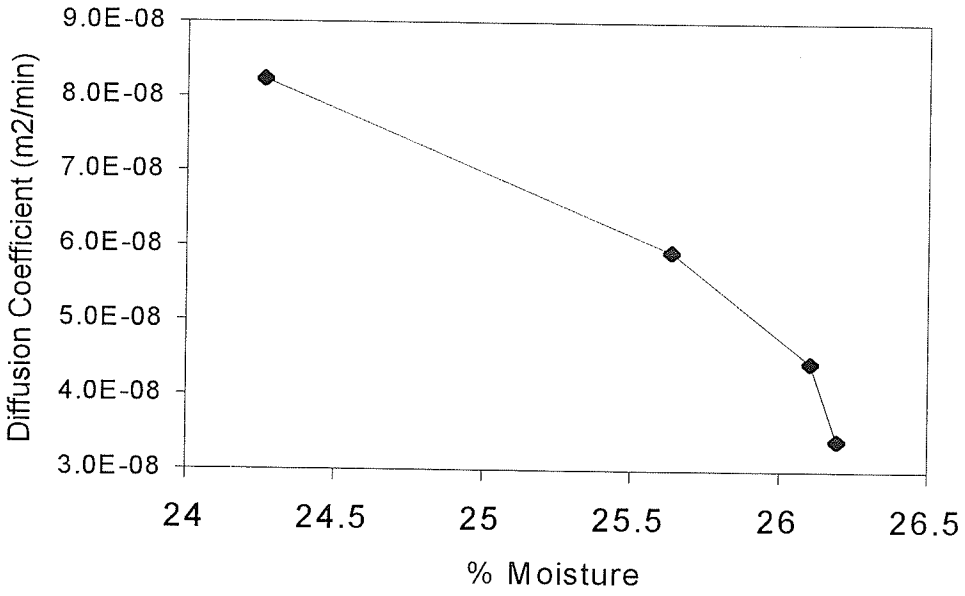
$$MR(r,\theta) = \frac{2R}{\pi r}\sin\left(\frac{\pi r}{R}\right)\exp\left(-\pi^{\theta}\frac{D_r\theta}{r^{\theta}}\right) \qquad (7)$$

Once the moisture ratio for a specific location and time is calculated, the moisture at that location and time can be calculated using equation 7:

$$M(r,\theta) = MR(r,\theta)[M_{\omega} - M_{\Omega}] + M_{\Omega} \qquad (8)$$



A. Green Peas



B. Yellow Peas

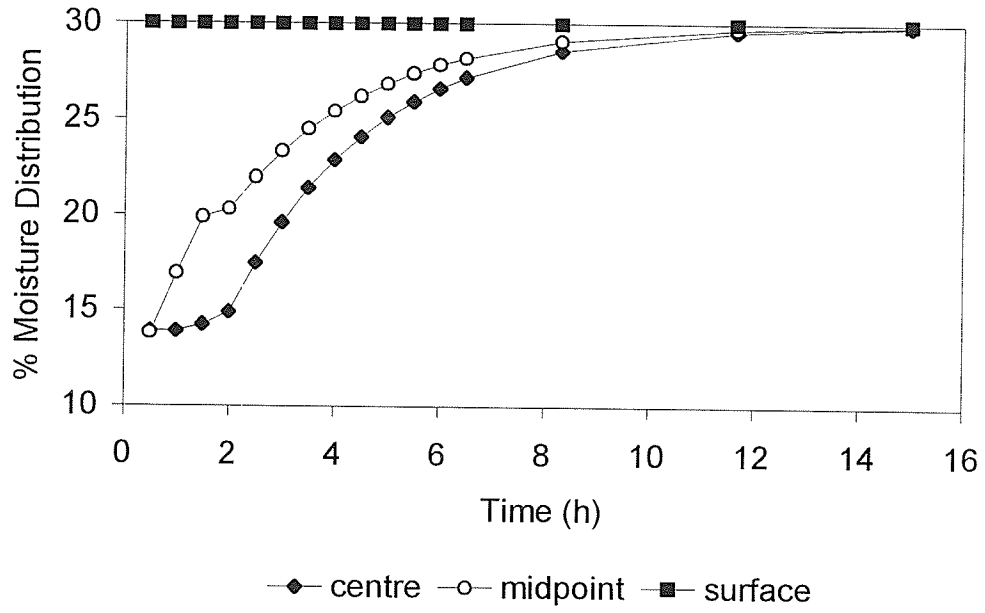
Figure 13. The diffusion coefficient calculated from equation 5 for green (A) and yellow (B) peas tempered for 15 h to 30% moisture.

where $M(r,\theta)$ is the moisture at a specific location and time (%)
M_o is the initial moisture content (%)
M_e is the equilibrium moisture content (%)

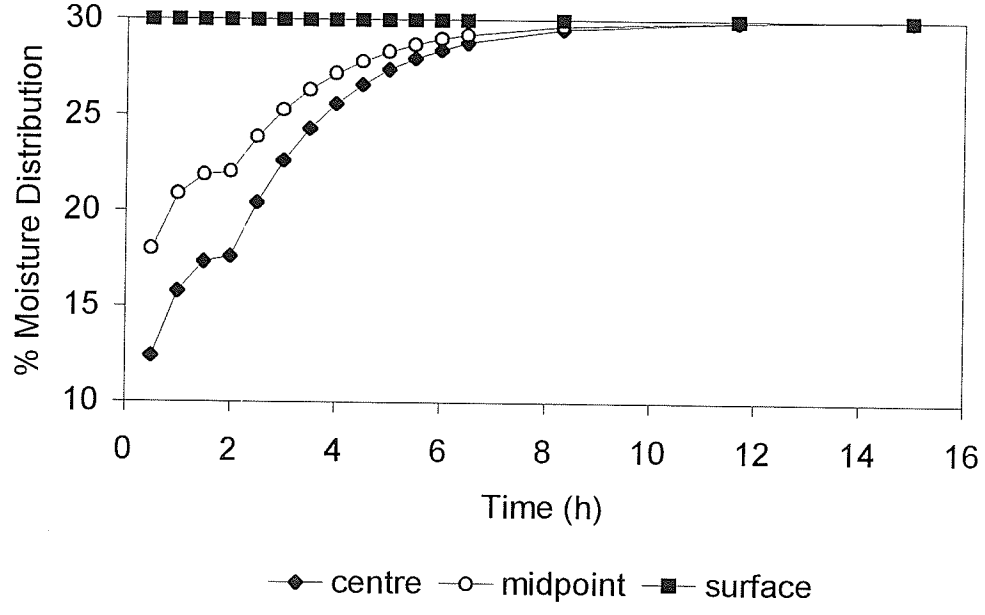
Figure 14 shows the calculated moisture changes over time at three points along the sphere radius from 0.5 to 15 h for both green (Figure 14A) and yellow (Figure 14B) peas. After 6 h of tempering, yellow peas had a more uniform theoretical moisture distribution that approached 30% moisture than the green peas. Interestingly, even though the green peas had a higher initial moisture content, the yellow peas absorbed water faster and reached equilibrium sooner (green peas: 15 h; yellow peas: 12 h). This was also demonstrated by the larger diffusion coefficient of yellow peas than green peas. Perhaps yellow peas have a more porous structure and more permeable seed coat than the green peas, which would allow moisture to enter and equilibrate through the seed at a faster rate. Although, complete theoretical water distribution throughout the seeds did not occur by 6 h, the moisture level at the centre of both green and yellow peas was greater than 27%.

When this information was put into context of the texture, gelatinized starch, soluble protein and pectin results, tempering green peas for 6 h gave higher gelatinized starch, and lower soluble protein, HM, LM and RF values than tempering for 20 h. This, however, did not lead to differences in the texture scores. Perhaps the higher moisture level in the outer layers of the micronized green peas tempered to 30% for 6 h permitted greater solubilization of pectin rather than starch gelatinization and reduced protein solubility.

Tempering yellow peas to 30% for 6 h gave higher gelatinized starch, HM, and LM values, and lower soluble protein and RF values than tempering for 20 h. This led to lower texture scores for yellow peas tempered to 30% for 6 h. Even though after tempering for



A. Green Peas



B. Yellow Peas

Figure 14. The theoretical moisture distribution calculated with equations 7 and 8 for green (A) and yellow (B) peas measured at the centre (0.5 mm from the centre), midpoint (3.1 mm from the centre) and outer surface (6.3 mm from the centre) of the seed.

6 h, the moisture did not fully penetrate into the middle of the seed where the starch is concentrated, the texture indicates shorter cooking times. Perhaps pectin and protein solubilization have a greater influence on the texture than starch solubilization and gelatinization.

4.5 Effect of Tempering Solutions on Micronized Green and Yellow Peas

After the optimal tempering conditions were established (tempering time of 6 h; tempering level of 30% moisture), various solutions (Table 17) were evaluated in terms of their ability to change the quality aspects, to decrease the cooking time and to reduce the ANF level. Sample texture, based on a set cooking time, was compared to the maximum acceptable texture measurements (CF = 125 N; F = 292 Nmm) determined by an expert panel. Samples with texture values less than this limit did not require the full cooking time. Therefore, they could be cooked for a shorter time. The chemical composition of the micronized peas was also measured to determine which component(s) contributed to a softer texture.

The results for treatment 1 in Tables 18, 20-24 and Figures 13-16 can also be found in Section 4.4: Effect of Tempering Level and Time on Micronized Green and Yellow Peas. They are included here for comparison purposes.

The pHs of the solutions used in this section are also given in Table 17. Four of the tempering solutions (1, 2, 5 and 7) were slightly acidic, one (6) was very acidic and five (3, 4, 8, 9 and 10) were alkaline. Both the use of organic acid and calcium chloride in soaking solutions have been shown to help improve the colour and firmness of canned rehydrated dry

beans (Sevilla & Luh, 1974; Luh *et al.*, 1975; Junek *et al.*, 1980). When treatment 4 (sodium tripolyphosphate) was used to temper the peas, a white residue was left on the pea surface. As a way to remove this residue, the peas were washed with 10 L of distilled water (treatment 8) just before micronization.

Table 17. The pH values of the tempering solutions used to temper green and yellow peas for 6 h to 30% moisture before micronization

Treatment	Tempering Solution	pH
1	distilled water	6.08
2	150 ppm disodium EDTA	5.37
3	0.06% sodium carbonate + 0.2% sodium bicarbonate	9.43
4	2% sodium tripolyphosphate	9.14
5	2% sodium chloride	6.19
6	1% citric acid + 2% ascorbic acid	2.86
7	0.5% calcium chloride	5.87
8	2% sodium tripolyphosphate; washed with 10 L distilled water	9.14
9	0.2% sodium bicarbonate + 0.1% sodium carbonate + 0.1% sodium phosphate dihydrate	9.91
10	2.5% sodium chloride + 0.5% sodium carbonate + 1.5% sodium bicarbonate + 1.0% sodium tripolyphosphate	8.34

4.5.1 Residual Moisture

The residual moisture levels for both green and yellow peas tempered for 6 h to 30% moisture in various solutions (Table 18) ranged from 18.01 to 20.49% (green peas) and from 16.48 to 18.87% (yellow peas). These residual moisture levels are considered too high for extended storage. It is interesting to note that yellow peas had consistently lower residual

moisture levels. This is because micronized yellow peas were collected at higher surface temperatures (92.5-97.5°C) than the green peas (80-85°C), and were thus exposed to greater amounts of IR radiation. This caused more water to evaporate from the seeds. McCurdy (1992) reported greater moisture loss for peas and canola after micronization at higher collecting temperatures. As expected, green and yellow peas washed with distilled water immediately before micronization (treatment 8) had the highest residual moisture level. During micronization of this treatment, the water needed to be removed from both the interior and surface of the peas, whereas with other treatments, the water just needed to be removed from the interior.

Table 18. Moisture remaining [1] in micronized green and yellow field peas tempered for 6 h at 30% moisture with various solutions [2]

Treatment No. [3]	% Moisture (Green Peas) [4]	% Moisture (Yellow Peas)[4]
1	20.37 ± 0.05 [a]	18.87 ± 0.05 [a]
2	19.22 ± 0.13 [d]	18.42 ± 0.14 [b]
3	18.01 ± 0.01 [g]	17.96 ± 0.01 [c]
4	18.99 ± 0.02 [e]	16.67 ± 0.07 [fg]
5	19.36 ± 0.00 [d]	17.52 ± 0.04 [d]
6	18.23 ± 0.02 [f]	16.97 ± 0.02 [e]
7	19.20 ± 0.03 [d]	17.82 ± 0.04 [c]
8	20.49 ± 0.09 [a]	18.77 ± 0.08 [a]
9	19.72 ± 0.10 [c]	16.79 ± 0.02 [ef]
10	19.99 ± 0.05 [b]	16.48 ± 0.07 [g]

[1] mean ± standard deviation
[2] see Table 17 for list of tempering solutions
[3] see Table 11 (green peas) and Table 12 (yellow peas) for % Moisture remaining after micronizing Treatment 1 (tempered for 6 h to 30% Moisture)
[4] different letters in the same column indicate significant differences ($P \leq 0.05$)

Although the differences in residual moisture levels were significant for the treatments applied to both green and yellow peas, a maximum of only 2.5% separated the lowest residual moisture level from the highest. This suggests that in practical terms, the tempering solution does not dictate the residual water level of the micronized peas; rather, other factors, such as tempering level, room environmental conditions and vibrating bed temperature, may be more influential.

4.5.2 Ash

The ash content (Table 19) of all micronized green peas tempered in various solutions (2.49-3.65% ash) is greater than the ash content for raw green peas (2.38%). This agrees with Igbasan and Guenter (1996) who found that micronized peas had a higher ash content. The lowest increase in ash content was for the micronized green peas tempered without added salts: distilled water (treatment 1; 2.49% ash) and citric/ascorbic acid (treatment 6; 2.49% ash). Treatment 10 had the largest increase (53% increase) in ash content, which corresponds to that solution having the largest amount of salt added (total of 5.5% salt). Treatments 4 and 5 (2% sodium tripolyphosphate and 2% NaCl respectively) had a 24% increase in the ash content (2.94% ash). Green peas tempered with treatment 8 had a lower ash content (2.56% ash) than those tempered with treatment 4 (2.94% ash). This difference occurred because sodium tripolyphosphate did not absorb into the seed as well as other salts. This was observed as a white powdery residue on the surface of the green peas. Thus, when the seed was washed (treatment 8), some of the salt was also removed, resulting in a lower ash content.

Table 19. Percent ash (DM) [1] for micronized green and yellow peas tempered for 6 h to 30% moisture with various solutions [2]

Treatment	% Ash DM (Green Peas) [3]	% Ash DM (Yellow Peas) [3]
1	2.49 ± 0.00 [f]	2.93 ± 0.01 [c]
2	2.56 ± 0.00 [e]	2.75 ± 0.00 [de]
3	2.61 ± 0.02 [d]	2.76 ± 0.01 [de]
4	2.94 ± 0.01 [b]	3.06 ± 0.04 [b]
5	2.94 ± 0.01 [b]	3.03 ± 0.04 [b]
6	2.49 ± 0.00 [f]	2.72 ± 0.04 [e]
7	2.56 ± 0.00 [e]	2.82 ± 0.02 [d]
8	2.51 ± 0.01 [f]	3.01 ± 0.01 [b]
9	2.67 ± 0.00 [c]	2.74 ± 0.00 [e]
10	3.65 ± 0.00 [a]	3.44 ± 0.02 [a]

[1] mean ± standard deviation
[2] see Table 17 for list of tempering solutions
[3] different letters in the same column indicate significant differences ($P \leq 0.05$)

The ash levels (Table 19) of micronized yellow peas tempered with various solutions (2.72-3.44% ash) were not always greater than that for raw yellow peas (2.91%). Treatments 1, 2, 3, 6, 7 and 9 gave ash levels less than or equal to that of raw peas. This lower ash content may have occurred because the seed coats and cotyledons of many yellow peas were separated during micronization. This could have then resulted in non-representative sampling for ash. Tempering solutions that had at least 2% salt added (treatments 4, 5, 8 and 10) had more ash that the raw peas. Treatment 10 had the largest increase in ash content (3.44% ash), followed by treatments 4 and 5 (3.06% and 3.03% ash

respectively). As with the green peas, washing prior to micronization (treatment 8) reduced the ash level.

Although the differences in percent ash were significant for treatments applied to both green and yellow micronized peas tempered in various solutions, the percent ash ranges were only 1.16% for green peas and 0.72% for yellow peas. All these ash values are also well within the range of 2.4-4.0% found in literature (Deshpande & Damodaran, 1990; Igbasan *et al.*, 1997; Bastianelli *et al.*, 1998). Thus, in practical terms, none of the tempering solutions altered the ash level beyond the normal range.

4.5.3 HunterLab Colour

Colour of the green and yellow peas (Tables 20 and 21 respectively) was measured on the whole micronized peas. A HunterLab Colorimeter (L = lightness/brightness; +a = redness; -a = greenness; +b = yellowness; -b = blueness) was used to measure the colour.

Overall, the micronized green peas tempered with various solutions were all lighter (i.e. higher L values), less green (i.e. higher -a values) and less yellow (i.e. lower +b values) than the raw green peas (L = 47.6; a = -3.8; b = 11.3). The loss of greenness may be from the degradation of chlorophyll, which occurs during processing and is dependant on temperature and pH (Hayakawa & Timbers, 1977; Mazza & Oomah, 1994).

Treatment 4 gave the lightest green peas (L = 54.7), followed by treatment 8 (L = 51.9). These high L values are probably the result of sodium tripolyphosphate residue on the outer surface of the peas. This white residue also reduce the greenness (treatment 4: a = -2.6; treatment 8: a = -3.2) and yellowness (treatment 4: b = 8.4; treatment 8: b = 9.5) by

covering up the actual colour of the peas. The washing step used in treatment 8 removed some of the white residue, which accounts for "Lab" values that are closer to the raw values than treatment 4.

Table 20. Hunter colorimeter values [1] for green micronized field peas tempered for 6 h to 30 % moisture with various solutions [2]

Treatment [3]	L [4]	a [4]	b [4]
2	48.5 ± 0.3 [e]	-3.6 ± 0.2 [e]	10.8 ± 0.2 [c]
3	48.7 ± 0.2 [e]	-3.4 ± 0.1 [d]	11.0 ± 0.1 [b]
4	54.7 ± 0.2 [a]	-2.6 ± 0.1 [b]	8.4 ± 0.1 [i]
5	48.6 ± 0.2 [e]	-3.5 ± 0.2 [d]	10.2 ± 0.2 [d]
6	48.4 ± 0.4 [e]	-2.4 ± 0.1 [a]	11.7 ± 0.1 [a]
7	49.3 ± 0.3 [d]	-3.4 ± 0.1 [d]	9.3 ± 0.1 [g]
8	51.9 ± 0.3 [b]	-3.2 ± 0.1 [c]	9.5 ± 0.1 [f]
9	49.8 ± 0.3 [c]	-3.2 ± 0.1 [c]	9.7 ± 0.1 [e]
10	49.8 ± 0.2 [c]	-2.5 ± 0.1 [ab]	8.8 ± 0.1 [h]

[1] mean ± standard deviation
[2] see Table 17 for list of tempering solutions
[3] Treatment 1 became moldy before colour analysis could be done
[4] different letters in the same column indicate significant differences ($P \leq 0.05$)

Treatment 6 (citric/ascorbic acid) produced the darkest (L = 48.4), most red (a = -2.4) and most yellow (b = 11.7) micronized green peas. When these peas were visually examined, a brown ring was seen in the seed coat at the juncture of the cotyledon halves. Perhaps during the tempering and micronization steps, chemical reactions enhanced by the low pH caused the colour changes. McCurdy *et al.* (1983) also found that peas soaked in citric acid were less green and more yellow than those soaked in distilled water or NaCl. These researchers, however, did not mention the appearance of a brown ring. Perhaps that

is a reaction with ascorbic acid rather than citric acid. When the citric/ascorbic acid tempering solution was used by Scanlon *et al.* (1998) to temper lentils to 20 and 40% moisture, they did not find an effect on the lentil appearance. This may be because the lentils used were dark and they differ in chemical composition from peas.

Scanlon *et al.* (1998) found that tempering lentils in sodium carbonate/bicarbonate tempering solution (treatment 3) produced dark brown spots. When this solution was used for green peas, the peas had a high "b" value (11.0), which suggests that browning may have ccurred. Al-Nouri & Siddiqi (1982) also found that soaking broad beans with sodium carbonate or bicarbonate caused discolouration, but soaking broad beans in a mixture of sodium carbonate, sodium bicarbonate, and sodium phosphate dihydrate (treatment 9) did not cause as much discolouration. The colour values obtained for treatment 9 agree with these results.

When sodium carbonate and sodium bicarbonate were used at higher concentrations in treatment 10 along with NaCl and sodium tripolyphosphate, the micronized green peas had the second highest "a" value and the second lowest "b" value; i.e., they were less green and yellow than most other micronized green peas. When this solution was used by Iyer *et al.* (1980) to soak pinto, kidney and Great Northern beans, they also found that the redness increased and the yellowness decreased.

As with the green peas, applying treatments 4 and 8 to yellow peas produced a white powdery residue on the outer surface that contributed to give the lightest (L = 59.4 for both) and greenest (a = 2.9 for both) yellow peas (Table 21). Treatment 4 was also the least yellow (treatment 4: b = 13.2; treatment 8: b = 14.4 respectively). Unlike the green peas,

the yellow peas tempered in treatment 3 (sodium carbonate/bicarbonate), 6 (acids), 9 (sodium carbonate, sodium bicarbonate and sodium phosphate dihydrate) and 10 (sodium carbonate, sodium bicarbonate, sodium tripolyphosphate and sodium chloride) were darker than the raw peas (raw peas: L = 55.2). Three of these treatments (2, 9 and 10) were also slightly greener and less yellow than the raw. Perhaps the salts used here caused some discolouration that was not as noticeable in the yellow-blue plane as it was in the lightness plane. The acid treatment (6) gave the darkest (L = 50.5), reddest (a = 3.8) and yellowest (b = 15.2) yellow peas. As with the green peas, a brown ring was seen in the seed coat at the juncture of the cotyledon halves.

Table 21. Hunter colorimeter values [1] for yellow micronized field peas tempered for 6 h to 30 % moisture with various solutions [2]

Treatment [3]	L [4]	a [4]	b [4]
2	55.5 ± 0.2 [b]	3.1 ± 0.1 [bc]	14.3 ± 0.1 [b]
3	54.0 ± 0.4 [bc]	3.0 ± 0.2 [cde]	14.2 ± 0.1 [bc]
4	59.4 ± 0.1 [a]	2.9 ± 0.1 [e]	13.2 ± 0.1 [d]
5	54.8 ± 0.2 [b]	3.1 ± 0.1 [bcd]	14.3 ± 0.2 [b]
6	50.5 ± 0.3 [d]	3.8 ± 0.1 [a]	15.2 ± 0.2 [a]
7	54.9 ± 0.2 [b]	3.0 ± 0.1 [cde]	13.3 ± 0.2 [d]
8	59.4 ± 4.7 [a]	3.2 ± 0.1 [b]	14.4 ± 0.1 [b]
9	53.6 ± 0.2 [bc]	2.9 ± 0.1 [e]	14.0 ± 0.1 [c]
10	52.7 ± 0.4 [c]	2.9 ± 0.0 [de]	13.3 ± 0.2 [d]

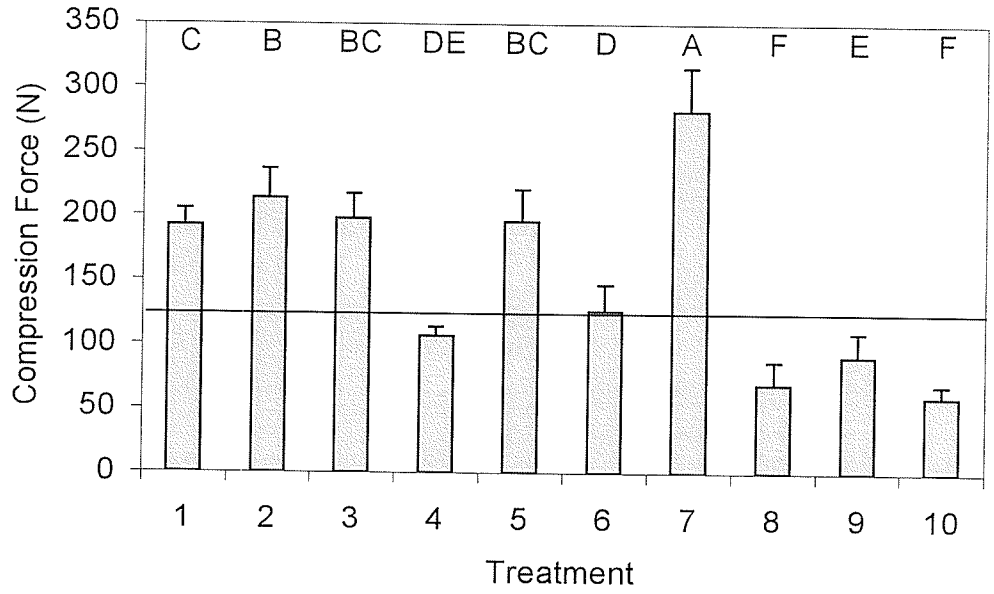
[1] mean ± standard deviation
[2] see Table 17 for list of tempering solutions
[3] Treatment 1 became moldy before colour analysis could be done
[4] different letters in the same column indicate significant differences ($P \leq 0.05$)

4.5.4 TEXTURE

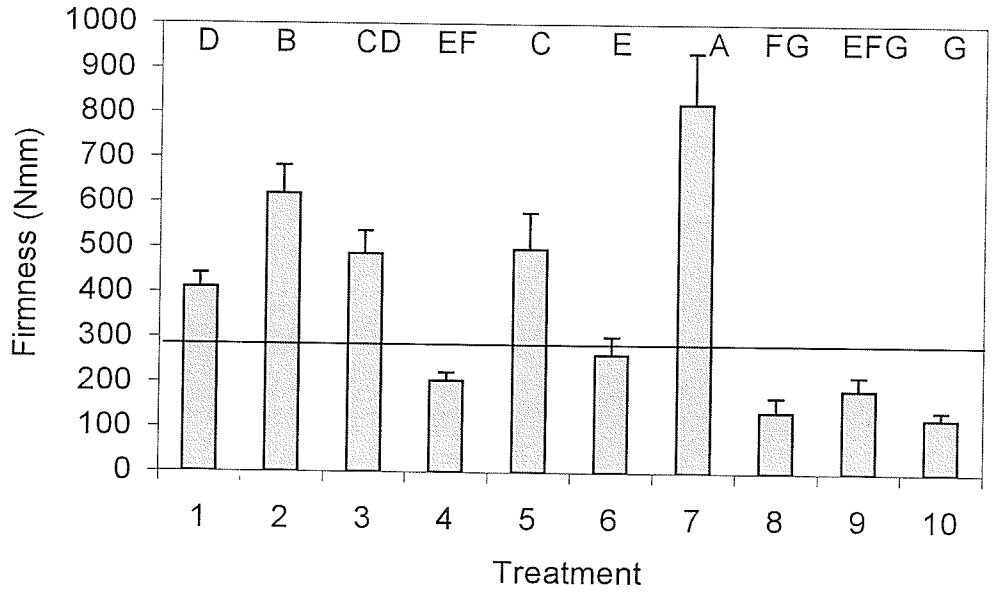
Figures 15 (green peas) and 16 (yellow peas) show the texture results for micronized peas tempered in various solutions. Green peas were cooked for 75 min, while yellow peas were cooked for 60 min prior to texture analysis. The type of solution used had a significant effect on both texture measurements.

As expected, treatment 7 (calcium chloride) gave the highest CF and F values for green (CF = 281.6 N; F = 821.0 Nmm) and yellow (CF = 288.2 N; F = 960.3 Nmm) peas. Calcium chloride (treatment 7) is typically used to soak dry peas before canning as a way to reduce turbidity in the brine and maintain an intact whole pea in the finished product (McCurdy *et al.*, 1983; Drake & Muehlbauer, 1985). It is thought that the calcium ions are chelated by pectic substances to form rigid structures, which cause an increase in the shear force (McCurdy *et al.*, 1983; Garcia-Vela *et al.*, 1991; Hentges *et al.*, 1991). This then reduces the migration of soluble components out of the peas and into the brine (Uzogara *et al.*, 1990). Clearly the intact peas resulting from this treatment also required more time to cook.

Also, as expected, treatments 9 (low concentrations of sodium salts) and 10 (high concentrations of sodium salts) gave low CF and F values for green (CF = 91.1 N and 59.2 N respectively; F = 187.3 Nmm and 121.6 Nmm respectively) peas, while only treatment 10 reduced the texture below the maximum acceptable values for yellow peas (CF = 165.7 N and 100.4 N respectively; F = 359.3 Nmm and 215.0 Nmm respectively). As mentioned in the literature review (Section 2.3.1.1), many researchers have found that adding sodium salts to the soaking/tempering solution increases the water absorption, which then reduces the

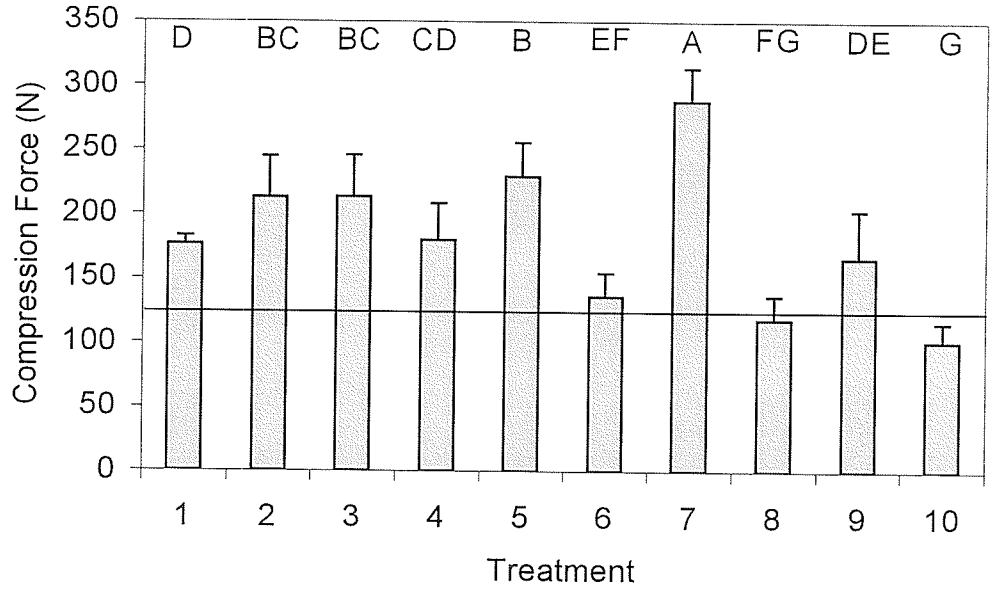


A. Compression Force

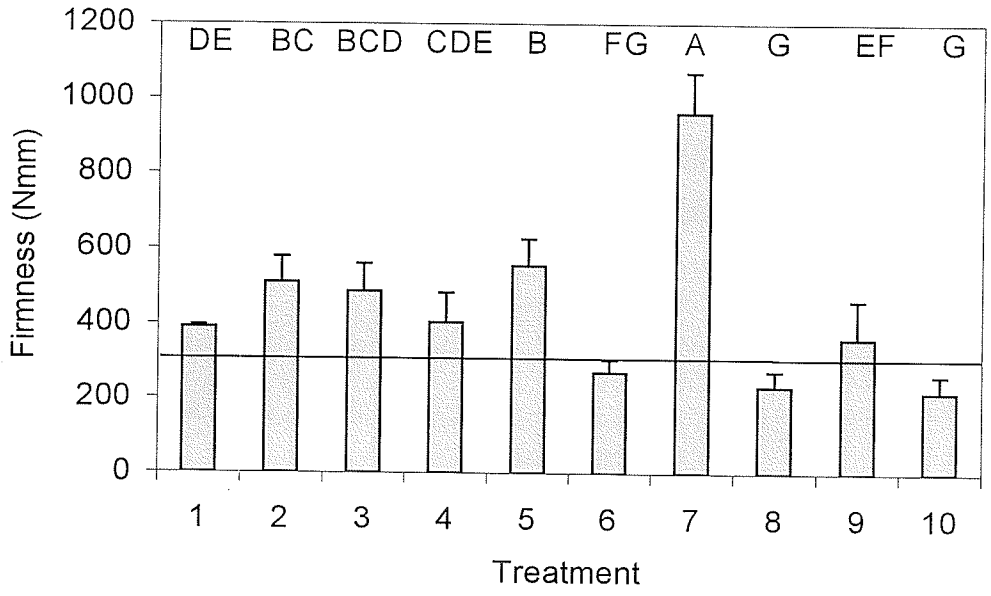


B. Firmness

Figure 15. The compression force (A) and firmness (B) of micronized green peas tempered for 6 h to 30% moisture with various solutions. A list of tempering treatments can be found in Table 17. These peas were cooked for 75 min before texture analysis. Treatment 1 can also be found in Figure 11. The horizontal line indicates the maximum acceptable texture measurement determined by an expert panel. Different letters above the treatments indicate significant differences ($P<0.05$). Standard deviation is indicated by the error bars.



A. Compression Force



B. Firmness

Figure 16. The compression force (A) and firmness (B) of micronized yellow peas tempered for 6 h to 30% moisture with various solutions. A list of tempering solutions can be found in Table 17. These peas were cooked for 60 min before texture analysis. Treatment 1 can also be found in Figure 12. The horizontal line indicates the maximum acceptable texture measurement determined by an expert panel. Different letters above the treatments indicate significant differences ($P<0.05$). Standard deviation is indicated by the error bars.

texture of cooked legumes. Garcia-Vela *et al.* (1991) suggested that a higher ionic strength of sodium would promote softer beans. Treatment 10 has the highest sodium concentration and it gave the lowest texture values for both green and yellow peas.

The use of treatments 8 and 4 on green peas also gave CF (68.7 N and 106.9 N respectively) and F (135.7 Nmm and 205.0 Nmm respectively) values that were below that which the expert panel deemed to be the maximum acceptable (CF = 125 N; F = 292 Nmm). Rockland and Metzler (1967) and Black *et al.* (1998b) also found that sodium tripolyphosphate (treatments 4 and 8) reduced the cooking time of field peas and increased the softness of beans. Interestingly, the washed peas (treatment 8) had a lower texture than the unwashed peas (treatment 4). Perhaps the high residual moisture level for treatment 8 contributed to the low texture by increasing the availability of water for *in situ* chemical component modifications, such as starch gelatinization and component solubilization. This trend was also true for the yellow peas, in that treatment 8 had lower CF (118.0 N) and F (230.7 Nmm) values than treatment 4 (CF = 179.5 N; F = 402.1 Nmm). Only treatment 8 lowered the texture below the maximum acceptable level for yellow peas.

Treatment 6 (acids) gave CF and F values that were also near the maximum acceptable texture level of both green (CF = 126.2 N; F = 262.4 Nmm) and yellow (CF = 136.1 N; F = 269.5 Nmm) peas. This is interesting since McCurdy *et al.* (1983) found that the shear force of field peas increased when they were soaked in citric acid, as opposed to distilled water, and Onayemi *et al.* (1986) found that citrate had no effect on the cooking time of cowpeas. Perhaps the combination of using citric and ascorbic acids helped lower

the texture through their chelation and pH effect. Also, McCurdy *et al.* (1983) used a lower concentration (0.25% and 0.5%) of citric acid than what was used here (1% citric acid).

The other four treatments (1: distilled water; 2: disodium EDTA; 3: sodium carbonate and bicarbonate; 5: NaCl) all gave CF and F values that were higher than the maximum acceptable texture level for green and yellow peas.

Various researchers have ranked the ability of salts to reduce the final cooked texture. McCurdy *et al.* (1983) found that 2% NaCl gave the softest peas, followed by distilled water, 0.5% citric acid and 0.5% calcium chloride. Iyer *et al.* (1980) suggest that the sodium mixture (treatment 10) would produce the softest beans followed by 1% sodium tripolyphosphate, 1.5% sodium bicarbonate, 2.5% NaCl and distilled water. Garcia-Vela *et al.* (1991) found that the nature of the anion was more important in determining the texture of soft black beans than the pH or sodium ion, where the carbonate anion was more effective than EDTA, followed by chloride. When these ranked solutions were compared to the ones used here, several discrepancies were found. First of all, the acid mixture was more effective in softening the peas than distilled water or NaCl, unlike what McCurdy *et al.* (1983) suggested. Secondly, NaCl was much less effective than distilled water. This was corroborated by Garcia-Vela *et al.* (1991) who found that NaCl was not an efficient promoter of softening, but it contradicted the results from both Iyer *et al.* (1980) and McCurdy *et al.* (1983). The carbonate mixture was more effective than EDTA and NaCl, but less effective than distilled water. This agrees with Garcia-Vela *et al.* (1991), but not with Iyer *et al.* (1980). Perhaps the micronization process and later cooking have an affect on the seed component-ion interaction that is not encountered when the seeds are just

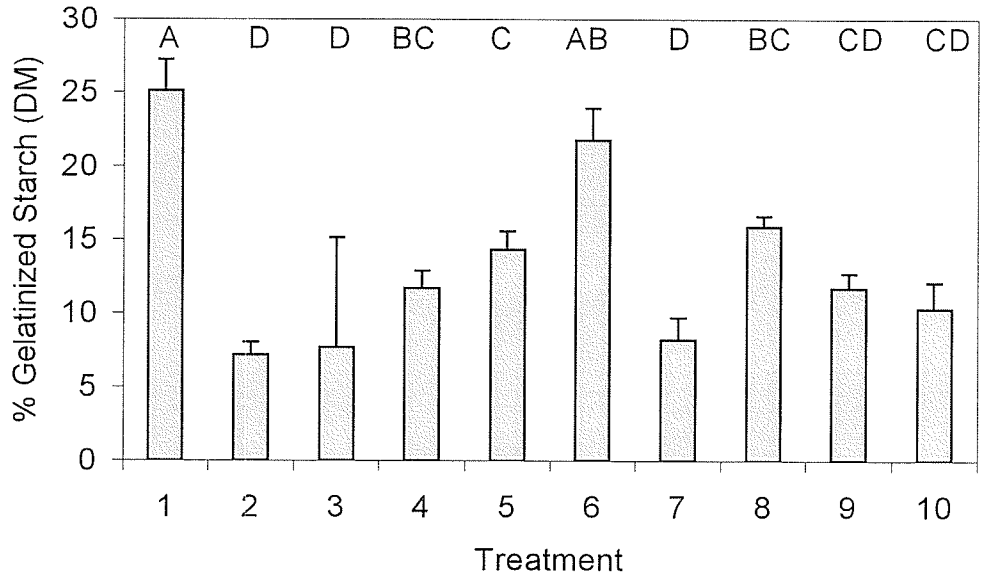
cooked after soaking. Also, the legume type used may give different results for the same solution.

The levels of gelatinized starch, soluble protein and dietary fibre fractions were measured to determine if one or more of these components influence the texture of the micronized peas. Dietary fibre fractions were measured as the overall soluble and insoluble fractions, and as pectin fractions.

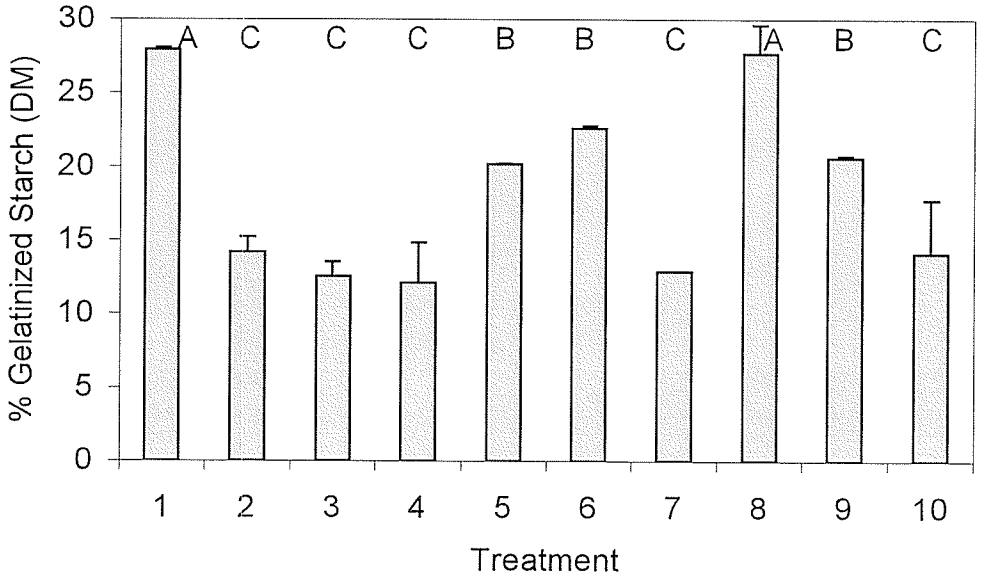
4.5.4.1 Gelatinized Starch. All micronized green peas tempered with the various solutions had a higher degree of starch gelatinization (Figure 17A) than the raw peas (6.79%). Starch gelatinization was also increased for micronized sorghum and corn (Croka and Wagner, 1975; Kouzeh-Kannai *et al.*, 1984; Savage and Clark, 1988).

As expected from the results of the because texture studies, green peas tempered with treatments 2 (disodium EDTA), 3 (sodium carbonate and bicarbonate) and 7 (calcium choride) had the lowest degree of starch gelatinization (7.18%, 7.70% and 8.19% respectively). Also, the phosphate solutions, treatments 4 and 8 (11.7 and 15.9% respectively) gave gelatinized starch levels corresponding to their texture values. Treatment 6 (acids) gave an acceptable texture with a high gelatinized starch level (21.75%). This suggests that the degree of starch gelatinization does influence the texture of micronized green peas.

However, the gelatinized starch level of the peas tempered with treatments 1, 5, 9 and 10 did not have the same influence on the corresponding texture results. Treatment 1 (distilled water) gave the highest degree of starch gelatinization (25.08%), yet this did not translated into a low texture score. In fact, the CF (193.0 N) and F (413.2 Nmm) for this



A. Green Peas



B. Yellow Peas

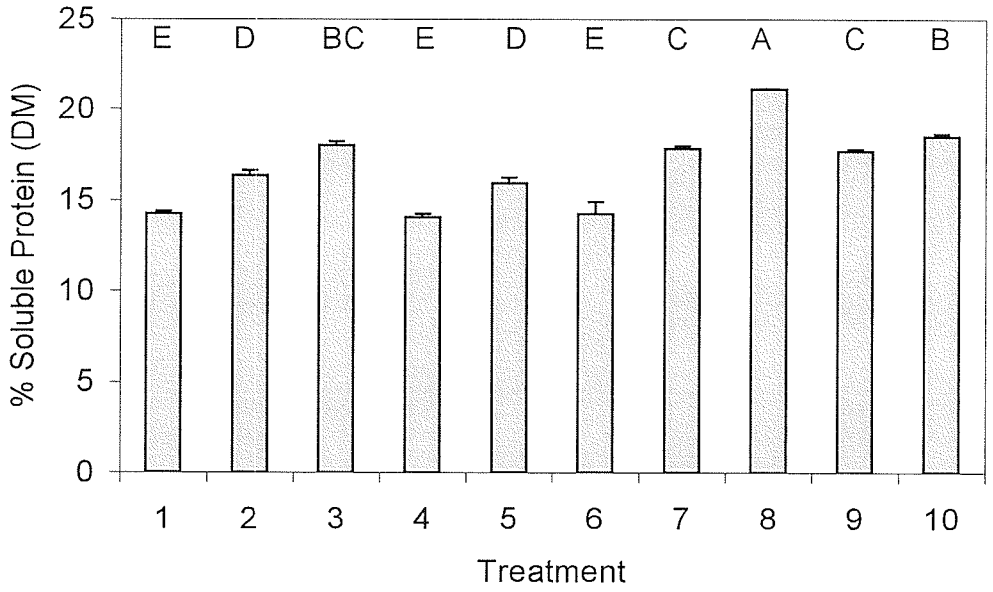
Figure 17. The degree of gelatinized starch for micronized green (A) and yellow (B) peas tempered for 6 h to 30% moisture with various solutions. A list of tempering solutions can be found in Table 17. Treatment 1 can also be found in Figure 8. Different letters above the treatments indicate significant differences ($P<0.05$). Standard deviation is indicated by the error bars.

treatment were higher than the maximum acceptable value determined by the expert panel (CF = 125 N; F = 292 Nmm). Similarly, an acceptable texture was not obtained when green peas were tempered with treatment 5 (NaCl), even though the degree of starch gelatinization was relatively high (14.32%). Finally, treatments 9 (low concentration of sodium salts) and 10 (high concentration of sodium salts) had very low texture results, but only 10-11% gelatinized starch. Thus, other chemical component(s) must have a greater influence on the texture when salts or acids are added to the tempering solution of green peas.

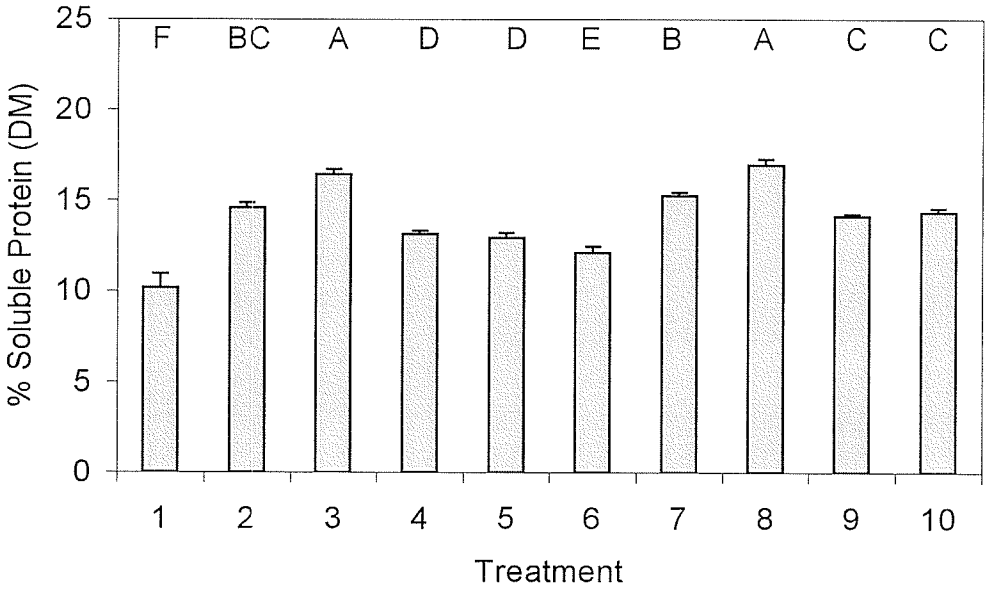
As with the green peas, all micronized yellow peas tempered with various solutions (Figure 17B) had a higher degree of starch gelatinization than the raw peas (7.19%). In section 4.4.2.1, it was determined that the texture and degree of gelatinized starch of micronized yellow peas had a significant ($P<0.05$) negative correlation. Thus, high texture results corresponded with low gelatinized starch levels. This was also the case for yellow peas tempered with treatments 2 (disodium EDTA), 3 (sodium carbonate and bicarbonate), 4 (sodium tripolyphosphate) and 7 (calcium choride). These treatments had high texture results and low gelatinized starch levels (14.14 %, 12.50%, 12.10 % and 12.84 % respectively). Also, the low texture results for treatments 6 (acids) and 8 (sodium tripolyphosphate, washed) corresponded to a high gelatinized starch levels (22.57% and 27.65% respectively). However, the yellow peas treated with treatments 1 (distilled water), 5 (NaCl), 9 (low concentration of sodium salts) and 10 (high concentration of sodium salts) did not seem to follow this pattern. Instead, like the green peas, gelatinized starch levels did not show negative correlations with their texture results. Thus, the texture of yellow peas tempered with various solutions must be influenced by other chemical components.

4.5.4.2 Soluble Protein. All soluble protein levels of micronized green (Figure 18A) and yellow (Figure 18B) peas tempered with various solutions were less than that for raw green (25.07%) and yellow (22.81%) peas, as expected. These reductions ranged from 16% (treatment 8) to 44% (treatments 1, 4 and 6) in green peas and from 26% (treatment 8) to 55% (treatment 1) in yellow peas. Many researchers have found that the solubility of protein diminishes and the coagulation of protein increases after heat treatment (Anonymous, 1979; Kouzeh-Kanani *et al.*, 1981; 1984; Savage and Clark, 1988; McCurdy, 1992; Metussin *et al.*, 1992; South and Ross, 1993; Arntfield *et al.*, 1997; Mustafa *et al.*, 1998; Zheng *et al.*, 1998). It has been reported that higher heat treatments reduce protein solubility more than lower treatments (Kouzeh-Kanani *et al.*, 1981; McCurdy, 1992; Arntfield *et al.*, 1997). This was also found here, where the micronized yellow peas (collected at 92.5-97.5°C) had consistently lower protein solubility than the green peas (collected at 80-85°C).

Douglas *et al.* (1991) and Arntfield *et al.* (1997) suggested that the loss of solubility after micronization was the result of denaturation. Researchers found that certain salts and salt mixtures enhance denaturation after heat treatment by first enhancing the protein's solubility during soaking or tempering (Rockland and Metzler, 1967; El-Tabey Shehata, 1992; Soetrisno and Holmes, 1992). Legume proteins have high levels of acidic and basic amino acids, which enable greater solubility at low and high pH values (Bastianelli *et al.*, 1998; Zheng *et al.*, 1998). By increasing the solubility of the protein during tempering either through pH or salt adjustment, the protein is no longer electrostatically bound to other cell components such as phytic acid salts and cations. Thus, the protein matrix becomes more



A. Green Peas



B. Yellow Peas

Figure 18. The soluble protein level for micronized green (A) and yellow (B) peas tempered for 6 h to 30% moisture with various solutions. A list of tempering solutions can be found in Table 17. Treatment 1 can also be found in Figure 9. Different letters above the treatments indicate significant differences ($P<0.05$). Standard deviation is indicated by the error bars.

porous, which enhances heat penetration into the seed. This can then increase protein denaturation, which is measured as a loss of solubility (El-Tabey Shehata, 1992). The heat-water effect is still valid for starch gelatinization.

As expected, large reductions in protein solubility occurred for treatments 4 (sodium tripolyphosphate: 44% reduction in green peas; 42% reduction in yellow peas) and 6 (acids: 44% reduction in green peas; 47% reduction in yellow peas). These solutions had pHs of 9.14 and 2.86 respectively. The small reduction in protein solubility after tempering with treatment 8, which also had a high pH value, was not as expected, however (21.11% protein for green peas; 16.95% protein for yellow peas). Treatment 8 was identical to treatment 4 except that the peas were washed between the tempering and micronization steps. Perhaps the high surface water level from washing the peas prevented sufficient IR radiation from penetrating into the seed through the porous microstructure. Thus, less protein was denatured.

Soluble protein results were significantly ($P<0.05$) correlated (Tables 22 and 23) with the pH of the tempering solutions ($R^2 = 0.5197$ for green peas; $R^2 = 0.4986$ for yellow peas). This has also been reported by Hulse (1994), who cautioned that higher protein solubility measurements at extreme pH values may be misleading. At these pH levels, proteins may break into smaller protein units, and thus they appear more soluble. Perhaps this is why treatments 3 (sodium carbonate and bicarbonate; pH = 9.43), 7 (calcium chloride; pH = 5.87), 9 (low concentration of sodium salts; pH = 9.91) and 10 (high concentration of sodium salts; pH = 8.34) gave relatively small reductions (green peas: 28%, 29%, 29% and 26% reductions respectively; yellow peas: 28%, 33%, 38% and 37% reductions

Table 22. Correlations [1] between seed components, texture and pH for micronized green peas tempered for 6 h to 30% moisture with various solutions [2]

	SDF	IDF	Residual Moisture	F	CF	Soluble Protein	RF
pH					-0.4494	0.5197	-0.4809
HM	0.8102			-0.5300	-0.5553		
LM		-0.7065	0.5193				
RF	0.6797						
SDF					-0.6201		

[1] $P<0.05$

[2] $n = 20$ for all correlations except SDF ($n = 10$) and IDF ($n = 10$)

Table 23. Correlations [1] between seed components, texture and pH for micronized yellow peas tempered for 6 h to 30% moisture with various solutions [2]

	pH	ash	Residual Moisture	Phytic Acid	LM	CF	F
HM		0.5072	-0.4923			-0.6954	-0.5830
LM				0.5459			
RF	-0.6465	-0.4654					
Soluble Protein	0.4986			-0.4507	-0.5647		
Gelatinized Starch				0.4691	0.5938		
Phytic Acid			0.5902		0.5459		
SDF						-0.6343	

[1] $P<0.05$

[2] $n = 20$ for all correlations except SDF ($n = 10$)

respectively), and treatment 1 (distilled water) gave a large reduction (green peas: 43% reduction; yellow peas: 55% reduction) in soluble protein level. Protein correlations with LM pectin and phytic acid are discussed in the following sections.

El-Tabey Shehata (1992) and Arntfield *et al.* (1997) have suggested that the loss of protein solubility is related to a softer textured product because the rigid, compact protein matrix has been opened into a more porous structure. When the soluble protein results for both green and yellow peas are compared with their texture results, very little is as expected. Low texture results for peas tempered with treatments 4 (sodium tripolyphosphate), 6 (acids), 8 (sodium tripolyphosphate, washed), 9 (low concentration of sodium salts) and 10 (high concentration of sodium salts) did not correspond consistently to low soluble protein or high soluble protein levels for the same treatments, as would be expected based on their extreme pH values. Similarly, high texture results for peas tempered with treatments 2 (disodium EDTA), 5 (NaCl) and 7 (calcium chloride) did not correspond consistently to low or high soluble protein levels. Thus, other seed components must influence the texture of micronized peas.

4.5.4.3 Dietary Fibre and Pectin. The third major component evaluated for its possible effect on the texture of micronized green and yellow peas tempered with various solutions is the dietary fibre. Dietary fibre found mainly in the seed coat and extracellular spaces, is composed of cellulose, hemicellulose, lignin and pectin. For this experiment, both the overall dietary fibre fractions (IDF, SDF and TDF) and the pectin fractions (HM, LM and RF) were evaluated. Dietary fibre was measured for green and yellow peas tempered with treatments 1(distilled water), 5 (NaCl), 6 (acids), 7(calcium chloride) and 10 (high

concentration of sodium salts). These treatments were chosen based on their texture, starch and protein results.

IDF and TDF values for micronized green peas (Table 24) were significantly affected by the tempering treatment. As with the raw peas, IDF consisted of more than 95% of the total dietary fibre. Brunsgaard *et al.* (1994) also found IDF to be the largest component. Generally, the TDF and IDF results for the micronized green peas were lower than the raw values (TDF = 22.14%; IDF = 21.03%). The five tempering solutions significantly affected the IDF and TDF values. Micronized green peas tempered with treatments 6, 7 and 10 had significantly larger IDF values than those tempered with treatments 1 and 5. Similarly, treatments 6, 7 and 10 gave significantly higher TDF values.

Table 24. Percent insoluble, soluble and total dietary fibre (DM) [1] of selected micronized green peas tempered for 6 h to 30% moisture with various solutions [2]

Treatment	% IDF (DM)[3]	% SDF (DM)[3]	% TDF (DM)[3]
1	18.4 ± 0.4 [b]	0.4 ± 0.3 [a]	19.7 ± 0.3 [bc]
5	18.4 ± 0.3 [b]	0.4 ± 0.2 [a]	19.1 ± 0.0 [c]
6	19.1 ± 0.2 [a]	1.1 ± 0.3 [a]	20.2 ± 0.0 [ab]
7	19.4 ± 0.0 [a]	0.5 ± 0.1 [a]	20.5 ± 0.6 [a]
10	19.1 ± 0.3 [a]	0.8 ± 0.1 [a]	20.6 ± 0.0 [a]

[1] mean ± standard deviation
[2] see Table 17 for list of tempering solutions
[3] different letters in the same column indicate significant differences ($P \leq 0.05$)

Treatment 7 gave the highest IDF (19.43%) and second highest TDF (20.50%) values. This treatment also gave the highest texture score. Perhaps the calcium in this solution increased the rigidity of the intercellular spaces by electrostatically binding to pectic substances and lignin (Torre *et al.*, 1992). Treatments 1 and 5 gave the lowest IDF (18.37

and 18.39% respectively) and TDF (19.70 and 19.12% respectively) values. These low values, however, did not promote a texture below the maximum acceptable CF (125 N) and F (292 Nmm), as determined by an expert panel.

Similar to the green peas, IDF was the predominant dietary fibre fraction (>92%) in micronized yellow peas (Table 25) and it was significantly affected by the tempering treatment. Generally, the IDF value was less than the raw value (IDF = 21.03%). Of the treated samples, treatment 5 gave the highest IDF value (19.85%) followed by treatment 7 (19.26%), while treatment 1 gave the lowest value (18.64%). These results are inconsistent with those obtained with the green peas. Perhaps, in practical terms, the tempering solutions did not influence the IDF and TDF of green peas and the IDF of yellow peas since these dietary fibre values change by only 1.1%, 1.5% and 1.2% respectively. Other factors, such as seed coat thickness and seed coat content may be more influential (Ali-Khan, 1993; Stanley and Aguilera, 1985).

Table 25. Percent insoluble, soluble and total dietary fibre (DM) [1] of selected micronized yellow peas tempered for 6 h to 30% moisture with various solutions [2]

Treatment	% IDF (DM)[3]	% SDF (DM)[3]	% TDF (DM)[3]
1	18.6 ± 0.1 [b]	1.1 ± 0.5 [a]	19.5 ± 0.2 [a]
5	19.9 ± 0.4 [a]	0.6 ± 0.3 [a]	19.9 ± 0.2 [a]
6	18.9 ± 0.3 [b]	1.5 ± 0.1 [a]	20.0 ± 0.1 [a]
7	19.3 ± 0.2 [ab]	0.6 ± 0.3 [a]	19.6 ± 0.2 [a]
10	18.8 ± 0.4 [b]	1.0 ± 0.1 [a]	20.0 ± 0.3 [a]

[1] mean ± standard deviation
[2] see Table 17 for list of tempering solutions
[3] different letters in the same column indicate significant differences ($P \leq 0.05$)

SDF values for green peas and SDF and TDF values for yellow peas were not significantly affected by the tempering treatment. For yellow peas, all TDF values were less than the raw (22.14%) and all SDF values were higher than the raw (0.30%).

Slight changes in the SDF/IDF ratio for the micronized peas may be from the solubilization of cellulose and pectinic substances and the degradation of hemicellulose and lignin (Nyman *et al.*, 1987; Vidal-Valverde and Frias, 1991; Vidal-Valverde *et al.*, 1992a). These modifications in dietary fibre are similar to those occurring during cooking, which lead to a softer-textured product (Iyer *et al.*, 1989). When the trends for the dietary fibre results were compared with the texture values (Tables 23 and 24), significant ($P \leq 0.05$) negative correlations were found between SDF and CF for both green ($R^2 = -0.6201$) and yellow ($R^2 = -0.6343$) peas. This indicates that individual dietary fibre constituents may affect the texture.

All three pectin fractions for both green (Table 26) and yellow (Table 27) peas were different than the raw and were significantly affected by the tempering treatments. Specifically, micronized green pea pectin fractions differed from the raw green peas (HM = 0.069%; LM = 0.011%; RF = 0.471%) in the following ways: HM values for treatments 3 (sodium carbonate and bicarbonate), 6 (acids), 8 (sodium tripolyphosphate, washed), 9 (low concentration of sodium salts) and 10 (high concentration of sodium salts) were all higher; all LM values (0.014-0.032%) were higher; and all RF values (0.103 - 0.349%) except that for treatment 6 (0.495%) were lower. Micronized yellow pea HM and LM fractions (HM = 0.062-0.115%; LM = 0.014-0.058%) were also higher than the raw values

Table 26. Percent high-methoxylated, low-methoxylated and residual fraction pectin (DM) [1] of green micronized field peas tempered for 6 h to 30% moisture with various solutions [2]

Treatment No.	% HM (DM) [3]	% LM (DM) [3]	% RF (DM) [3]
1 [4]	0.059 ± 0.001 [cd]	0.032 ± 0.007 [a]	0.221 ± 0.003 [e]
2	0.052 ± 0.015 [d]	0.016 ± 0.011 [bc]	0.312 ± 0.086 [bcd]
3	0.071 ± 0.000 [bc]	0.023 ± 0.000 [abc]	0.103 ± 0.000 [f]
4	0.062 ± 0.003 [cd]	0.022 ± 0.004 [abc]	0.267 ± 0.003 [de]
5	0.069 ± 0.003 [bc]	0.031 ± 0.003 [a]	0.309 ± 0.013 [cd]
6	0.090 ± 0.003 [a]	0.018 ± 0.000 [bc]	0.495 ± 0.010 [a]
7	0.068 ± 0.003 [bc]	0.014 ± 0.004 [c]	0.295 ± 0.027 [cd]
8	0.077 ± 0.002 [b]	0.026 ± 0.003 [ab]	0.377 ± 0.016 [b]
9	0.075 ± 0.004 [b]	0.026 ± 0.008 [ab]	0.349 ± 0.022 [bc]
10	0.093 ± 0.005 [a]	0.031 ± 0.002 [a]	0.274 ± 0.004 [de]

[1] mean ± standard deviation
[2] see Table 17 for list of tempering solutions
[3] different letters in the same column indicate significant differences ($P \leq 0.05$)
[4] pectin fraction values from Table 13 for green peas tempered for 6 h to 30% moisture using distilled water

Table 27. Percent high-methoxylated, low-methoxylated and residual fraction pectin (DM) [1] of yellow micronized field peas tempered for 6 h to 30% moisture with various solutions [2]

Treatment No.	% HM (DM) [3]	% LM (DM) [3]	% RF (DM) [3]
1 [4]	0.080 ± 0.002 [c]	0.058 ± 0.002 [a]	0.351 ± 0.007 [e]
2	0.080 ± 0.005 [c]	0.019 ± 0.001 [de]	0.392 ± 0.021 [c]
3	0.062 ± 0.001 [g]	0.024 ± 0.006 [d]	0.267 ± 0.006 [g]
4	0.075 ± 0.001 [de]	0.026 ± 0.005 [cd]	0.341 ± 0.004 [e]
5	0.073 ± 0.000 [e]	0.042 ± 0.006 [b]	0.371 ± 0.005 [d]
6	0.101 ± 0.002 [b]	0.024 ± 0.005 [d]	0.566 ± 0.012 [a]
7	0.067 ± 0.000 [f]	0.014 ± 0.001 [e]	0.373 ± 0.004 [cd]
8	0.073 ± 0.001 [e]	0.034 ± 0.003 [c]	0.346 ± 0.003 [e]
9	0.078 ± 0.001 [cd]	0.019 ± 0.001 [de]	0.440 ± 0.007 [b]
10	0.115 ± 0.001 [a]	0.033 ± 0.001 [c]	0.313 ± 0.001 [f]

[1] mean ± standard deviation

[2] see Table 17 for list of tempering solutions

[3] different letters in the same column indicate significant differences ($P \leq 0.05$)

[4] pectin fraction values from Table 14 for yellow peas tempered for 6 h to 30% moisture using distilled water

(HM = 0.061%; LM = 0.007%), while the RF values (0.267-0.392%) except treatments 6 and 9 (RF = 0.566%, 0.440% respectively) were lower than the raw value (0.427%).

Many researchers have found that heat treatments increased the solubility of pectin from the raw state, which leads to a softer texture (Kon, 1968; Lee *et al.*, 1979; Wang *et al.*, 1988; Uzogara *et al.*, 1990; Ben-Shalom *et al.*, 1992). In most cases, the water soluble (HM) fraction increased (Kon, 1968; Lee *et al.*, 1979). Ben-Shalom *et al.* (1992) reported that after blanching and dehydrating carrots, both water soluble (HM) and EDTA soluble (LM) fraction had an increase in their pectic substances. They proposed that an interchange of pectic fractions occurred in the cell wall/middle lamella region during heat processing. This resulted in more water soluble (HM) and EDTA soluble (LM) pectic substances. Others have suggested that pectin undergoes β-elimination reactions at elevated temperatures in near-neutral cellular media (Uzogara *el al.*, 1990; Liu *et al.*, 1993), such as for treatments 1 (distilled water, pH = 6.08), 2 (disodium EDTA, pH = 5.37), 5 (NaCl) and 7 (calcium chloride). In these conditions, pectin degrades to lower molecular-weight products via the breakage of glycosidic bonds adjacent to the carboxymethyl groups.

These explanations do not, however, explain why the values for all three pectin fractions increased and the texture was acceptable after tempering with treatment 6 (citric/ascorbic acid). Citric and ascorbic acids are able to hydrolyze protopectin, a component of RF into pectic acids and soluble pectin salts; i.e. into HM and LM pectin fractions (Dietz and Rouse, 1953). These acids also act as chelators of minerals electrostatically bound to pectin moieties (El-Tabey Shehata, 1992). This would lead to less rigid structures in the intercellular spaces, which would soften the texture. This would

explain the increases in HM and LM, but not the increase in RF pectin. Perhaps, the low pH (2.86) sufficiently modified some of the insoluble fibre components, such that they were extracted and subsequently measured as RF pectin.

It was expected that treatment 7 (calcium chloride) would increase the LM and RF fractions, while not affecting the HM fraction for both green and yellow peas because of the texture scores (Uzogara *et al.*, 1990). LM and RF pectin fractions are able to electrostatically bind calcium and other divalent cations by forming ionic cross-links (Talbott and Ray, 1992). As expected, the HM values for micronized green and yellow peas tempered with treatment 7 (0.068% and 0.067% respectively) were similar to the raw values (0.069% and 0.061% respectively). However, LM and RF pectin values did not show the expected large increases. Perhaps it was more favourable for the calcium to bind with the lignin than the pectin. This would still result in a rigid structure, which could explain the high texture scores.

When the pectin values were compared to the texture results, significant ($P<0.05$) negative correlations (Tables 22 and 23) were found between HM and CF (green: $R^2 = -0.5553$; yellow: $R^2 = -0.6954$), and HM and F (green: $R^2 = -0.5300$; yellow: $R^2 = -0.5830$). These correlations indicate that green and yellow peas with high HM levels would also have low texture scores. Thus, they could be cooked for a shorter time. These correlations agree with the results reported by Wang *et al.* (1988), Uzogara *et al.* (1990) and Hentges *et al.* (1991).

As expected, HM pectin of micronized green peas had a significant ($P<0.05$) positive correlation with the trends found for SDF ($R^2 = 0.8102$). This correlation indicates that the solubility of both pectin and fibre impacts the texture of micronized green peas.

The pectin and dietary fibre results for yellow peas showed better defined trends than the results for the green peas. This may be because the yellow peas were micronized at higher temperature; thus, providing a greater heat intensity during the micronization process. Yellow peas may have a more permeable structure than green peas. This is evidenced by the larger diffusion coefficient of the raw peas and the shorter cooking times needed for texture analysis of the micronized peas.

4.5.5 ANF

As mentioned earlier, the third purpose of tempering with various solutions was to evaluate the effect these treatments had on reducing the ANF of micronized peas. In this study, phenolics, phytic acid and α-galactosides (raffinose sugars) were evaluated.

4.5.5.1 Phenolic Compounds. An assay measuring the phenolic content was done on the raw green and yellow peas. For both types of peas, the phenolic content was not detectable. Researchers have found that detectable amounts of phenolic compounds are only in peas whose parent plant had coloured flowers (Grosjean and Gatel, 1989; Igbasan *et al.*, 1997; Bastianelli *et al.*, 1998). Since the raw peas did not have detectable levels, analysis of the micronized peas was not done.

4.5.5.2 Phytic Acid. The phytic acid level found in the raw green (1.09%) and yellow (1.36%) peas was higher than that measured in the micronized peas treated with

various solutions (Table 28), the majority of which contained sodium salts. The tempering treatments had significant effects on the phytic acid level for the micronized green and yellow peas. Treatments 2 (disodium EDTA) and 9 (low concentration of sodium salts) gave the largest reduction in phytic acid for green peas (32% reduction) followed by treatments 3 (sodium carbonate and bicarbonate) and 5 (NaCl; 28% and 23% reduction respectively), while treatments 1 (distilled water), 6 (acids), 7 (calcium chloride) and 10 (high concentration of sodium salts) had the smallest reductions (13%, 16%, 17% and 14% reductions respectively). For micronized yellow peas, treatments 2 (disodium EDTA), 4 (sodium tripolyphosphate) and 10 (high concentration of sodium salts) had the largest reduction in phytic acid (26%, 27% and 28% reduction respectively), while treatments 1 (distilled water) and 7 (calcium chloride) had the smallest (2% and 15% reductions respectively). The majority of treatments (2-6, 8-10) applied to yellow peas, however, were not significantly different. This suggests that perhaps the amount of sodium available does not influence the phytic acid loss after tempering and micronization.

Unlike many other chemical components, the phytic acid level did not differ between green and yellow peas tempered with treatments 4 and 8 (green: phytic acid = 0.88% and 0.89% respectively; yellow: phytic acid = 1.00% and 1.06% respectively). Therefore, the washing step used in treatment 8 (occurring right after tempering and before micronization) did not significantly affect the phytic acid level. Thus, the majority of phytic acid reduction must have occurred during the tempering stage. Cheryan (1980) and Maoja (1982) also found that phytic acid only underwent partial hydrolysis during thermal treatments.

Table 28. Percent phytic acid (DM) [1] found in micronized green and yellow peas tempered for 6 h to 30% moisture using various tempering solutions [2]

Treatment No.	% Phytic Acid DM (Green Peas)	% Phytic Acid DM (Yellow Peas)
1 [4]	0.950 ± 0.179 [a]	1.340 ± 0.074 [a]
2	0.745 ± 0.047 [cd]	1.007 ± 0.023 [c]
3	0.787 ± 0.000 [bcd]	1.048 ± 0.032 [c]
4	0.884 ± 0.014 [abc]	0.999 ± 0.040 [c]
5	0.843 ± 0.044 [abcd]	1.052 ± 0.027 [c]
6	0.914 ± 0.009 [ab]	1.020 ± 0.045 [c]
7	0.900 ± 0.060 [ab]	1.154 ± 0.018 [b]
8	0.890 ± 0.023 [abc]	1.063 ± 0.074 [bc]
9	0.736 ± 0.009 [d]	1.030 ± 0.006 [c]
10	0.936 ± 0.047 [a]	0.978 ± 0.013 [c]

[1] mean ± standard deviation
[2] see Table 17 for list of tempering solutions
[3] different letters in the same column indicate significant differences ($P \leq 0.05$)
[4] % phytic acid (DM) from Figure 10A (green peas) and Figure 10B (yellow peas) for micronized peas tempered for 6 h to 30% moisture using distilled water.

Researchers have reported that phytic acid losses occur from leaching into soaking or cooking media (Iyer *et al.*, 1980; Estévez *et al.*, 1991; Bishnoi *et al.*, 1994; West *et al.*, 1994). Tempering, however, does not provide this opportunity. Thus, phytic acid loss during tempering is through enzymatic hydrolysis (Reddy *et al.*, 1989b) and insolubilization (Crean and Haisman, 1963). Phytic acid in raw peas is usually in a water soluble form (Crean and Haisman, 1963; West *et al.*, 1994) and can be extracted using both water (cooking) and hydrochloric acid (phytic acid assay). After peas are cooked, however, some

phytic acid is converted to an insoluble form and is thus harder to extract (Crean and Haisman, 1963).

The phytic acid level of micronized yellow peas tempered with various solutions was significantly ($P<0.05$) correlated (Table 23) with the gelatinized starch, LM pectin and soluble protein. However, the phytic acid level of micronized green peas did not have any significant correlations at the $P<0.05$ level. Perhaps the lower micronizing collecting temperature was not sufficient enough to impact the chemical components in the green peas to the same degree as for the yellow peas. Also, the enzymatic hydrolysis of phytic acid may have been held back because of the lower diffusion coefficient for green peas. Chemical differences between the green and yellow raw peas (Table 4) may also have influenced the hydrolysis and insolubilization of phytic acid.

4.5.5.3 α-Galactosides. The third ANF examined was the α-galactosides (Tables 29 and 30), namely verbascose, stachyose and raffinose. The sucrose and galactose levels were also measured. Reductions in the verbascose and stachyose levels with increases in sucrose and galactose were the desired modifications of the α-galactosides.

The tempering solutions applied to green peas had a significant effect on the sugars. Generally, micronized green peas tempered with various solutions had lower verbascose and stachyose levels, and larger raffinose, sucrose and galactose levels than the raw peas (verbascose = 1.504%; stachyose = 2.664%; raffinose = 0.750%; sucrose = 1.485%; galactose = 0.000%). Tempering with distilled water (treatment 1) gave the largest reduction in verbascose and stachyose (26% and 38% reduction respectively), and the largest increase in sucrose and galactose (96% and 417%). Modifications to the sugar levels

Table 29. Percent verbascose, stachyose, raffinose, sucrose and galactose (DM) [1] of micronized green field peas tempered for 6 h to 30% moisture with various solutions [2]

Treatment No.	Ver [3] (% DM)	Sta [3] (% DM)	Raf [3] (% DM)	Suc [3] (% DM)	Gal [3] (% DM)
1	1.114 ± 0.042 ^{e}	1.646 ± 0.069 ^{d}	0.818 ± 0.032 ^{cd}	2.906 ± 0.124 ^{a}	0.417 ± 0.023 ^{a}
2	1.712 ± 0.012 ^{a}	2.444 ± 0.019 ^{a}	0.748 ± 0.020 ^{e}	1.641 ± 0.037 ^{g}	0.000 ± 0.000 ^{i}
3	1.272 ± 0.100 ^{d}	2.205 ± 0.144 ^{bc}	0.830 ± 0.052 ^{cd}	2.508 ± 0.141 ^{b}	0.056 ± 0.023 ^{h}
4	1.369 ± 0.033 ^{c}	2.202 ± 0.043 ^{bc}	0.807 ± 0.014 ^{d}	2.145 ± 0.011 ^{c}	0.138 ± 0.013 ^{de}
5	1.555 ± 0.072 ^{b}	2.384 ± 0.124 ^{ab}	0.941 ± 0.025 ^{a}	2.413 ± 0.124 ^{b}	0.122 ± 0.013 ^{ef}
6	1.440 ± 0.087 ^{c}	2.111 ± 0.379 ^{c}	0.785 ± 0.038 ^{d}	1.833 ± 0.080 ^{f}	0.076 ± 0.008 ^{gh}
7	1.269 ± 0.041 ^{d}	2.122 ± 0.093 ^{c}	0.782 ± 0.037 ^{d}	1.891 ± 0.050 ^{ef}	0.159 ± 0.028 ^{d}
8	1.188 ± 0.050 ^{de}	2.148 ± 0.071 ^{c}	0.779 ± 0.036 ^{de}	2.000 ± 0.052 ^{de}	0.299 ± 0.017 ^{b}
9	1.445 ± 0.056 ^{c}	2.305 ± 0.144 ^{abc}	0.875 ± 0.078 ^{bc}	2.079 ± 0.110 ^{cd}	0.197 ± 0.021 ^{c}
10	1.425 ± 0.040 ^{c}	2.228 ± 0.069 ^{abc}	0.929 ± 0.038 ^{ab}	2.816 ± 0.088 ^{a}	0.098 ± 0.017 ^{fg}

[1] mean ± standard deviation

[2] see Table 17 for a list of tempering solutions

[3] different letters in the same column indicate significant differences ($P \leq 0.05$)

Table 30. Percent verbascose, stachyose, raffinose, sucrose and galactose (DM) [1] of micronized yellow field peas tempered for 6 h to 30% moisture with various solutions[2]

Treatment No.	Ver [3] (% DM)	Sta [3] (% DM)	Raf [3] (% DM)	Suc [3] (% DM)	Gal [3] (% DM)
1	1.593 ± 0.167 [a]	2.335 ± 0.232 [d]	0.912 ± 0.108 [bc]	1.936 ± 0.197 [a]	0.038 ± 0.000 [a]
2	1.618 ± 0.062 [a]	2.742 ± 0.092 [abc]	0.908 ± 0.034 [bc]	1.755 ± 0.036 [bc]	0.036 ± 0.008 [ab]
3	1.640 ± 0.093 [a]	2.624 ± 0.133 [bc]	0.867 ± 0.044 [bc]	1.612 ± 0.065 [de]	0.024 ± 0.043 [abcd]
4	1.566 ± 0.077 [a]	2.665 ± 0.113 [bc]	0.835 ± 0.032 [bc]	1.629 ± 0.054 [cde]	0.010 ± 0.010 [cd]
5	1.532 ± 0.152 [a]	2.784 ± 0.247 [ab]	0.892 ± 0.088 [bc]	1.554 ± 0.044 [e]	0.012 ± 0.008 [bcd]
6	1.607 ± 0.085 [a]	2.603 ± 0.114 [bc]	1.024 ± 0.071 [a]	1.567 ± 0.051 [de]	0.022 ± 0.022 [abcd]
7	1.639 ± 0.056 [a]	2.661 ± 0.085 [bc]	0.890 ± 0.020 [bc]	1.680 ± 0.026 [cd]	0.032 ± 0.009 [abc]
8	1.655 ± 0.052 [a]	2.698 ± 0.085 [abc]	0.908 ± 0.033 [bc]	1.818 ± 0.058 [ab]	0.037 ± 0.015 [ab]
9	1.516 ± 0.052 [a]	2.541 ± 0.083 [d]	0.830 ± 0.035 [c]	1.568 ± 0.039 [de]	0.000 ± 0.000 [d]
10	1.712 ± 0.087 [a]	2.886 ± 0.133 [a]	0.915 ± 0.048 [b]	1.514 ± 0.048 [e]	0.000 ± 0.000 [d]

[1] mean ± standard deviation

[2] see Table 17 for a list of tempering solutions

[3] different letters in the same column indicate significant differences ($P \leq 0.05$)

after tempering with disodium EDTA (treatment 2) were the furthest from the ideal: verbascose level increased by 14%; stachyose level decreased by only 8%; and raffinose, sucrose and galactose levels had minimal increases. Treatment 5 (NaCl) also gave the undesired effect of an increase in the verbascose level to 1.555%.

When treatments 4 (sodium tripolyphosphate) and 8 (sodium tripolyphosphate, washed) were compared, treatment 4 gave higher verbascose and sucrose levels, while treatment 8 gave a higher galactose level. Perhaps, the higher residual moisture level for treatment 8 enabled more of the oligosaccharides to be hydrolyzed and to release their galactose. Interestingly, treatment 9 (low concentration of sodium salts) and treatment 10 (high concentration of sodium salts) had significantly different sugar levels for only sucrose (treatment 9: 2.079%; treatment 10: 2.816%) and galactose (treatment 9: 0.197%; treatment 10: 0.098%). Perhaps the combination of sodium salts used for these treatments influenced the sugar modifications more than the concentration of these salts.

The tempering solutions applied to yellow peas had a significant effect on the stachyose, raffinose, sucrose and galactose levels. The verbascose levels measured were not significantly different, but all treatments gave higher levels than the raw peas (1.509%). This was not a desirable effect. Perhaps, yellow peas have a larger concentration of adjuose than green peas. Thus, during tempering, this α-galactoside would be hydrolyzed into verbascose before the other α-galacotsides could be hydrolyzed. Generally, the sucrose and galactose levels were higher than in the raw peas (1.328% and 0.000% respectively) and the stachyose and raffinose levels were lower (2.786% and 0.937% respectively).

Treatment 1 (distilled water) gave the lowest stachyose (2.335%) level and highest sucrose (1.936%) and galactose (0.038%) levels. These results best fit the ideal α-galactoside modifications. Treatment 10 (high concentration of sodium salts), on the other hand, gave the highest stachyose (2.886%) and lowest sucrose (1.514%) and galactose (0.000%) levels. Comparisons between the sodium tripolyphosphate treatments (4 and 8) on yellow peas show that treatment 8 (washed) had higher sucrose and galactose levels, while the remaining sugar levels were not significantly different.

Interestingly, the two treatments using sodium salt mixtures, 9 (low concentration) and 10 (high concentration), gave high sucrose and galactose levels for green peas, but the lowest levels for yellow peas. Similarly, green peas tempered with treatment 2 (disodium EDTA) had the lowest sucrose and galactose levels, while yellow peas had high levels. Even more interesting is the relative sucrose and galactose levels in green and yellow peas. Lower quantities of these sugars were consistently measured in yellow peas. Perhaps, as Dey (1980) suggests, the released sucrose and galactose in yellow peas was more rapidly metabolized than in green peas. Thus it is more difficult to detect and large variations were measured.

Akinyele and Akinlosotu (1991) and Vidal-Valverde *et al.* (1992b) reported that a metabolic process similar to germination or fermentation occurs during soaking. During the soaking step, enzymes are able to hydrolyze cell components, such as α-galactosides and phytic acid. Akinyele and Akinlosotu (1991) reported losses in verbascose (50%), stachyose (30%) and raffinose (1%), and an increase in sucrose (42%) after cowpeas were soaked for 4 h in distilled water. The α-galactosidase enzyme preferably removes galactose from

verbascose first, followed by stachyose and raffinose. Green peas treated with distilled water (treatment 1) did not lose as much verbascose, but had greater losses for stachyose and greater gains for sucrose. Yellow peas tempered with treatment 1 had similar modifications to raffinose and sucrose as the cowpeas, but less stachyose loss. Jood *et al.* (1985) soaked red beans, chick peas and pigeon peas for 6 h in either water or a sodium bicarbonate solution. Generally, these researchers found that verbascose, stachyose and raffinose were reduced more after soaking in the bicarbonate solution. This was not the case for both green and yellow peas. Distilled water (treatment 1) provided a better environment for sugar modifications than the sodium carbonate and bicarbonate mixture (treatment 3).

When the sugar results were analyzed statistically, several correlations were found (Tables 31 and 32). In green peas, verbascose and stachyose, and raffinose and sucrose had significant ($P<0.05$) positive correlations. Galactose had a significant ($P<0.05$) negative correlation with both verbascose and stachyose, and sucrose had a significant ($P<0.1$) negative correlation with verbascose and a positive correlation with galactose. These results indicate that the increases in sucrose and galactose are the result of verbascose and stachyose hydrolysis.

In the yellow peas, the trends found in verbascose were significantly positively correlated with those found in stachyose ($P<0.05$), raffinose ($P<0.05$) and sucrose (($P<0.1$). Stachyose also had a significant ($P<0.1$) positive correlation with raffinose. Sucrose and galactose had a significant ($P<0.05$) positive correlation. These correlations suggest that although some hydrolysis of the larger oligosaccharides occurs during tempering and micronization, it is not as pronounced as in the green peas. This may be related to the higher

collecting temperature for yellow peas and the differences in chemical composition of the two types of field peas. However, these correlations also do not take into account the possible metabolism of sucrose and galactose during the 6 h of tempering.

Table 31. Correlations between ANF and residual moisture for micronized green peas tempered for 6 h to 30% moisture with various solutions (n = 20)

	Stachyose	Sucrose	Galactose	Residual Moisture
Verbascose	0.8052**	-0.3845*	-0.7189**	
Stachyose			-0.6758**	
Raffinose		0.6359**		
Sucrose			0.4172*	
Galactose				0.7115**

* P < 0.1; ** P < 0.05

Table 32. Correlations between ANF and residual moisture for micronized yellow peas tempered for 6 h to 30% moisture with various solutions (n = 20)

	Verbascose	Raffinose	Galactose	Phytic Acid	Residual Moisture
Stachyose	0.6475**	0.3838*		-0.5734**	
Raffinose	0.6641**				
Sucrose	0.4022*		0.6614**	0.6679**	0.7799**
Galactose				0.4175**	0.7375**

*P < 0.1; ** P < 0.05

The sugar levels in micronized yellow peas were also significantly correlated with phytic acid levels. Specifically, low phytic acid levels indicate that the stachyose levels are high and the sucrose and galactose levels are low. This suggests that the enzymes that hydrolyze phytic acid and the α-galactosides have different optimal conditions.

To determine suitable tempering solutions for both green and yellow micronized peas, the primary focus was reductions in the texture values, which would give a shorter cooking time. Based on the texture scores and chemical analyses, treatment 10 (high concentration of sodium salts) was the most suitable tempering solution for both green and yellow peas. Green and yellow peas treated with this had the lowest texture results (Figures 15 and 16) and greater solubility of pectin (Tables 26 and 27) and dietary fibre (Table 24). This treatment, however, did not give large reductions in ANF (Tables 28-30). Other treatments also gave acceptable texture results.

Green and yellow peas tempered with treatment 9 (low concentration of sodium salts) had high pectin solubility (Tables 26 and 27) and reasonable improvements in gelatinized starch (Figure 17) and soluble protein (Figure 18) levels. This treatment also improved phytic acid (Table 28) and α-galactoside (Tables 29 and 30) levels. Treatments 4 (sodium tripolyphosphate) and 8 (sodium tripolyphosphate, washed) gave suitable texture, chemical and ANF results. However, the white powdery residue on the surface of the peas lowers the colour quality (Tables 20 and 21), and in the case of treatment 8, the washing step is a hinderance in the micronization process. Finally, green and yellow peas tempered with treatment 6 (acids) gave high gelatinized starch, HM and SDF and low soluble pectin results. However, the presence of a brown ring (Tables 20 and 21) is a deterrent for using this treatment.

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Appendix 1. Ballot given to panelists for evaluation of both green and yellow peas.

Evaluation of Peas

Instructions:

Place one teaspoon of chick peas in your mouth, move to the molars and evaluate the force required to bite through the sample.
Chew the sample slowly and evaluate the way the sample is perceived in the mouth throughout the chewing and just prior to swallowing. Repeat this procedure taking another teaspoon of sample.

Note your observations in the space provided.

Evaluate the samples in the order listed.

Code No. _____

Code No. _____

Code No. _____

Code No. _____

Code No. _____

Appendix 2. Detailed comments from the panelists for the group of five (A) and three (B) cooked green pea samples

A. Five Cooked Green Pea Samples

Cook Time (min)	Comments
65	Not as firm as 828 (75 min sample) but still a bit too firm, doesn't seem to break down as smoothly as 828, no skin left by end of significant number of chews; Hard, tough, crunchy; Smooth, not a lot of force needed, grainy, seed coat chewy, do not breakdown as quickly (as previous sample - 105 minute sample) but more force required to bite down; Hard sample, more time to swallow the sample, a little abrasiveness of the particles, possess a smooth surface on the peel when it is perceived by the tongue and mouth; Too hard;
75	Flavor hits you right away, good green pea flavor, very firm, but when does break down tends to be smoother breakdown than 512 (105 minute sample), small percentage of peas are leathery (not good!), significant number of chews to reduce in size, I don't object to this, as a result there is very little skin remaining when cotyledons disappear; Very hard, required lots of force, grainy, tough, chewy; Very tough/chewy/firm, requires a lot of force to break down, breaks down into pieces, not very smooth; Harder than the previous one (85 minute sample), I feel more cohesiveness of the peas, it is a firm sample; Too hard, fractures, doesn't yield smoothly, crunchy, skin not very evident, packs around teeth (like peanuts);
85	Good firmness but fractures into fragments, some skin left, not as good as 512 (105 minute sample) in this regard but still okay; Too hard, gritty and grainy, but skin is better; Not much force required, good firmness/hardness, do not fall apart in mouth, a bit gritty; The sample is perceived a little hard, and the peas possess some abrasiveness between the teeth and the tongue, particles not cohesive; Mid hard, chunky, less tooth packing, skins separate and remain after the rest is swallowed;

Cook Time (min)	Comments
95	variable but not as bad as 512 (105 minute sample), breaks down easy, perhaps too easy, smooth on the whole, very little cotyledon chunk formation, lots of skin remaining , gets stuck in back of throat, not good; Skin is hard, separates, not smooth, gritty; Dissolve in mouth, bite down easily, fairly smooth; The samples have a firm consistency, the skin is more perceived and has a rough surface, the abrasiveness of the material is regular; Less hard, some chunks remain, breakdown into slightly grainy texture, skin in evidence seems a bit tough;
105	Find this sample quite variable (from one pea to another), not great, fractures into fairly big chunks, although some are smooth, gritty slightly objectionable, skin okay, bit remaining when cotyledons disappear, not objectionably tough, not much flavor; Soft, skin separates, almost mushy inside, inside smooth, much less grainy, no flavor; A bit of force needed to bite down, a little gritty, breaks down quickly; Soft sample, practically the abrasiveness is not perceived, the skin is perceived Softest = best, still chunky;

B. Three Cooked Green Pea Samples

Cook Time (min)	Comments
85	Too firm, too crunchy when break down, bits of skin present providing throat irritability; Very hard, need lots of force, grainy, tough; A bit of firmness, smooth texture during breakdown; Different grades of hardness, soft and hard sample, seed coat is practically not perceived, this is the least preferred; Too hard, crunchy, breaks down with chunks, no smooth interior;
95	Some firmness mixed with some a bit too smooth, on average fairly good, skin okay, best of the three; Unevenly cooked, crunchy; Very soft/little resistance, grainy, not smooth breakdown; Seed coat is more detectable, soft sample (not too soft), it is the most preferred; Almost crunchy (chunky, grainy);
105	Highly variable, too watery for many, causing firm ones to stand out too much, skins okay - although present don't seem to make you gag; Some cooked well, some stayed hard; Very soft, less resistance, smoother, not much there, easily separates between seed coat and cotyledon; Feel the seed coat, how the product is fractured, not uniform consistency, not uniformly cooked; Soft, some chunky ones, hard to disintegrate skins more evident and somewhat tough and chewy;

Appendix 3. Detailed comments from the panelists for the group of five (A) and two (B) cooked yellow pea samples

A. Five Cooked Yellow Pea Samples

Cook Time (min)	Comments
20	Moderate force, slightly chunky; Firm, slightly crunchy, separates into distinct pieces, not cooked; Does not break down quickly, crunchy, you can detect whole peas, tough skins but chewable; More firmness, still overcooked, smooth seed coat; Firmer, more chewy than 574 (35 minute sample); Hardest of all, smooth consistency on the whole (although odd gritty one present), skin good and well comminuted at end; Fairly smooth, skin a bit tough, soft, a bit grainy;
25	Hardest, mild to moderate force, some peas tender, the others breakdown, somewhat chunky pieces, adheres to mouth, chewy skins, not smooth; Very firm, crunchy, separates into distinct pieces, not cooked; Skin separates and tough, crunchy, gritty, grainy, tough skin but chewable, you can detect whole peas; Grainy, good cohesiveness, too wet, I can't feel the peas; Firmer and more chewy than 186 (30 minute sample); Slightly on the too soft side (but still good) although odd gritty one present, skin break up was good, hardly noticeable except as smaller piece; Initially a bit of crunch, firm but breaks down quickly and smoothly;
30	Best, firm not hard, medium force, integrity good, slightly chewy skins, fairly smooth interior on breakdown, not chunky; Skins very chewy, similar to 412 (40 minute sample), best of the lot but the skins have to go; Chewy, crunchy, tough skin, you can detect whole peas; Too soft, the peas are overcooked, I can't feel the peas, I just feel the seed coats, low cohesiveness; Firmer than 412 (40 minute sample); Little bit too soft although palatable, not too much flavor, slightly raspy effect from large pieces of skins; A bit firmer than 412 (40 minute sample), soft, seed coats tough;

Cook Time (min)	Comments
35	soft, slightly watery, interior disintegrates rapidly, skins more evident; Somewhere in between 239 (20 minute sample) and 412 (40 minute sample) for firmness, again skins are chewy, distinct, interior is very slightly crunchy; Soft but tougher skin, little chewy; Wetness (interior part), smooth surface, smooth interior, cohesiveness is still low; Smoother than 726 (25 minute sample), the best for interior texture; Large pieces of skin, but don't gag you like some, some harder and gritty and some a bit watery-mushy but overall pretty good; Firmer than 412 (40 minute sample) about like 186 (30 minute sample), smooth when bite down, a bit grainy;
40	Very watery - overcooked, soft, all skin no interior texture/firmness, skins slightly chewy; Soft, somewhat smooth interior, skins are not soft, very chewy and distinct, (many broken down peas in the dish); Soft, skin is not tough, little mushy; Overcooked, not grainy, too smooth, smooth interior, cohesiveness is too low; Soft, mush; Far too watery, no taste, skin okay though, present towards end but not objectionable; Very soft/mushy, very little in mouth, smooth;

B. Two Cooked Yellow Pea Samples

Cook Time (min)	Comments
30	Best, but could be cooked 2-5 minutes more, that is just a very little more but not to the point of 467 (35 minute sample); Inconsistent, some are hard, others are soft chewy; Little hard, but chewable, crunchy prefer this sample over other sample; Interior is still watery, skin is okay (smooth), little hard; Firmer and more chewy than other sample, skin was hard; Good, skin breaks down fairly well; A bit of a crunch when bite, firmer than other sample, smooth breakdown, seed coat a bit chewy;
35	Too overcooked; Less inconsistent, firm, chewy skins, interior not soft enough; Good but skin is tough; Too watery the interior, little grainy the interior, too chewy Softer, but the skin was harder; Bit too watery, quite a lot of left over skin that needs to be ground down; Very soft, smooth breakdown, a bit of firmness when bite down, seed coat a bit chewy;

Appendix 4. Information used to calculate the diffusion coefficient and moisture changes over time (0.5-15 h) at three points along the sphere radius (0.5 mm, 3.13 mm and 6.25 mm) for both the green (A) and yellow (B) peas

A. Green Peas [1]

						"As is" M (r, θ) [2]			Adjusted M (r, θ) [3]		
Time (min)	Mass Increase	M(θ)	MR(θ)	Dm	MRavg	M(centre,θ)	M(midpoint, θ)	M(surface, θ)	M(centre,θ)	M(midpoint, θ)	M(surface, θ)
30	0.284	22.257	0.481	3.1E-08	0.481	4.819	13.817	29.987	13.900	13.817	29.987
60	0.341	23.741	0.389	3.0E-08	0.389	9.645	16.919	29.990	13.900	16.919	29.990
90	0.398	25.156	0.301	3.1E-08	0.301	14.248	19.877	29.992	14.248	19.877	29.992
120	0.406	25.359	0.288	2.5E-08	0.288	14.908	20.301	29.992	14.908	20.301	29.992
150	0.406	25.363	0.288	2.5E-08	0.239	17.480	21.954	29.994	17.480	21.954	29.994
180	0.406	25.363	0.288	2.5E-08	0.198	19.613	23.325	29.995	19.613	23.325	29.995
210	0.406	25.363	0.288	2.5E-08	0.165	21.383	24.462	29.996	21.383	24.462	29.996
240	0.406	25.363	0.288	2.5E-08	0.137	22.852	25.406	29.996	22.852	25.406	29.996
270	0.406	25.363	0.288	2.5E-08	0.113	24.070	26.189	29.997	24.070	26.189	29.997
300	0.406	25.363	0.288	2.5E-08	0.094	25.080	26.838	29.997	25.080	26.838	29.997
330	0.406	25.363	0.288	2.5E-08	0.078	25.919	27.377	29.998	25.919	27.377	29.998
360	0.406	25.363	0.288	2.5E-08	0.065	26.614	27.824	29.998	26.614	27.824	29.998
390	0.406	25.363	0.288	2.5E-08	0.054	27.191	28.195	29.999	27.191	28.195	29.999
500	0.406	25.363	0.288	2.5E-08	0.027	28.584	29.090	29.999	28.584	29.090	29.999
700	0.406	25.363	0.288	2.5E-08	0.008	29.592	29.738	30.000	29.592	29.738	30.000
900	0.406	25.363	0.288	2.5E-08	0.002	29.883	29.925	30.000	29.883	29.925	30.000

[1] M_o = 13.9%; M_e = 30%; R = 0.00625 m; centre radii = 0.0005 m; midpoint radii = 0.00313 m; surface radii = 0.00625 m

[2] Calculated M (r, θ) values

[3] Initial M (r, θ) values adjusted to M_o value if calculated value was lower

B. Yellow Peas [1]

						"As is" M (r, θ) [2]			Adjusted M (r, θ) [3]		
Time (min)	Mass Increase	M(θ)	MR(θ)	Dm	MRavg	M(centre,θ)	M(midpoint, θ)	M(surface, θ)	M(centre,θ)	M(midpoint, θ)	M(surface, θ)
30	0.399	24.260	0.326	8.2E-08	0.326	11.334	18.004	29.990	12.400	18.004	29.990
60	0.453	25.636	0.248	5.9E-08	0.248	15.807	20.879	29.993	15.807	20.879	29.993
90	0.472	26.103	0.221	4.5E-08	0.221	17.328	21.856	29.994	17.328	21.856	29.994
120	0.476	26.194	0.216	3.4E-08	0.216	17.622	22.045	29.994	17.622	22.045	29.994
150	0.476	26.194	0.216	3.4E-08	0.167	20.443	23.858	29.995	20.443	23.858	29.995
180	0.476	26.194	0.216	3.4E-08	0.129	22.621	25.258	29.996	22.621	25.258	29.996
210	0.476	26.194	0.216	3.4E-08	0.100	24.303	26.339	29.997	24.303	26.339	29.997
240	0.476	26.194	0.216	3.4E-08	0.077	25.601	27.173	29.998	25.601	27.173	29.998
270	0.476	26.194	0.216	3.4E-08	0.059	26.604	27.817	29.998	26.604	27.817	29.998
300	0.476	26.194	0.216	3.4E-08	0.046	27.378	28.315	29.999	27.378	28.315	29.999
330	0.476	26.194	0.216	3.4E-08	0.035	27.976	28.699	29.999	27.976	28.699	29.999
360	0.476	26.194	0.216	3.4E-08	0.027	28.437	28.995	29.999	28.437	28.995	29.999
390	0.476	26.194	0.216	3.4E-08	0.021	28.793	29.224	29.999	28.793	29.224	29.999
500	0.476	26.194	0.216	3.4E-08	0.008	29.533	29.700	30.000	29.533	29.700	30.000
700	0.476	26.194	0.216	3.4E-08	0.001	29.917	29.946	30.000	29.917	29.946	30.000
900	0.476	26.194	0.216	3.4E-08	0.000	29.985	29.990	30.000	29.985	29.990	30.000

[1] M_o = 12.4%; M_e = 30%; R = 0.00625 m; centre radii = 0.0005 m; midpoint radii = 0.00313 m; surface radii = 0.00625 m

[2] Calculated M (r, θ) values

[3] Initial M (r, θ) values adjusted to M_o value if calculated value was lower