Incorporation of Pulse Flours with Coarse and Fine Particle Size Milled from Green Lentils (*Lens culinars*), Yellow Peas (*Pisum sativum* L.), Navy Beans (*Phaselous vulgaris* L.), and Pinto Beans (*Phaselous vulgari* L.) into Baked Products

by

Yulia Borsuk

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Department of Food Science
University of Manitoba
Winnipeg, Manitoba

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ABSTRACT

The effect of utilization of pulse flours with coarse and fine particle size milled from green lentils, yellow peas, navy beans, and pinto beans in pita bread and pan bread was studied. Composites containing 25, 50, 75, and 100% pulse flours were studied for pita baking, and 10, 15, and 25% for pan bread baking. Addition of the pulse flours produced pitas with the pockets, but they were smaller in diameter and firmer in texture than the wheat control. Supplemented pan bread had lower specific loaf volume and firmer crumb with coarser grain. The recommended tolerance levels of pulse flour addition were 25% for pita bread and 10-15% for pan bread depending on the pulse flour and particle size. It appears that navy beans and pinto beans are more suitable for baking applications using composite flours than lentils and yellow peas, and coarse flours produced breads with improved quality compared to fine flours.

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1. INTRODUCTION

Pulses are unique for a human diet in terms of their nutritional and health-related benefits. They are rich in protein, carbohydrates, dietary fibre, some minerals and vitamins (Tharanathan& Mahadevamma, 2003). In addition, consumption of pulses on a regular basis has been linked to decreased risk of diabetes, atherosclerosis, cardiovascular disease, colon cancer, and immune deficiency disease (Rochfort & Panozzo, 2007; Arntfield et al., 2008). Pulses do not contain gluten; therefore, they are suitable for the diet of people suffering from celiac disease (Han et al., 2010).

The Canadian pulse industry is an important contributor to agriculture and the economy of the country, and there has been a remarkable increase in pulse production over the last fifteen years which is expected to continue (Pulse Canada, 2007a). However, pulses are mostly cultivated for export, and their domestic processing and consumption are limited. Introduction of new pulse-based products to the market would obviously facilitate local utilization of pulses and enhance consumption (Pulse Canada, 2007a; Arntfield, 2009). In addition, consumers, as the final target, will get food of higher nutritive value with health related benefits.

Pulse crops and their derivatives including flours, hulls, and fibre and protein particle sizes are very diverse. They have been the subject of much scientific research in terms of their functionality in food systems, incorporation into traditional foods for fortification, and innovative processing methods. For example, bakery goods such as bread, tortillas, pita bread, cookies, and so on are considered suitable for incorporation of pulse flours at the low levels of substitution (Chavan & Kadam, 1993). However, little attention has been paid to specific physical properties of the pulse flours, for instance degree of milling, in terms of their possible effects on the end-product quality.

This project was undertaken to evaluate the suitability of pulse flours milled from green lentils (*Lens culinars*), yellow peas (*Pisum sativum* L.), navy beans (*Phaselous vulgaris* L.), and pinto beans (*Phaselous vulgaris* L.) for bakery application at the high levels of substitution. White pan bread and pita bread were chosen as the target products for partial or complete substitution of wheat flour. The effect of pulse flour on the physical characteristics of baked products was evaluated. Traditionally, those types of bread products are made of refined wheat flour, and they are low in nutritive value and deficient in fibre, minerals, and vitamins (Chavan & Kadam, 1993). By incorporation of pulse flours, their nutritive value would be substantially improved. In addition, protein of such a pulse-based product would be of superior biological value compared to that of a traditional product. Legume proteins would complement wheat proteins with some essential amino acids such as sulphur containing methionine and cysteine, tryptophan, and, in particular, lysine, the amino acid for which wheat is relatively deficient (Adsule & Kadam, 1989).

Another aim of this work was to compare pulse flours of coarse and fine particle sizes in terms of their effect on the physical properties of the bakery products when partially or totally substituted for wheat flour. That might be an important consideration for milling of the pulse crops as pulse flours with specific particle sizes could produce a product of superior quality depending on the subject of utilization.

It is expected that some of the pulse flours will be priorized in terms of suitability to specific baked products at the optimum level of substitution of wheat flour.

Also the desired degree of milling of pulse flours will be recommended for a successful application in specific bakery products. As only the basic ingredients were used in the formulas, further development of the formulations and processing methods could be advantageous for sensory properties.

2. LITERATURE REVIEW

2.1. Importance of Pulses

Pulses, or grain legumes, belong to the Leguminosae family that are used for human consumption and include lentils (*Lens culinars*), peas (*Pisum sativum* L.), chickpeas (*Cicer arietinum* L.), different types of dry beans (*Phaselous vulgaris* L.), and lupins. They are harvested for their mature dry seeds only and do not include legumes which are grown for oil such as soybeans and peanuts (Roy et al., 2010). Pulses have been cultivated and consumed by humans since ancient times. For example, according to archaeological finds after 6,500 B.C, peas were probably the oldest domestically cultivated crop in the Near East. Then, by 5000 B.C. peas had spread into Egypt and through Greece into the Balkans. Then by 4000 B.C, the crop had spread in central Europe. From the West, field peas were introduced to China by 200 B.C. By the early 17th century, European colonists brought the crop to North America, and it was cultivated in English colonies (Sauer, 1993). The early French settlers introduced field peas to Canada as an ingredient of the hearty pea soup (The Saskatchewan Pulse Crop Development Board, 1994). Now pulse crops are grown in all continents of the world (Chavan & Kadam, 1993).

The world population is constantly growing, and the problem of providing people with sufficient food of balanced quality (most problems related to protein quantity and quality) must be addressed simultaneously by agricultural, scientific, and food manufacturing sectors of many countries. By expanding the seeded area of the pulses and breeding of crops of higher yields, that problem could be partially solved (Chavan & Kadam, 1993; Khattab & Arntfield, 2009; Khattab et al., 2009).

From a nutritional point of view, pulses are rich in protein, ranging from 20 to 40g/100g dry matter, and can supply a high-protein diet (Khattab & Arntfield, 2009; Khattab et al., 2009). Pulse proteins are not considered to be complete proteins in terms of quantity of the essential amino acids compared to those from meat and other animal products. However, they contain relatively high amount of lysine in comparison to other plant foods. Therefore, pulses can complement the existing carbohydrate staples such as wheat and rice by providing essential amino acids as well as dietary fiber, minerals, and vitamins which are also essential for human health (Chavan & Kadam, 1993). In addition to nutritional benefits, pulses possess health promoting properties such lowering cholesterol, managing diabetes, and reducing the risk of different forms of cancer (Roy, 2010).

Traditionally, whole or split pulses are processed for consumption in a number of ways. Soaking, cooking, germination, and heat treatments including roasting and frying improve not only palatability but also increase the bioavailability of nutrients (Tharanathan & Mahadevamma, 2003). Novel physical treatments such as autoclaving, micronization, and microwave cooking, which showed improvements in protein quality and reduced the antinutritional factors, have also been developed (Khattab & Arntfield, 2009; Khattab et al., 2009).

Pulses can be ground into flour or fractionated into a variety of products such as a fiber fraction, protein concentrates and isolates and used in different food applications. Scientific work has revealed that in a food system pulse proteins interact with other components or food ingredients and demonstrate specific functional properties such as water holding, fat binding, foaming, and gelation. Research is now focused on new approaches for utilization of pulses by development of a wide variety of pulse-based food products suitable for industrial manufacturing (Boye et al., 2010).

2.1.1. Pulse Production

Pulses are cultivated in many parts of the world with the major production areas located in North America, Asia, and the Middle East (Chavan & Kadam, 1993; Boye et al., 2010). According to the Food and Agricultural Organization of the United Nations (FAO), in 2009 the total world production of lentils, dry peas, dry beans, and chickpeas, was at around 43.5 million tonnes. Dry beans were produced in the biggest proportion, followed by dry peas, chickpeas, and lentils (Figure 2.1) (FAOSTAT, 2010a).

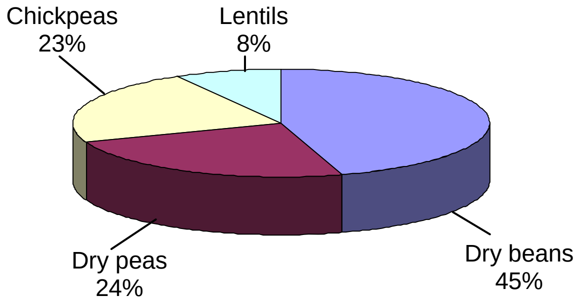

Figure 2.1. Share of the Total World Production of Selected Pulse Crops in 2009 (FAOSTAT, 2010a)

In 2009, the three leading world producers of pulses were Canada, Brazil, and India. Canada accounted for the largest world production of dry peas and lentils, whereas Brazil was the top grower of dry beans (FAOSTAT, 2010b).

This research study focuses on the following pulse crops: green lentils, dry yellow peas, navy beans, and pinto beans grown in Canada. Therefore, in this sub-section only these crops will be covered in terms of production with emphasis on their Canadian origin. The trends regarding pulse production in Canada within the last 10 years are discussed, and the diversity of the crops cultivated in particular areas of Canada are included.

Soil and climatic conditions of the Canadian prairies are very suitable for growing pulse crops (Pulse Canada, 2007b). Historically wheat has been considered the most important crop in Canada. Recently, a diversity of non cereal grains has been recognized as beneficial for the economic strategy of the country, and that resulted in a growing production of pulses in Canada. Now pulses are included in the top of five agricultural commodities cultivated in Canada after wheat, barley, canola, and corn (Pulse Canada, 2007a; Campbell et al., 2002). From 1998 to 2008, there has been a steady increase in lentil and dry pea production in Canada. However, there has been no similar increase in dry bean production (FAOSTAT, 2010c).

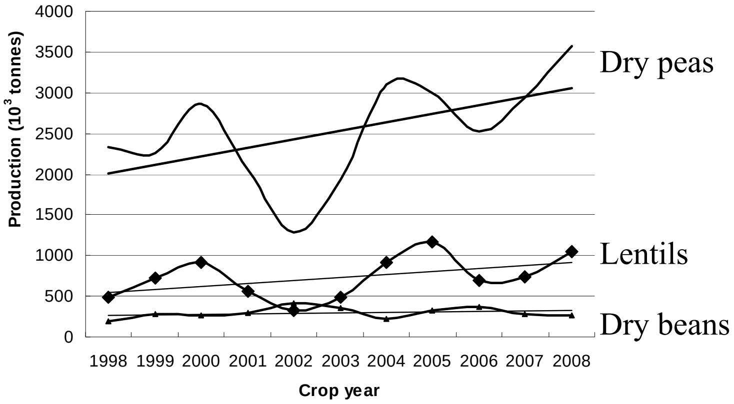

Figure 2.2. Production of Selected Pulse Crops in Canada from 1998 to 2008 (FAOSTAT, 2010c).

According to Pulse Canada, lentils and peas are mostly grown in Saskatchewan followed by Manitoba and Alberta. Dry white and colored beans are produced in Manitoba, Southern Ontario, Alberta, Saskatchewan, and Quebec (Pulse Canada, 2007b). In 2008, the total pulse production of lentils, dry peas, and dry beans in Canada was 4.9 million tonnes (FAOSTAT, 2010c) of which 63% was exported (FAOSTAT, 2010d).

To make people healthier and increase domestic consumption of pulse crops, Health Canada has recommended beans and lentils as a meat alternative and included them on a list of recommended products in Canada's Food Guide (Health Canada, 2010a). In addition, investments provided by Canadian pulse growers, processors, and some governmental and federal organizations support pulse research in order to boost the knowledge about pulse functionality and find possible applications of these crops in the food industry (Pulse Canada, 2007b; Pulse Canada, 2009).

2.1.2. Nutritional Benefits and Antinutritional Factors

Pulses supply the human diet with relatively high levels of nutrients compared to the other field crops, for example cereals. They are a good source of protein, slowly digestible carbohydrates, dietary fiber, minerals, and vitamins (especially folate). Pulses are also low in fat and sodium (Tharanathan & Mahadevamma, 2003; Sandberg, 2000). Approximate levels of the nutrients for raw mature seeds of lentils, split peas, navy beans, and pinto beans compared to refined wheat flour are shown in Table 2.1 (UDSA, 2009a).

Table 2.1. Nutritional Value per 100 grams of Wheat Flour and Raw Mature Pulse Seeds*

Nutrient	Units	Wheat Flour	Lentils	Split Peas	Navy Beans	Pinto Beans
Water	g	11.92	10.40	11.27	12.10	11.33
Energy	Kcal	364	353	341	337	347
Protein	g	10.33	25.80	24.55	22.33	21.42
Total Lipid (fat)	g	0.98	1.06	1.16	1.50	1.23
Ash	g	0.47	2.67	2.65	3.32	3.46
Carbohydrate, by difference	g	76.31	60.08	60.37	60.75	62.55
Fiber (Total Dietary)	g	2.7	30.5	25.5	24.4	15.5
Sugars, total	g	0.27	2.03	8.00	3.88	2.11
Minerals						
Calcium, Ca	mg	15	56	55	147	113
Iron, Fe	mg	1.17	7.54	4.43	5.49	5.07
Magnesium, Mg	mg	22	122	115	175	176
Phosphorus, P	mg	108	451	366	407	411
Potassium, K	mg	107	955	981	1185	1393
Zinc	mg	0.70	4.78	3.01	3.65	2.28
Vitamins						
Thiamin	mg	0.120	0.873	0.726	0.775	0.713
Riboflavin	mg	0.040	0.211	0.215	0.164	0.212
Niacin	mg	1.250	2.605	2.889	2.188	1.174
Pantothenic acid (B5)	mg	0.438	2.140	1.758	0.744	0.785
Vitamin (B6)	mg	0.044	0.540	0.174	0.428	0.474
Folate (B9)	mcg	26	479	274	364	525
Amino acids	g					
Tryptophan	g	0.127	0.232	0.275	0.247	0.237
Threonine	g	0.281	0.924	0.872	0.711	0.810
Isoleucine	g	0.357	1.116	1.014	0.952	0.871
Leucine	g	0.710	1.871	1.760	1.723	1.558
Lysine	g	0.228	1.802	1.772	1.280	1.356
Methionine	g	0.183	0.220	0.251	0.273	0.259
Cystine	g	0.219	0.338	0.373	0.187	0.187
Phenylalanine	g	0.520	1.273	1.132	1.158	1.095
Tyrosine	g	0.312	0.689	0.711	0.484	0.427
Valine	g	0.415	1.281	1.159	1.241	0.998
Histidine	g	0.230	0.727	0.597	0.507	0.556

* Adapted from the USDA National Nutrient Database for Standard Reference, Release 22 (2009) (USDA, 2009a, b)

This study deals also with wheat flour products; therefore, the amounts of the nutrients of unenriched wheat flour are included in Table 2.1 (UDSA, 2009b). These values might give more insight on the level of possible fortification of wheat bakery products with pulse flours.

Pulse proteins are classified as globulins (mostly storage proteins), albumins (enzymatic proteins, protease and amylase inhibitors, and lectins), and glutelins representing 70%, 10-20%, and 10-20% respectively of the total protein content of pulses (Boye et al., 2010; Roy et al., 2010).

Pulse proteins contain a wide range of the essential amino acids, and most of the protein is found in the cotyledon. For example, 93% of methionine and tryptophan of the whole seed is found in the cotyledon. Although pulse proteins are low in sulphur amino acids (methionine and cysteine) and tryptophan, the amounts of these amino acids are higher than the amounts found in wheat. Lysine content of pulses is approximately 6-8 times greater than that found in wheat which is deficient in lysine (Adsule & Kadam, 1989). That is why a combination of pulses and cereals is a good approach in providing a diet that has a more nutritionally balanced protein which can better meet the essential amino acid requirements for adults as recommended by a joint WHO/FAO/UNU Expert Consultation (2007) (Table 2.2).

Pulse carbohydrates consist of starch as the predominant component serving the main source of energy in a diet. Pulse starch is digested in the body at a much lower rate compared to that of cereals and is considered as a ‘slow release carbohydrate’ because of its higher amount of amylose. Wheat contains 26-31% of amylose on average; whereas the range of amylose in pulses is from 35 to 43% depending on the pulse crop (Blanshard, 1986; Rao, 1976). Inclusion of pulses in the diet of diabetics on a regular basis helps to maintain normal glycemia levels (Tharanathan & Mahadevamma, 2003; Sandberg, 2000).

Table 2.2. Summary of Adult Amino Acid Requirements*

Amino acid protein[a]	Estimates	
	mg/kg per day	mg/g protein[a]
Histidine	10	15
Isoleucine	20	30
Leucine	39	59
Lysine	30	45
Methionine + cysteine	15	22
Methionine	10	16
Cysteine	4	6
Phenylalanine + tyrosine	25	38
Threonine	15	23
Tryptophan	4	6
Valine	26	39
Total indispensable amino acids	184	277

* Adapted from the Report of a Joint WHO/FAO/UNU Expert Consultation (WHO/FAO/UNU, 2007). Values were calculated as the individual amino acid requirement divided by the total protein requirement.

[a] Mean nitrogen requirement of 105 mg nitrogen/kg of body weight per day (0.66 g protein/kg per day)

Dietary fiber is mostly located in the husk or hull fraction of the pulse seeds and represents cell wall materials (lignin and plant polysaccharides) which remain after human digestion. Chemically, dietary fiber consist of insoluble dietary fiber (IDF) which includes cellulose, lignin, and some hemicelluloses and soluble dietary fiber (SDF) which includes pectins, gums, and also some hemicellulose particle sizes (Tharanathan & Mahadevamma, 2003). The distribution of these two fiber particle sizes for specific pulse crops is shown in Table 2.3 (Tosh &Yada, 2010). Both ISD and SDF have health-related properties and will be discussed in more detail in Section 2.4.

Pulses are rich in vitamins such as riboflavin, niacin, pantothenic acid, vitamin B6, and folate. However, the bioavailability of some vitamins, for example B6, may be reduced by possible binding with non-digestible polysaccharides and lignin. Also the amount of vitamins may be reduced after long storage periods (Kadam & Salunkhe, 1989a).

Table 2.3. Dietary Fiber Contents (Total, Insoluble, and Soluble) of Raw Pulse Seeds*

Pulse Crop	Dietary Fiber Content, g/100g		
	Total Dietary Fiber	Soluble Fiber	Insoluble Fiber
Dry Peas	14 - 26	2 - 9	10 - 15
Lentils	18 - 20	2 - 9	11 - 17
Dry Beans	23 - 32	3 - 6	20 - 28

* Adapted from Tosh &Yada, 2010.

Processing causes unavoidable reduction of some vitamins. For example soaking, which is often the first step in preparing pulses followed by cooking, results in leaching of water-soluble vitamins into the soaking or cooking media (Prodanov et al., 2004; Kilgore & Sistrunk, 1981).

Pulses are rich in minerals, especially in potassium, calcium, magnesium, iron, phosphorus, and zinc. Similar to vitamins, the bioavailability of minerals is reduced by their association with phytic acid, polyphenols, and lignin. In addition, loss of minerals also occurs during soaking because of their leaching into a soaking media (Kadam & Salunkhe, 1989a; Urbano et al., 2006).

Nutritional benefits of pulses are reduced because of the presence of antinutritional components which negatively affect bioavailability of nutrients. These antinutritional components include some proteins, such as trypsin inhibitors and lectins, as well as non-protein components which include phytates, polyphenols (tannins), and flatulence-causing raffinose oligosaccharides (Sandberg, 2000; Khattab & Arntfield, 2009). Commonly, cooking of pulses reduces or completely eliminates those antinutritional factors and improves palatability of the pulses (Khattab & Arntfield, 2009; Khattab et al., 2009; Wang et al., 2003).

2.1.3. Health-related Benefits

Pulses have been the subject of much research regarding their health benefits.

Table 2.4. Summary of the Health Benefits of Pulses*

Heath Issue	Action
Cardiovascular Health	• Reduced risk of coronary heart disease; reduced total and LDL cholesterol levels • Modulation of glucose, insulin, and homocysteine and lipid peroxidation in coronary artery disease patients • Reduced blood pressure
Weight Management	• Decreased body weight or body mass index and low risk of obesity • Decreased waist circumference or abdominal obesity
Diabetes	• Improved glycaemic control • Risk reduction to develop type II diabetes
Gut health	• Served as prebiotic material • Increased levels of healthy gut bacteria • Lowered levels of putrefactive and pathogenic gut bacteria

* Adapted from Pulse Canada, 2009 and summarized from Anderson et al., 1995; Bazzano et al, 2001; Campos-Vega et al., 2010; Flight and Clifton, 2006; Greenwood eat al., 2000; Haveman-Nies et al., 2001; Jang et al., 2001; Lerer-Metzger et al., 1996; Tang et al., 2008; Venn & Mann, 2004; Wang 2004; Feregrino-Perez et al., 2008.

Table 2.4 summarizes the results of human clinical studies, which were conducted under the initiative of the Canadian pulse industry in order to find the possible correlation between pulse consumption and managing human health (Pulse Canada, 2009). Also, the studies confirming health benefits of pulses are cited.

All of the health-related benefits of pulses are associated with specific components such as dietary fiber and starch. In addition, some antinutritional components of pulses (phytic acid, polyphenolics, and saponins) are now considered as beneficial to human health (Table 2.5) (Guillon & Champ, 2002; Empson et al., 1991; Rochfort & Panozzo, 2007; Roy et al., 2010; Sandberg, 2000; Tharanathan & Mahadevamma, 2003; Tosh &Yada, 2010; Campos-Vega et al., 2010).

Because of their unique nutritional and health benefits, pulses are used not only as whole or split seeds but also in a variety of processed forms including flours, protein isolates, and fiber fractions. Thus, pulses serve as promising ingredients in different food applications.

Table 2.5. Summary of Pulse Compounds and their Health-Related Benefits*

Compound	Physiological effect	Health Disorder
Dietary Fiber – insoluble	- Delayed nutrient absorption - Increased faecal bulk - By fermentation in the large intestine - Growth of probiotic microflora	- Colonic health - Diverticulosis
Dietary Fiber - soluble	- Lowering of blood cholesterol - Regulate blood glucose level	- Cardiovascular disease - Diabetes mellitus
Resistant starch	- Substrate for microbiological fermentation - probiotic effect (prevent abnormal colonic cell population) - Increased faecal bulk - Reduced post-prandialglucose and insulin responses	- Colonic health - Diabetes
Polyphenolic compounds	- Antioxidant properties by scavenging free radicals and inhibiting lipid peroxidation	- Cardiovascular disease - Cancer - Atherosclerosis - Diabetes - Immune deficiency - Aging
Isoflavones	- Antioxidant properties	- Reduction in osteoporosis - Cardiovascular disease - Hormodependant cancerprevention - Treatment of menopause symptoms
Phytic acid	- Antioxidant properties	- Cancer - Heart disease
Protease inhibitors	- Anticarcinogenic properties - Anti-inflammatory properties	- Cancer - Human immunodeficiency virus
Lectins	- Antitumor properties - Can be absorbed into the blood while biologically active and delay digestion - Activation of innate defense mechanisms	- Cancer prevention - Controlling obesity - Enhance immune system
Saponins	- Anti-cancer property	- Hyperlipidemia - Heart diseases
Phytosterols	- Reduction of serum low-density lipoprotein (LDL) cholesterol	- Cardiovascular disease

* Summarized from Campos-Vega et al., 2010; Guillon & Champ, 2002; Empson et al., 1991; Han & Baik, 2008; Rochfort & Panozzo, 2007; Roy et al., 2010; Sandberg, 2000; Tharanathan & Mahadevamma, 2003; Tosh &Yada, 2010.

2.1.4. Milling

Typical processing methods of pulses include milling, soaking, cooking, germination, fermentation, and canning. All these methods are intended to convert the raw seeds into palatable food with improved nutritional characteristics. Dehulling and milling are among the oldest types of grain processing and are tightly connected to the development of human civilization. Even the ancient people were familiar with grinding of grains and seeds using a mortar and pestle (Kadam & Salunkhe, 1989b).

Pulse flour can be obtained by milling of cleaned raw whole seeds. Also soaking, tempering and dehulling can be applied prior to milling. Soaking is used for wet milling processes where the seeds are mixed with water once or a few times followed by draining and drying. This makes the hull much easier to separate from the cotyledon and reduces the antinutritional factors. Pulse flour ground by the wet method can be used for high purity protein isolates (Guillon & Champ, 2002; Kadam & Salunkhe, 1989b). Dry milling includes grinding of the dehulled seeds and further classification by air into a light and fine particle sizes consisting of starch and dietary fiber and a heavy and coarse particle size consisting of proteins and lipids (Guillon & Champ, 2002).

Pulse seeds can be milled into flour by a variety of mills such as plate mill, hammer mill, and pin mill. Grinding can be done to a certain degree and then the material is usually passed through a sieve to produce a particular particle size distribution (Maskus, 2010).

If dehulling of the seeds is used prior to milling, that can affect the nutritional benefits of the pulse flours in two opposite ways. On the one hand, there is a remarkable decrease in the level of nutrients such as total fiber and minerals, especially calcium, of the flour as those components are mostly located in the hull. In addition, the level of phytic acid and activity of the protease inhibitors, which are considered antinutrients, are increased due to removal of the seed coat as these compounds are present at higher concentration in the cotyledon. Therefore, after milling the flour loses some of its nutritional value. On the other hand, polyphenols including tannins are also removed with the hull; therefore, amino acids of the protein become more available for absorption resulting in improved protein digestibility. Also the levels of protein, starch, and resistant starch are increased (Kadam & Salunkhe, 1989b; Wang et al., 2009).

2.1.5. Food Applications

Pulses as whole or split seeds are common ingredients in the traditional cuisine of many countries of the Middle East, Africa, and Europe. They can be cooked, roasted, oil fried, fermented, and milled and then prepared into individual dishes or used in a combination with cereal products, vegetables, and spices. Typically pulses are cooked within one hour or more and can be consumed as soup, main course, desserts, baby food, and snacks (Boye et al., 2010). Consumers are currently looking for healthier food which is easy and fast to cook or ready-to-eat. Extensive research regarding nutritional and health-related benefits of pulses, as well as innovative production methods, are fundamental for development of novel pulse-based products.

Whole or dehulled pulses can be milled into flours and utilized directly in a variety of foods. Hulls can be also ground separately and used in food applications (Sosulski & Wu, 1988; DeFouw et al., 1982; Jeltema et al., 1983). Pulse flour can be further fractionated into fiber and protein products including protein powder, concentrates, and isolates. Those pulse derivatives are utilized in food for three main purposes which include overall fortification of nutrients, enrichment of a certain component, and as a functional ingredient for textural improvement (Boye et al., 2010; Tosh & Yada, 2010).

Incorporation of pulse products into food has been the subject of much research resulting in a diversity of possible food applications for pulses (Maskus, 2010; Boye et al., 2010). Cereal-based products including pan and flat breads, bakery goods, pasta, and noodles are very promising applications (Bahnassey et al., 1986; Sosulski &Wu, 1988; Edwards et al., 1995; Wang et al., 1999; Gómez et al., 2003; Li & Vasanthan, 2003; Zhao et al., 2005; Anton et al., 2008a; Bildstein et al., 2008). Extruded and fried snack foods are also suitable for pulse utilization (Annapure et al., 1998; Thakur & Saxena, 2000; Anton et al., 2008b; Anton et al., 2009a; Ryland et al., 2010).

Meat products of high and low fat content have been demonstrated to have potential for inclusion of pulse flours and fibers where they can bind and retain fat thus serving as extenders. Sausages, meatballs, chicken nuggets and chicken patties represent a variety of processed meat products suitable for incorporation of pulses (Taiseer, 1987; Nagamallika et al., 2005; Serdarglu et al., 2005; Singh et al., 2008). Also, proteins extracted from pulses can be used as meat analogs in functional foods (Asgar et al., 2010). In dairy products, modified pea starch can replace fat in light vanilla ice cream, and pulse protein isolates can be included into milk pudding formulation (Aime et al., 2001; Nunes et al., 2003).

Soy-based products might be another possible application for inclusion of pulses into the formulas where pulses can be substituted for soy. For example, similar to soybean coagulated proteins, which are the base for tofu, pulse proteins have also shown the ability to form curds (Cai et al., 2001). In fermented soybean products such as miso and tempe, pulse seeds can replace the main ingredient (Reib & Kreuznach, 1993; Nassar et al., 2008).

2.2. Pita Bread

Pita is double-layered flat bread which is widely consumed by the people of the Middle East and North Africa countries (Qarooni, 1996). This type of bread has gained wide acceptance in other parts of the world as well (Amr & Ajo, 2005). Pita or Arabic bread is a circular flat loaf with a golden brown crust varying in diameter from 20 to 30 cm. The feature of this bread is having a pocket which is formed during baking. Pita is typically consumed with other food stuffed into the pocket (Qarooni, 1996).

2.2.1. Ingredients and Manufacturing

The main ingredients for pita bread are wheat flour, yeast, salt, and water (Quarooni et al., 1987). Wheat flour, which is milled from hard wheat of intermediate protein content (9.5 to 12.0 g/100g) and dough strength is considered as being the most suitable for pita baking (Quarooni et al., 1993). The amount of yeast in the formula is usually 1% (flour basis), and the function of yeast is mostly for flavour rather than used to leaven the dough (Abdel-Aal et al., 1993). Water and salt have the same functionality as for pan bread.

The initial processing step is mixing all the ingredients to promote gluten development. The mixed dough is allowed to ferment for 1 h, and then weighted, rounded, and again allowed to rest (intermediate proofing) for 10-15 min. After resting, the dough is flattened and sheeted by passing through a pair of the rolls a few times to obtain the desired thickness, rotating the dough 90° each time. Final proofing for 30 min is followed after sheeting, and then pitas are baked in a high temperature oven. Baking temperature for pita varies from 400 to 500°C, and the pita is baked within 60-90 s depending on the thickness of the dough. During baking, a crust forms in a few seconds, and CO_2 and steam expand the dough resulting in a separation of its lower and upper layers, producing a pocket. Baked pitas are then cooled and packed (Quarooni et al., 1987; Quarooni, 1996).

2.2.2. Nutritional Enrichment

Flat breads are considered to be of higher protein content compared to the other types of bread products. For example, pita bread made from unenreached white wheat flour contains 9.10g/100g of protein, and commercial white bread contains 7.64/100g of protein (USDA, 2010). However, there are a few studies which have focused on nutritional fortification of flat breads (Hallab et al., 1974; Abdel-Aal et al., 1993; Chavan & Kadam, 1993; Sharma et al., 1995; Anton et al., 2008a). Incorporation of pulse flours into pita formulation can benefit by providing a more balanced amino acid profile, improved protein efficiency ratio (PER), and higher protein content.

According to Sharma et al. (1995), flat breads of acceptable sensory attributes could be produced by replacing wheat flour with up to 20% dehulled chickpea flour or up to 10% dehulled pigeon pea flour. Significant increases (35% and 26%) in the protein content were observed for flat breads containing 20% chickpea flour and pigeon pea flour respectively. Mineral content of supplemented flat breads was also much higher. The average increase was 26% for Mg, 60% for P, 9% for Ca, 112% for Fe, and 159% for K.

Animal studies confirmed that the diets containing pulse flat breads resulted in higher values for body weight gain in rats compared to those on unsupplemented diets. Protein Efficiency Ratio (PER) was 1.61 for breads containing 20% chickpea flour and 1.40 for breads containing 10% pigeon pea flour whereas PER for the 100% wheat control was only 1.09. Also, higher levels of hemoglobin content of blood (4.4 – 8.7% increase) were observed for rats on the supplemented diet.

Hallab et al. (1974) determined that flour containing 20% chickpea milled with the hull or 10% defatted soybean flour can be added to white Arabic bread. The resulting breads were evaluated as acceptable in terms of color, taste, texture, and overall acceptability. The nutritive value was improved with a 67.7% increase in lysine for the 20% chickpea flat bread and 87.7% increase in lysine for the 10% soybean flat bread. Also supplemented breads showed enhanced values for net protein utilization as confirmed by animal experiments.

Abdel-Aal et al. (1993) calculated that a blend containing 27% of fababean flour and 73% wheat flour would provide a good source of dietary protein which could meet the protein requirement for a 2-5 year old child (FAO/WHO/UNU, 1985). That blend was baked into flat bread, and the product was evaluated as acceptable and similar to the wheat control in taste, texture, and color. Only the extent of puffing and layer separation in the flat bread was slightly lower than those of the control. There was a 25% increase in the protein content, 35% increase in the total dietary fiber content, and 18% increase in the mineral content for the supplemented flat bread compared to those of the wheat control. The amino acid score was improved from 31 units for the control to 54 units for the supplemented flat bread, and the protein efficiency ratio was doubled.

Wheat flour tortillas were subjected to partial substitution with bean flours milled from small red, black, pinto, and navy beans. Anton et al. (2008a) concluded that tortillas of satisfactory texture with improved nutritional properties could be produced at 25% replacement with the bean flours. All the sample tortillas were superior in protein content with an average of 14 g/100g compared to the wheat tortilla with 10.98 g/100g of the protein content. Small red bean flour at the level 25% produced tortillas of the highest total phenolic content (137 mg FAE/100 g versus 17 mg FAE/100 g for wheat tortilla). The DPPH$^{\cdot}$ antioxidant activity was 392 µmol TE/100g for those tortillas whereas the value of the wheat control was 37 µmol TE/100g.

Overall, it was concluded that flat breads can tolerate protein supplement using pulse flours extremely well (Abdel-Aal et al., 1993). However, some adjustments in the formulation might be required to obtain a product with improved texture and shelf life. For example, hydrocolloids (guar gum) or emulsifiers (di-acetyl tartaric acid esters of monoglycerides, DATEM, and sodium stearoyl-2-lactylate, SSL) could help in retaining the soft texture and prolonging shelf stability up to 5-7 days (Farvili et al., 1995; Anton et al., 2009b).

2.3. Pan Bread

Bread has been a staple of the human diet for centuries and is consumed widely in different parts of the world. However, bread consumption has been declining with the rate varying depending on the country and the type of bread (Cauvain, 2007). For example, in the UK the decline has been considered to be slow (Table 2.6).

Table 2.6. Consumption of Bread (kg per capita) in UK*

Year	Consumption (kg)
1985	45.86
1990	45.70
1995	39.36
2000	37.44

* Adapted from Cauvain, 2007

On the other hand, consumption of grain-based products such as pasta, cereal-based snacks, and bakery products has been increasing. For example, Statistics Canada has reported that the consumption of grain-based food has increased from 72 kg per person in 1991 to 89 kg per person in 2001 (Statistics Canada. Food Consumption in Canada – Part 1, 2001). Both Health Canada and USDA promote healthy eating by including grain products such as bread and cereals into Canada's Food Guide and USDA's Food Guide Pyramid and recommend 6-8 or 6-11 servings of grain per day, respectively (Health Canada, 2010b; USDA, 1995).

2.3.1. Ingredients and Manufacturing

Typically wheat flour, water, yeast, and salt are the basic ingredients in breadmaking. Wheat flour can be considered the key material containing two main components (starch and gluten protein) which are responsible for forming the dough with visco-elastic properties which allow for gas-retention capacity and setting the crumb during baking. Water is the second main ingredient which is absorbed by the starch and protein of the flour during mixing. In addition, water serves as the medium for many biochemical reactions which take place during fermentation and dough development. Yeast is a leavening agent which transforms starch and sugar into CO_2 and ethanol and thus creating a foam structure from the dough. By the action of yeast, the dough expands in volume during fermentation and baking. Also, many chemical products accumulate during fermentation and thus contributing to specific flavor of bread. Salt is added for flavor at the level of 1.5-2.5% (flour basis) and improves elasticity of the dough. Optional ingredients such as fat, sugars, and milk products are also commonly added to bread formulations for nutritional enrichment and better eating characteristics. Addition of processing aids including emulsifiers, vital gluten, oxidizing agents, enzymes, rope and mold inhibitors is a common practice in breadmaking today (Sluimer, 2005).

Industrial breadmaking is a straightforward process, which includes a few steps, and can be completed within 4 - 8 h depending on the processing method. Mixing is the first step in breadmaking by which all the ingredients undergo uniform distribution to allow for dough development. During bulk fermentation, the mixed dough is further developed by the action of yeast resulting in an increase in dough volume. Bulk fermentation can be interrupted by re-mixing during which yeast cells and carbohydrates are allowed to further react, and the gas cells are divided resulting in finer bread crumb. After fermentation, the dough is divided into pieces, rounded, and allowed to rest (intermediate proofing). After resting, a piece of dough is sheeted, moulded, and put into a baking pan. During final proofing, the dough is still fermenting and increasing in volume. Baking, during which the crust and crumb of the bread are formed, follows the final proofing. Baked bread is allowed to completely cool before slicing and packing. All the steps are conducted under controlled conditions which are favorable for physical processes and chemical reactions to occur during breadmaking (Sluimer, 2005; Pyler, 1985).

2.3.2. Nutritional Enrichment

Although pan bread appears to be a good source of energy as it is high in carbohydrate content provided by refined wheat flour, bread is quite deficient in fiber, minerals, and vitamins because those nutrients are removed during milling. In addition, wheat protein is low in lysine, methionine, and threonine and that is why wheat protein is not well-balanced in terms of amino acid composition (Chavan & Kadam; 1993). According to Food and Drugs Act and Regulations (2011), refined wheat flour must be enriched with several B vitamins and iron by direct blending of those micronutrients. Other alternative materials such as flours and fiber and protein particle sizes from legumes, oilseeds, and other cereals can be used for fortification of bread products (Chavan & Kadam; 1993).

If whole wheat flour is used instead of refined wheat flour in bread formulation, the resulting bread is more nutritious because it has higher levels of protein, fiber, vitamins, and minerals which are mostly concentrated in the bran of wheat grain (USDA, 2009b). However, it has been reported that sensory characteristics of whole wheat bread are lower compared to those of regular white bread. Specifically the whole wheat bread has decreased loaf volume, reduced crumb softness, and darker crumb color due to a gluten dilution effect and possible disruption of the gluten network (Pomeranz et al., 1977; Galliard, 1986; Zhang & Moore, 1999). These might be improved by using baking improvers, enzymes, and adjusting the processing parameters and baking techniques (Katina, 2003).

Inclusion of pulses in the form of flour, fiber fraction, ground hulls, protein concentrates, and protein flours into yeast-leavened bread for fortification has been extensively studied. Pulse flours milled from yellow peas (*Pisum sativum* L.), lentils (*Lens culinars*), navy beans (*Phaselous vulgaris* L.), pinto beans (*Phaselous vulgaris* L.), mung beans (*Phaselous aureus*), and faba beans (*Vicia faba*) were evaluated and were successfully substituted for wheat flour in bread formulations at levels ranging from 2.5 to 20% (D'Appolonia, 1977; Repetsky & Klein, 1981; Chavan & Kadam; 1993).

High-fiber pan bread can be obtained by addition of commercial pea fiber at the level of 3% (flour basis) and replacement of wheat flour at the level of 2 or 5% (Wang et al., 2002; Gómez et al., 2003). Also substitution of wheat flour with field pea hulls at the level of 15% can produce bread of acceptable quality (Sosulski & Wu, 1988).

Protein concentrates obtained from yellow peas, chick peas, and soybean by extraction and freeze-frying have been evaluated for bread supplementation at the levels of 2, 5, and 8% (Fenn et al., 2010). In another study, dry-roasted navy beans and pinto beans were milled and air-classified into high-protein particle size and used for replacement of wheat flour in bread producing loaves with satisfactory sensory scores at 10% replacement (Silaula et al., 1989). Protein concentrates extracted from Great Northern beans (*Phaseolus vulgaris* L.) and then lyophilized were also evaluated for substitution of wheat flour. Based on sensory analysis and measured loaf volume, the tolerant level of protein concentrates was recommended to be 10% (Sathe et al., 1981).

Protein concentrates which were obtained from lentils and white beans using an enzyme-based extraction followed by spray-drying, were incorporated into bakery products as alternatives to pea and soy proteins. Protein extracts from white beans and lentils demonstrated similar or superior foaming and emulsifying functionality to pea and soybean, while providing nutritional benefits to bread (Bildstein et al., 2008).

Utilization of pulse products in bread has been shown to affect properties of dough and physical and sensory characteristics of bread compared to those of regular white pan bread. It was reported that the doughs containing flours from mung beans, faba beans, and lentils showed lower Farinograph Water Absorption (FAB), and doughs containing the flours from navy beans and pinto beans had higher FAB compared to that of wheat dough. Dough development time (DDT) and dough stability were decreased in all composite flours (D'Appolonia, 1977).

The opposite changes in FAB and DDT of pulse-wheat blends were noticed when fiber or protein particle sizes were used in the formulation resulting in greater water absorption and longer DDT than those of the control. All the doughs containing pulse flours, fiber or protein particle sizes were weaker than the control (Sosulski & Wu, 1988; Gómez et al., 2003; Fenn et al., 2010; Silaula et al., 1989).

Based on the reviewed studies, incorporation of different pulse products into bread has resulted in decreased loaf volume, less soft crumb, and changes in the crumb color depending on the type of pulse crop utilized. Sensory bread attributes, such as color, flavour, and crumb grain, showed lower scores with an increased proportion of pulses in the formula. The negative effect of pulse flour inclusion on dough properties and bread quality could be explained by the dilution of wheat gluten in the dough as pulses do not have this type of protein, and it could be also due to the disruption of the wheat protein-starch interface by non-wheat proteins and interaction between wheat gluten and fiber resulting in lower gas-retention capacity (D'Appolonia, 1977; Gómez et al., 2003).

Acceptability of bread containing pulses at relatively low levels or even possibly higher levels of inclusion can be achieved by some pre-treatments of pulse seeds before milling, for example roasting and germination (D'Appolonia, 1978; Hsu et al., 1980). Also inclusion of emulsifiers and oxidizing agents in formulas or using wheat flour with very strong gluten are possible alternatives for improving pulse containing bread (D'Appolonia, 1977; 1978).

3. Incorporation of Pulse Flours from Green Lentils (*Lens culinars*), Yellow Peas (*Pisum sativum* L.), Navy Beans (*Phaselous vulgaris* L.), and Pinto Beans (*Phaselous vulgaris* L.) of Different Particle Size into Pita Bread

3.1. Abstract

Pita bread was fortified with pulse flours milled from green lentils, yellow peas, navy beans, and pinto beans. Dehulled yellow pea flour with a fine particle size was obtained commercially. All remaining pulses were ground to produce fine and coarse flours. Composites were prepared by mixing of the pulse flours and wheat flour at different levels (25, 50, 75, and 100% pulse flours), and made into pita bread. The amount of water required for mixing was determined based on Farinograph absorption of the composite flours. The blends made from the pulse flours with coarse particle size demonstrated higher rates of water absorption than the blends made from the fine pulse flours (58.0±8.9% and 55.8±8.2% on average respectively). Pita bread quality was evaluated according to bread diameter, pocket height, specific loaf volume, texture, and crust color. All the composite flours, regardless of the flour type and level of substitution, produced pitas with the pockets thus confirming their suitability for this product. The crust color of the pitas containing navy bean flour was affected less than that for lentil flour. Pita bread made with pinto bean was superior in texture to all other pitas. Overall, navy and pinto bean flours appeared to be most suitable for pita bread than lentil flour. Flours with coarse particle sizes produced pitas with better color and texture than those with fine particle sizes. Sensory evaluation of selected pitas containing 25% coarse pinto

and 25% coarse navy bean flours showed that they were not significantly different from the wheat control in aroma, appearance, color, and flavor. However, the scores for texture and overall acceptability for pitas made with 100% navy bean flour were significantly lower.

3.2. Introduction

Baking of flat breads from a mixture of cereal and pulse flours is a common practice for the Indian subcontinent countries. Flat breads, however, vary in flavour and texture. Obtaining a product with higher protein quality and quantity is another benefit of adding pulse flours (Qarooni, 1996). A diet containing a combination of pulses and cereals provides the human body with protein with improved amino acid score as pulse proteins have higher levels of lysine, and they can beneficially complement the protein in cereals, such as wheat, which are rich in sulphur-containing amino acids and tryptophan. This results in higher protein efficiency ratio for pulse-wheat based products. Protein digestibility is also improved as well as the net protein utilization (Adsule & Kadam, 1989; Boye et al., 2010; Abdel-Aal et al., 1993; Hallab et al., 1974). In addition, supplementing flat breads with pulse flours makes the product higher in fibre content, as well as minerals (phosphorus, iron, zinc, and calcium) and vitamins (Abdel-Aal et al., 1993). If the whole pulse seeds are ground into flour, the final product can also be superior in phenolic content with higher antioxidant activity compared to a wheat control, resulting in enhanced health-related benefits (Anton et al., 2008a).

Attempts to improve the protein quality and quantity of flat breads by addition of different pulse flours have been reported in the literature. Flours milled from chickpeas, pigeon peas, fababeans, small red, black, pinto, and navy beans, as well as defatted soybean flour, were incorporated into flat bread formulations for nutritional fortification. The optimal tolerance level of pulse flour addition varied from 10 to 27% depending on the type of pulse crops (Sharma et al., 1995; Hallab et al., 1974; Abdel-Aal et al., 1993; Anton et al., 2008a).

Not only does the pulse crop influence the quality of the end product, but so does the processing method. For example, the treatments which can be done on the seeds (dehulling of the seeds prior to milling, grinding the whole seeds, and degree of grinding which determines particle size) affects the bread making process and the quality and nutrient value of the baked product. It has been reported that dehulling results in reduced amounts of polyphenol and tannin, which are considered anti-nutrientional compounds, and increased protein digestibility and net protein utilization (Wang et al., 2009). On the other hand, with seed coat removal, significant amounts of fibre, polyphenolic compounds, and minerals are also discarded reducing nutritional value and health-related benefits (Kadam & Salunkhe, 1989b; Han & Bail, 2008; Ramulu & Rao, 1997). Studies on flat breads have concluded that particle sizes of wheat flour or substituting flours have an effect on dough handling properties and the quality of the final product (Wang & Flores, 2000; Prasopsunwattana et al., 2009). The protein content, damaged starch, color, and Falling Number of the flour also affect pita breadmaking (Qarooni et al., 1988; Qarooni et al., 1993; Qarooni et al., 1994; Wang & Flores, 2000).

Pita bread was chosen as the subject of this study as it was previously reported that flat breads appear to tolerate protein supplements, including pulse flours, at low levels (Abdel-Aal et al., 1993). However, no results were reported for high levels of pulse flour incorporation, to the extent of the author's knowledge. In addition, this type of bread, which originally came from the Middle East and North Africa countries, has gained wide acceptance in many parts of the world (Amr & Ajo, 2005).

In this study, wheat flour in pita bread formulation was partially substituted with pulse flours of coarse and fine particle sizes milled from yellow peas (fine particles only), green lentils, navy beans, and pinto beans at 25, 50, 75, and 100%. The main objectives were: 1) to determine the most suitable pulse flour for wheat flour substitution in pita bread; 2) to determine the optimum level of incorporation of the pulse flours resulting in a product of acceptable quality; 3) to evaluate the effect of particle size distribution on product quality.

3.3. Materials and Methods

3.3.1. General

Four pulse flours were examined in this study. Commercial dehulled yellow pea flour with fine particle sizes (Parrheim Foods, Saskatoon, SK, Canada) was used. Green lentils were obtained from Simpson Seeds in Moose Jaw, SK, Canada. Navy beans and pinto beans were obtained from Parent Seed Farm, Ltd. in St. Joseph, MB, Canada. The pulse seeds were ground into fine and coarse particle size at the Canadian International Grains Institute, Winnipeg, MB, Canada. Green lentils were dehulled prior to milling using a Buhler pilot scale dehuller and splitter operated at 530 rpm. Navy beans and pinto beans were milled with the hull. Flour with a coarse particle size was obtained using a Jacobson 120-B lab scale hammer mill with a 1.5 screen. Flour was further milled using a Hosokawa Alpine 100 UPZ pin mill at 18,500 rpm to obtain flour with a fine particle size. Flour particle size distribution was determined using a CILAS 1180 particle size analyzer. The characteristics of all the pulse flours including particle size distribution cumulative at 90%, composition, and color are summarized in Table 3.1.

Commercially available enriched pre-sifted Robin Hood all purpose wheat flour (Smucker Foods of Canada Co., Markham, ON, Canada) was used for preparation of the composite flours and the controls. Blends containing 25, 50, and 75% of each pulse flour, as well as 100% pulse flour were referred as the composite flours in this study. The composite flours were stored in the zip-locked plastic bags and held at room temperature until required for testing.

Table 3.1. Characteristics of Wheat Flour and Pulse Flours

	Wheat flour	Pea flour	Green lentil flour		Navy bean flour		Pinto bean flour	
			Fine	Coarse	Fine	Coarse	Fine	Coarse
Moisture[1] (g/100g)	12.9±1.0	7.92 ± 0.10	6.30 ± 0.01	7.75 ± 0.03	6.70 ± 0.02	10.98 ± 0.03	6.72 ± 0.04	9.90 ± 0.02
Protein[2] (g/100g)	13.4 ± 0.13	22.36 ± 0.09	25.02 ± 0.03	24.43 ± 0.01	22.13 ± 0.33	21.45 ± 0.27	22.04 ± 0.24	21.53 ± 0.19
Fat[3] (g/100g)	1.0 ± 0.07	0.94 ± 0.10	1.09 ± 0.09	0.84 ± 0.11	1.91 ± 0.09	2.24 ± 0.10	2.15 ± 0.02	2.44 ± 0.08
Ash[4] (g/100g)	0.38 ± 0.09	2.83 ± 0.10	2.22 ± 0.04	2.26 ± 0.01	4.03 ± 0.07	3.91 ± 0.02	4.15 ± 0.14	4.23 ± 0.04
Carbohydrates [5] (g/100g)	72.3 ± 0.32	61.95 ± 0.55	65.38 ± 0.08	64.72 ± 0.13	65.23 ± 0.22	61.42 ± 0.13	64.91 ± 0.14	61.82 ± 0.25
Whiteness Index[6]	78.08±0.36	80.83 ± 0.11	80.95 ± 0.09	72.82 ± 0.22	91.16 ± 0.10	87.5 ± 0.17	87.91 ± 0.21	85.22 ± 0.37
D [v,0.1][7](μm)	24.36±1.14	0.92 ± 0.02	0.29 ± 0.01	10.19 ± 0.65	0.38 ± 0.05	12.38 ± 2.63	0.30 ± 0.00	8.37 ± 0.43
D [v,0.5][7](μm)	75.67 ± 0.30	21.69 ± 0.07	16.05 ± 0.08	135.05 ± 10.13	21.73 ± 0.35	58.91 ± 2.63	21.78 ± 0.06	59.83 ± 2.71
D [v,0.9][7](μm)	129.81± 0.35	47.70 ± 0.43	35.52 ± 0.01	438.91 ± 2.91	48.47 ± 0.27	424.18 ± 1.94	48.38 ± 1.05	416.04 ± 2.15
Mean particle size (μm)	77.33 ± 0.30	23.45 ± 0.14	17.09 ± 0.05	189.74 ± 5.33	23.08 ± 0.22	155.28 ± 1.52	23.10 ± 0.05	149.69 ± 2.15

[1] Air Oven Method AACC 44-15A

[2]

[3]

[4]

[5]

[6]

[7]

[8] D[v , 0.1], D[v, 0.5], D[v, 0.9] are particle sized corresponding to the cumulative distribution at 10%, 50% and 90% respectively (e.g. D[v, 0.1] represents the value below which 10% of the cumulative distribution lies). Mean diameter provides the average size of all particles

3.3.2. Pita Bread Preparation

The formulation used for making the pita breads is given in Table 3.2. The weight of flour or blend used was adjusted to 14% moisture content. The amount of added distilled water for baking was based on farinograph water absorption (FAB) corrected to 14% moisture basis as determined with a Brabender Farinograph (Duisburg, Germany) at 500 BU of dough consistency. The Farinograph was equipped with a 50 g bowl, and the constant flour-weight procedure was applied (Method 54-21; AACC, 2000). The preliminary Farinograph tests showed that the maximum amount of added water, which results in a dough of acceptable handling properties, was equal to the FAB value. The other ingredients including active dry yeast (Fleischmann's, Montreal, QC, Canada) and salt (sodium chloride USP/FCC Granular, Fisher Scientific, Canada) were also used for pita preparation. A gum system consisting of cellulose gum, guar gum, and xanthan gum (TIC Gums, Inc., White Marsh, MD, USA) was added as a texture improver. Two controls were used in this study. The main control was baked entirely from wheat flour. The commercial fine particle yellow pea flour was considered a second control as only one particle size was available. It was used at substitution levels of 25, 50, 75, and 100%.

Table 3.2. Pita Bread Formulation

Ingredient	Weight, g
Flour or blend (14% mb)	100.0
Yeast (active dry)	1.0
Salt	1.5
Gum system *	0.40
Water	variable

* mixture of cellulose gum, guar gum, and xanthan gum (TIC Gums, Inc., White Marsh, MD, USA)

To prepare the pitas, the blend/flour, salt, yeast, water, and gum system were placed into the mixing bowl of a 100-g recording pin mixer (National MFG Co., Lincoln, NB, USA) and mixed at 140 rpm orbital speed for 120 s scraping the sides of the bowl after the first 45 s period and after the next 45 s. Mixing of the ingredients for 120 s produced the dough of acceptable handling properties and was standardized based on preliminary studies. After mixing, the dough was removed from the mixer, formed by hand into a ball and placed in a lightly greased bowl, covered, and allowed to ferment for 60 min at 37 °C and 85% relative humidity in a fermentation cabinet (National MFG Co., Lincoln, NB, USA). Then the dough was removed from the cabinet, divided into four pieces of approximately equal weight, placed into the bowl, and allowed to rest in the fermentation cabinet for 10 min. After that, the dough was sheeted by a Somerset dough sheeter (Somerset Industries, Inc., Billerica, MA, USA) by running the dough through the sheeter four times for the wheat control rotating 90° each time with a final gap of 2 mm. Doughs containing pulses were put through the sheeter three times, rotating 90 ° each time with a final gap of 3 mm. Different sheeting treatments for the wheat control and the samples were based on the ability of the dough to produce the pocket as a result of maximum separation between the top and bottom layers. That was established based on preliminary studies. The sheeted pieces of dough were cut using a round cookie cutter of 11.0 cm in diameter, placed on the tray, and allowed to proof for 30 min in the fermentation cabinet. The pitas were baked in an air impingement oven (Lincoln Food Services Inc., Footway, AN, USA) for 1 min at 288 °C. Baked pitas were cooled on a wooden rack for 5 min, evaluated for weight, pocket height, and diameter. Then the pitas were placed into zipped plastic bags and kept at room conditions until evaluated for their physical properties on the second day after baking. Four pitas were baked from each blend, and the three most uniform pitas were used for evaluations.

3.3.3. Physiochemical Analysis

Determination of the moisture content of wheat flour and the composite flours was carried out based on the AACC one-stage procedure (Method 44-15A; AACC International, 2000).

Physical properties of pitas and their color characteristics were measured on the same day of baking after the samples were completely cooled. Pitas were weighed and evaluated for pocket height and diameter (2 readings for each pita rotating 90 ° turn between readings) using an electronic caliper (Model SDV-6"A, Mitutoyo Corp., Japan). The mean diameter was calculated for each pita. Loaf volume was determined by a rapeseed displacement method. Specific loaf volume was calculated as a ratio between loaf volume and weight and expressed in cm^3/g.

Crust color (CIE tristimulus system, L*, a*, and b* values) of the top and bottom parts of the pita was measured using a Minolta CM-700d/600d spectrophotometer (Konica Minolta Sensing, Inc., Japan) with 10° standard observer and D65 daylight illuminant calibrated with the white plate. Two readings of the color values were taken for the top and bottom parts of each pita, and then the average of the respective values was calculated. The color was expressed as a whiteness index based on the formula (Al-Hooti et al., 2000):

$$\text{Whiteness} = 100 - [(100-l^*)^2 + a^{*2} + b^{*\,2}]^{0.5}$$

The other color characteristics, such as hue angle and chroma, were also calculated using the following formulas (Al-Hooti et al., 2000):

$$\text{Hue Angle}=\tan^{-1}(b^*/a^*);$$

$$\text{Chroma}=(a^{*2} + b^{*2})^{0.5}$$

Texture parameters of pitas were measured on the second day after baking. Pita texture was measured by an extension test using a TA.XT2 texture analyser (Texture Technologies Corp., Scarsdale, NY and Stable Micro Systems, Godalming, Surrey, UK) with a hook speed of 3.3 mm/sec and a trigger force of 1g. A procedure for the dough extensibility test using a TA.XT2 texture analyser was based on an established method (Suchy et al., 2000) with some modifications. For pita bread testing, the “go to time” setting was adjusted to 5.05s. Texture was expressed as the maximum peak force as well as the total area under the curve. Prior to measuring, each pita was cut horizontally into the top and bottom parts, and then each part was cut into strips of 6.5 mm in width using a pasta machine with attachments (Marcato MultiPasta, Italy). Each individual strip was placed across the Kieffer dough holder and immediately tested for the texture. The two strips from the top part and two strips from the bottom part of the same pita were used for each measurement. The mean values of the top and bottom parts were calculated for each pita.

3.3.4. Sensory Evaluation

Pitas containing coarse navy bean flour at 25 and 100% supplementation and coarse pinto bean flour at 25% supplementation were selected for sensory evaluation based on the limitation of 3 samples desire to see differences between flour type and level of substitution. The procedure was scaled up for baking and was conducted at the Food Processing Development Centre, Leduc, AB. Other than different equipment, the main difference was that the cooking temperature for the pitas prepared at this scale was only 274°C lower than the 288°C used for laboratory preparation, due to equipment limitations. Eighty untrained panelists were asked to evaluate the samples for aroma, appearance, color, flavor, texture, and overall acceptability. Panelists rated the samples using 9 point hedonic scales where 1 equals dislike extremely and 9 equals like extremely.

3.3.5. Statistical Analysis

All the composite flours (28 in total) were baked into pitas in duplicate batches, and all the data were expressed as means ± SD. The statistical analyses were performed using SAS software (SAS version 9.1.2) using a GLM with differences at a 0.05 level of significance. A 3x2x4 factorial experiment was conducted to determine the effect of flour type, flour particle size, and level of substitution respectively on pita bread quality. A series of contracts was performed to make general comparisons between both the wheat control and commercial yellow pea flour and the remaining pulse flours for pita bread baking suitability.

3.4. Results and Discussion

All significant ($p<0.05$) main effects and interactions between effects on the characteristics of composite flours and baked pitas are summarized in Table 3.3.

Table 3.3. Significant Effects of the Main Factors and their Interactions on Some Parameters of Composite Flours and Pita Bread*

Factor	Moisture	FAB	Diameter	Pocket Height	SLV	Force	Area under the Curve	Whiteness
Flour	NS	S	S	NS	S	S	S	S
Particle size	S	S	NS	NS	NS	NS	S	S
Level	S	S	S	NS	S	S	NS	S
Flour*Particle size	S	NS	S	S	NS	NS	NS	NS
Flour*Level	NS	S	S	S	S	S	S	S
Particle size*Level	NS	NS	NS	NS	NS	S	NS	NS
Flour*Particle size*Level	NS	NS	NS	NS	NS	NS	NS	NS

* Results are obtained by SAS (3x2x4 factorial experimental design where Flour –flour type effect, Particle size – flour particle size effect, and Level – flour substitution level effect)
FAB – Farinograph water absorption
SLV – Specific Loaf Volume
S – significant effect ($P<0.05$);
NS – not significant effect ($P>0.05$)

The dashed line on the figures, which are included in the following discussions, represents the mean value of each measured or calculated parameter for the wheat control.

3.4.1. Analyses of the Composite Flours

Moisture

The moisture of the composite flours, as well as wheat flour, was evaluated in order to adjust the weight to 14% moisture content in the pita formulation. The raw moisture data are summarized in Appendix 1. Statistical analyses confirmed that the interaction between flour type and its particle size was significant (Table 3.3). The moisture content of the composite flours containing navy bean and pinto bean flours with the coarse particle size was significantly higher than the moisture content of the same composite flours with the fine particle size (Figure 3.1). Therefore, coarse flours appeared to have a greater water-holding capacity than fine flours. That was in agreement with the results reported by Zhang & Moore (1997) and Prasopsunwattana et al. (2009) where wheat bran and whole barley milled into different particle sizes were added to baked products.

Level of substitution also had a significant effect on the moisture content of the composite flours (Table 3.3). With increased proportion of pulse flours in the composites, there was a steady decrease in their moisture content as the pulse flours of lower moisture content were blended with wheat flour of higher moisture content (Figure 3.2).

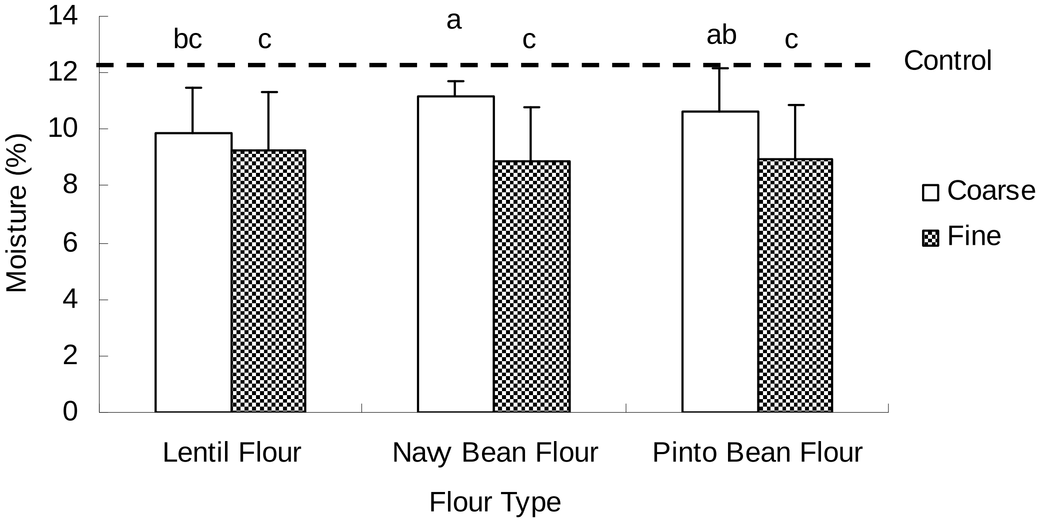

Figure 3.1. Effect of Flour Type and Flour Particle Size on the Moisture Content of the Composite Flours. Bars with the same character are not significantly different (P>0.05). Control is the wheat control.

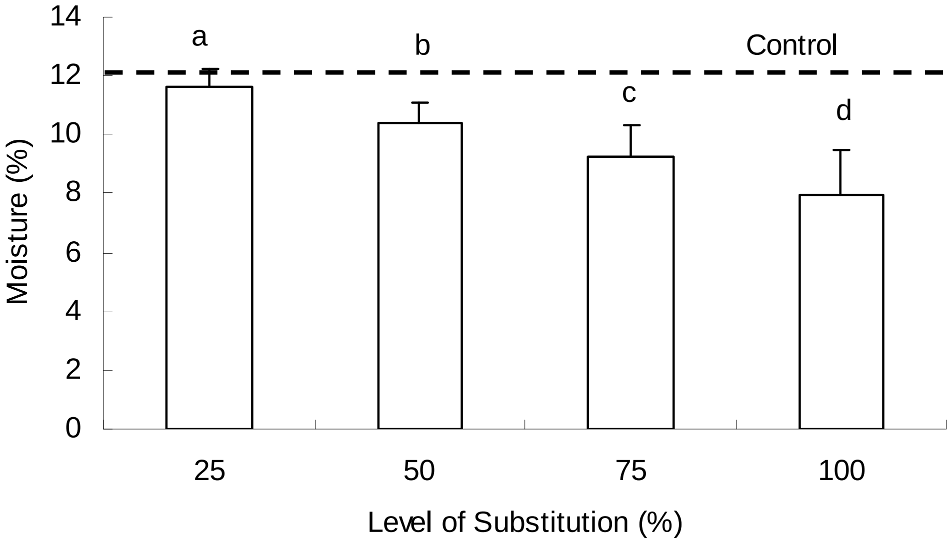

Figure 3.2. Effect of Level of Substitution on the Moisture Content of the Composite Flours. Bars with the same character are not significantly different (P>0.05)

Based on the contrast analyses, the composite flours containing yellow pea flour were not significantly different from the wheat control; all the remaining composites were significantly different from the wheat control and yellow pea control (Table 3.4).

Table 3.4. Comparison of Pulse Flour-Based Pitas with Wheat and Commercial Yellow Pea Flour-Based Pitas *

Parameter	Wheat Flour				Commercial Yellow Pea Flour		
	Green Lentil	Yellow Pea	Navy Bean	Pinto Bean	Green Lentil	Navy Bean	Pinto Bean
Moisture	S	NS	S	S	S	S	S
FAB	S	S	S	S	S	S	S
Diameter	S	NS	S	S	NS	S	NS
Pocket Height	NS	NS	NS	NS	NS	NS	NS
Specific Loaf Volume	S	S	S	S	S	S	S
Force	S	S	S	NS	S	S	S
Area Under Curve	NS	S	S	S	S	S	S
Whiteness	S	S	S	S	S	S	S

* Results are obtained by Contrast Analyses;
FAB – Farinograph water absorption
S – Significant effect ($P<0.05$);
NS – No significant effect ($P>0.05$)

Farinograph Water Absorption (FAB)

Farinograph Water Absorption (FAB) of the composite flours as well as wheat flour was determined to establish the amount of water added to the pita formulation. Although the other Farinograph parameters, such as dough development time and dough stability, were also recorded, they did not affect the procedure of pita preparation as the mixing time was standardized for 2 min for all the composite flours. All the Farinograph parameters are shown in Appendix 1; however, only the changes in the FAB are discussed in detail. An increase in the level of substitution of wheat flour with the pulse flours resulted in a decrease in FAB with the range in values from 38.6 to 65.0% depending on the pulse flour (Figure 3.3). Contradictory results were found in similar studies where lower percentages of pulse flours of different pulse crops were included into the blends. For example, a similar conclusion was reported by D'Appolonia (1977; 1978); however, the opposite results were found by Sadowska et al. (2003) and Anton et al. (2008a). The lowest range of difference in the FAB values was observed for the blends containing navy bean flour at 25, 50, and 75% and pinto bean containing blends at 75 and 100%. This might be because of the higher proportion of the fibre content, which accounted for higher hydration in the bean flours than in lentil flour as beans were milled with the hull, and the lentil seeds were dehulled prior to milling. The most significant variation and the greatest reduction in FAB were observed for the blends containing green lentil flour at all levels. In addition, particle size of the pulse flours had a significant effect on FAB resulting in an average value of 58.02±8.93% for the blends containing coarse pulse flours and 55.82±8.20% for the blends containing fine pulse flours (Table 3.3). That was in agreement with the results obtained for the moisture content where the blends with fine particle sizes retained less water than the blends with coarse particle sizes (Figure 3.1). Wang & Flores (2000) had a similar observation when comparing Farinograph characteristics of doughs prepared from three different wheat varieties with different particle sizes. They revealed that the greater the particle size of the flour, the higher its water absorption.

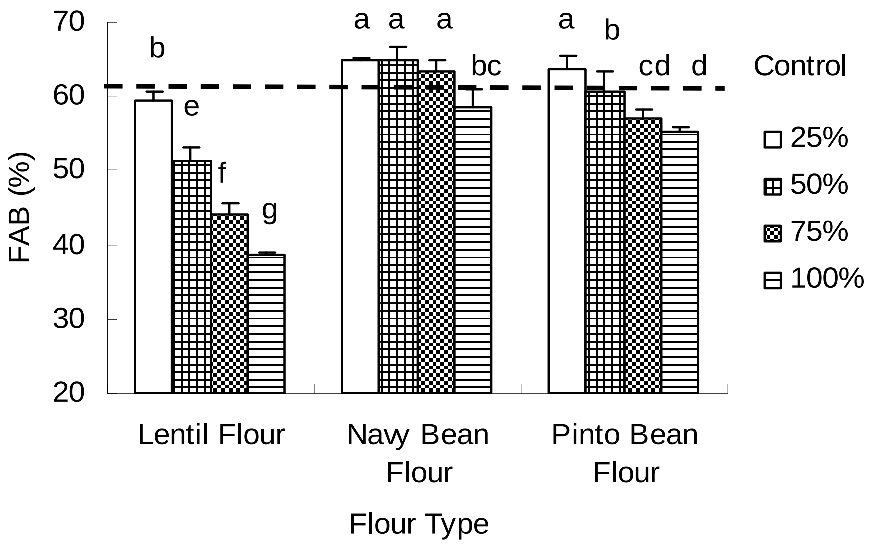

Figure 3.3. Effect of Flour Type and Level of Substitution on FAB of the Composite Flours. Bars with the same character are not significantly different (P>0.05)

Contrast analyses showed that all the composite flours were significantly different from the wheat control and yellow pea control with respect to FAB (Table 3.4).

Reduction in FAB of the composite flours can be because of the different composition and solubility of wheat and pulse proteins. Wheat gluten proteins, which account for 80 – 90 % of the total protein content in wheat, contribute to visco-elastic properties of the dough and allow development of optimal dough consistency at the corresponding optimal level of absorbed water (Schofield, 1988). Pulse proteins do not contain gluten, and consist mostly of albumins, globulins, and glutelins which are soluble in different solutions (Roy et al., 2010). Therefore, the proportion of gluten in wheat-pulse blends is reduced with an increased level of pulse flours. While pulse proteins absorb water, they might contribute to dough viscosity, but not dough elasticity, and thus reducing the amount of water required to produce the dough of the same optimum consistency.

Starch is another flour component which influences the ability of the flour to absorb water. It has been numerously reported that the level of starch damage in wheat plays an important role in water absorption and baking performance (Holas & Tipples, 1978; Tipples et al., 1978; Farrand, 1972). Wheat flour, which has been subjected to excessive grinding, has higher level of damaged starch and thus results in increased water absorption (Okada et al., 1986; Kurimoto & Shelton, 1988). However, each wheat variety has individual optimal level of damaged starch which results in bread of optimal quality (Okada et al., 1986). In commercial wheat flour, the level of damaged starch varies between 5 and 10%. If the level is higher than 10%, the dough becomes slack, sticky, and difficult to handle (Sluimer, 2005). In this study, pulse flours with coarse particle size was obtained by grinding of the seeds using hummer mill, and pulse flours with fine particle size was produced by additional grinding using pin mill. Therefore, an assumption can be made that pulse flours with fine particle size had a higher level of damaged starch than these with coarse particle size, and the composites containing pulse flours with fine particle size are expected to have higher water absorption. However, that is not in agreement with the results obtained in this study as the composites prepared with fine lentil and pinto bean flours had significantly lower water absorption than these prepared with coarse lentil and pinto bean flours. It could be due to the pulse flours with fine particle size had excessive level of damaged starch. Further studies on pulse starch content and its physical state are recommended in order to get more insight on the mechanism of water absorption by the composites with different particle size.

3.4.2. Analyses of Pita Bread

Diameter

Diameter of pita bread is an important parameter as it describes the degree of shrinkage or expansion during baking (Qarooni et al., 1987; Williams et al., 1988). In this study, all the circular dough pieces were consistent in diameter (110 mm) before they were left for the final proofing and baking, and then measured in diameter when baked and cooled. The raw data are shown in Appendix 2. An interaction between type of flour and level of substitution was significant (Table 3.3). For the pitas containing navy bean flour, those containing 50, 75, and 100% navy bean flour had a significantly smaller diameter than was observed for the pitas containing 25% navy bean flour (Figure 3.4). Pitas baked from lentil flour and pinto bean flour at all the levels of substitution were not significantly different in diameter. Flour particle size had no significant effect on the diameter of the pitas containing lentil, navy bean, and pinto bean flour (Table 3.3.; Figure 3.5). However, the interaction between flour type and flour particle size was significant such that the pitas containing fine navy bean flour resulting in pitas with smaller diameter than the pitas containing coarse and fine lentil flours (Table 3.3).

Based on the contrast analyses, pitas containing yellow pea flour were not significantly different from the wheat control in diameter, but pitas containing navy bean and pinto bean were significantly different than the wheat control (Table 3.4). If compared to the yellow pea control pitas, only navy bean pitas were significantly different in diameter.

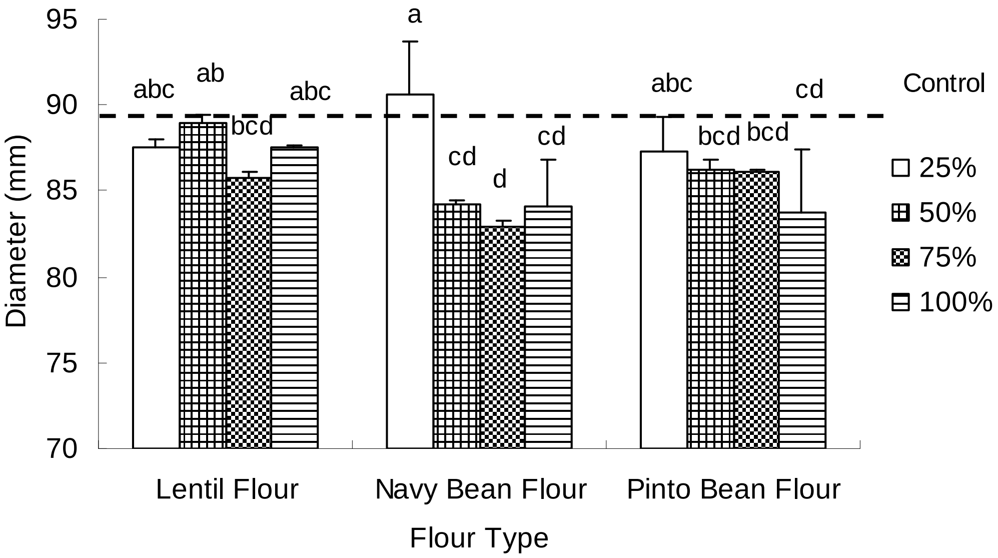

Figure 3.4. Effect of Flour Type and Level of Substitution on the Diameter of Pita Bread. Bars with the same character are not significantly different (P>0.05)

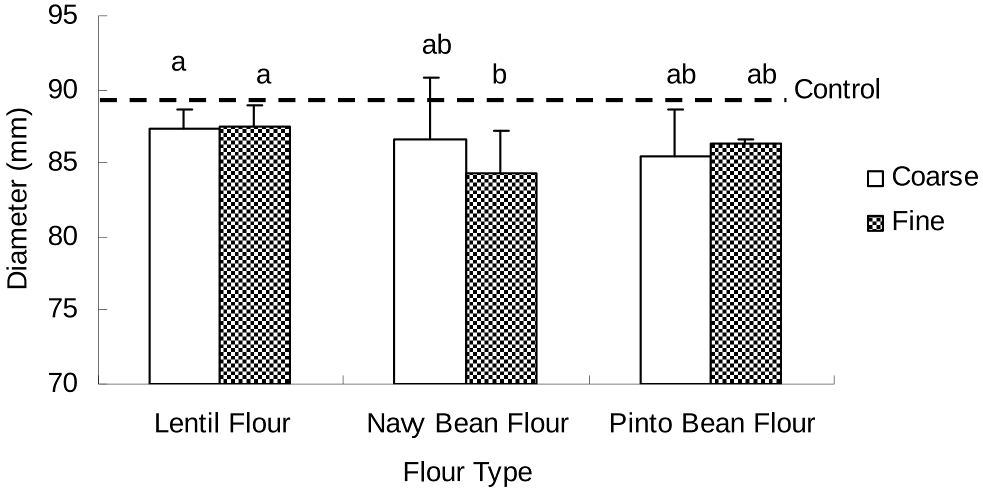

Figure 3.5. Effect of Flour Type and Flour Particle Size on the Diameter of Pita Bread. Bars with the same character are not significantly different (P>0.05)

Pocket Height

A unique characteristic of pita bread is having a pocket which is formed during baking at high temperature (Qarooni, 1996; Williams et al., 1988). The extent of the separation of the upper and lower layers of pita bread was measured and expressed as a pocket height. The raw data are included in Appendix 2. All the composite flours were able to produce pockets in the pitas which were not significantly different in the pocket height (Figure 3.6). The only exception was for a comparison of the pitas containing 75 and 100% lentil flour where pocket height was significantly lower for the 100% lentil pita. Flour particle size had a significant effect on the pocket height only for the pitas containing navy bean resulting in a lower value for the coarse particle size (36.97±2.91mm) and a higher value for the fine particle size (41.27±2.10mm) (Table 3.3; Figure 3.7). Particle size had no significant effect on the pocket height of pitas made from lentil and pinto bean flours (Table 3.3). Overall, compared to the wheat control and yellow pea control, pitas from the blended experimental flours were not significantly different in the pocket height (Table 3.4).

During baking, the pocket of pita bread is formed due to an expansion of two types of gases which are CO_2 accumulated during fermentation, and the steam from the cells (Williams et al., 1988; Faridi & Rubenthaler, 1984). Based on the data obtained, all the composite flours even at higher levels of substitution produced doughs with structures which were able to expand and produce a pocket during baking without rupture of the top and/or bottom the surface.

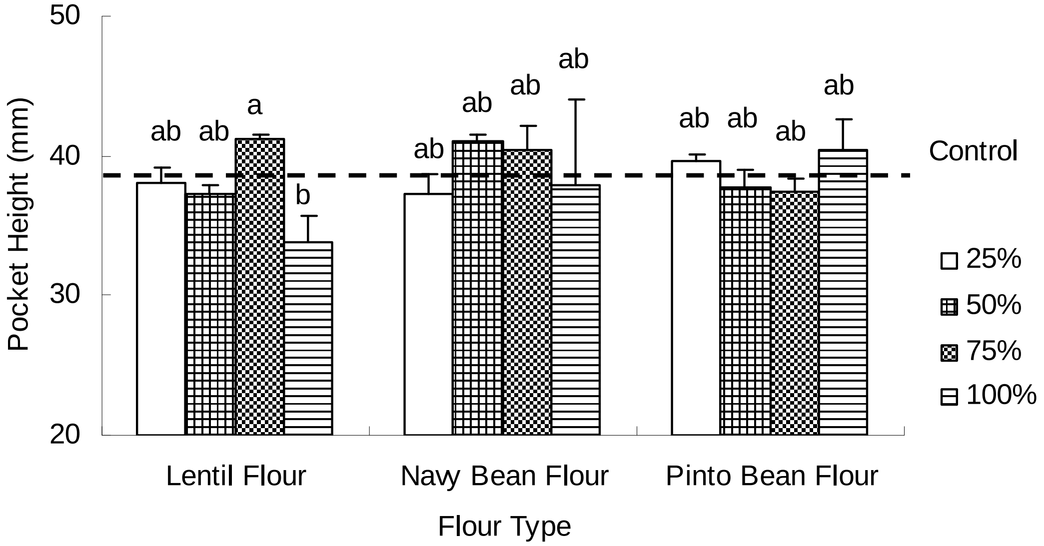

Figure 3.6. Effect of Flour Type and Level of Substitution on the Pocket Height of Pita Bread. Bars with the same character are not significantly different (P>0.05)

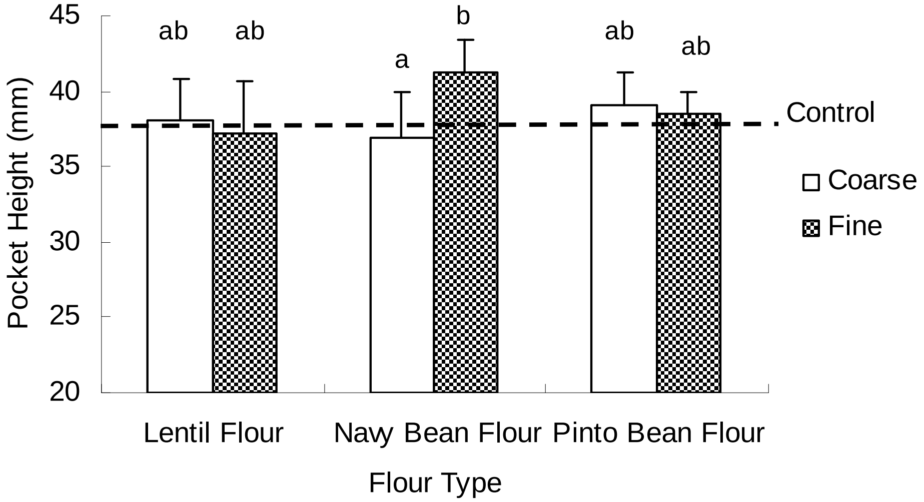

Figure 3.7. Effect of Flour Type and Flour Particle Size on the Pocket Height of Pita Bread. Bars with the same character are not significantly different (P>0.05)

Specific Loaf Volume (SLV)

Loaf volume, as well as specific loaf volume (SLV), accounted for the ability of the doughs prepared from the composite flours to retain the gas cells accumulated during fermentation and the puffed shape produced during baking. For the wheat control and the pitas containing all pulse flours of the coarse and fine particle sizes at 25% substitution, LV and consequently SLV were a challenge to measure. At these levels, the pitas were not able to keep their shape during the measurement; they were flattened under the weight of the rapeseeds used in the measuring test because of the soft texture. In these cases, LV of the flattened pitas was recorded. However, the ability to be easily flattened can be advantageous for the industrial scaling of pita bread as in retail a few flattened pitas are often included in one package. All the remaining pitas were stable in shape while analyzed for LV. All data are shown in Appendix 2.

Statistical analyses confirmed that an interaction between flour type and level of substitution had a significant effect on SLV (Table 3.3; Figure 3.8). The pitas containing 25% lentil flour were significantly lower in SLV than the pitas containing 50, 75, and 100% lentil flour. A similar tendency was observed for the pitas baked from navy bean flour where there was a significant difference in SLV between 25% navy bean pitas and 50, 75, and 100% navy bean pitas. Pitas containing pinto bean at all substitutions were not significantly different in SLV. The significant effect of flour type was seen only at 50% where pitas containing 50% pinto bean were significantly different in SLV than the pitas containing 50% lentil flour or 50% navy bean flour (Figure 3.8). Flour particle size was not significant for SLV (Table 3.3). Contrast analyses confirmed that all pulse containing pitas were significantly different from the wheat control and yellow pea control (Table 3.4).

It appears that relatively high values for SLV can be due to the ability of all composite flours to produce a pocket and keep the puffed shape resulting in high SLV. Only the wheat control and the pitas containing 25% the pulse flours were exceptions, due to flattening during the measurement.

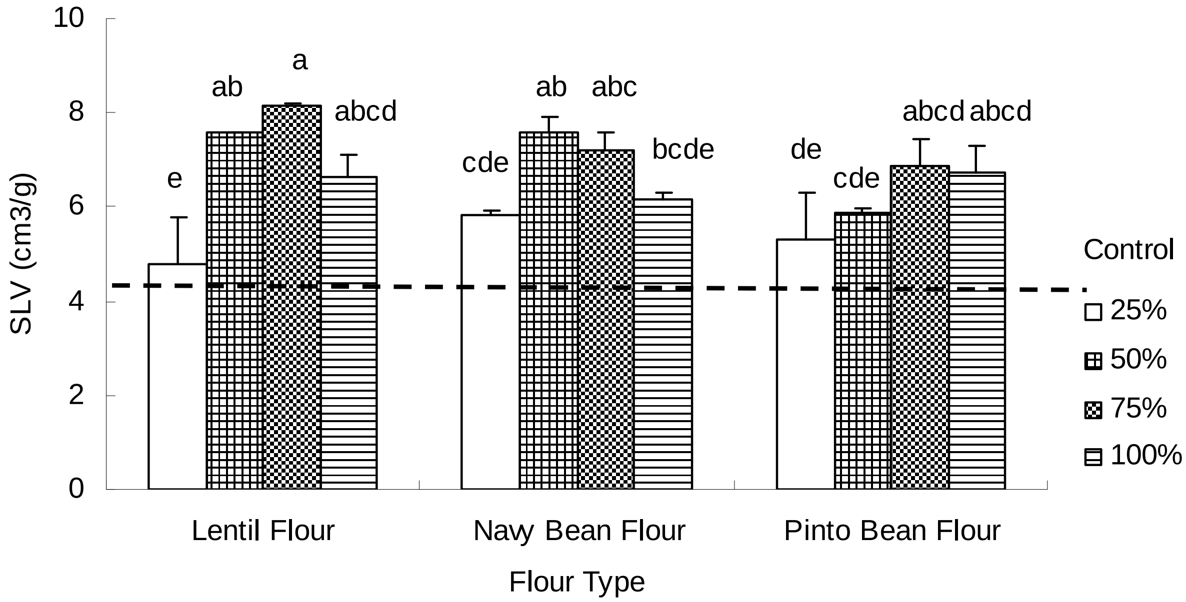

Figure 3.8. Effect of Flour Type and Level of Substitution on Specific Loaf Volume of Pita Bread. Bars with the same character are not significantly different (P>0.05)

Texture

Texture of pita bread is relatively dense because it has two solid top and bottom layers. Each layer has crust and crumb parts, and the crumb is a thin inner wall of the crust. Texture, being an important indicator of consumer's acceptability of pita bread, is expected to be pleasant and easy to chew (Williams et al., 1988). In this study, texture was measured objectively with an extension test and expressed as force required to rupture the strips of the top and bottom layers and the total area under the curves which characterized the extensibility. As the texture of the bottom layer of the pita bread can be influenced by contact with the hot oven tray, only the data related to the top layer of the pita bread is discussed. The raw data related to the texture of the bottom and top layers of pita bread are included in Appendix 3. For the pitas containing 100% pulse flours, except for navy bean flour, the data are not available since the texture of these pitas was very brittle and the surface cracked during separation into the top and bottom layers or when cutting into the strips.

For the pitas containing pinto bean flours, an increase in the level of pulse flour in the formulation from 25 to 75% resulted in an increase in the force values when data for coarse and fine particles were combined (Table 3.3; Figure 3.9). A significant increase in force values was detected when comparing pitas made from pinto bean flour at 25% substitution (0.088±0.001kg) to those at 75% substitution (0.146±0.035kg). For navy bean pitas, there was no significant difference in the force values at all levels. Lentil flour affected the texture differently. When the level of substitution increased from 25 to 50%, a significant increase was observed in the force values (0.120±0.004kg versus 0.220±0.010kg) followed by a decrease in the force at the level of 75% (0.177±0.025kg). At this level, it was observed that the top layer lost its ability to tear while extended, and the breaking point was achieved by a rapid cracking but not tearing. Flour particle size significantly affected texture for pitas at 75% substitution producing softer texture for the coarse particle size (0.152±.030kg) than that for the fine particle sizes (0.187±0.015kg) at

75% level (Figure 3.10). At 25 and 50% levels, there was no significant difference in the force to break between pitas made from the coarse and fine particle sizes. Contrast analyses showed that only the pitas made from pinto bean flour were not significantly different from the wheat control in the force. All the remaining pitas were significantly different from the wheat control and yellow pea control (Table 3.4).

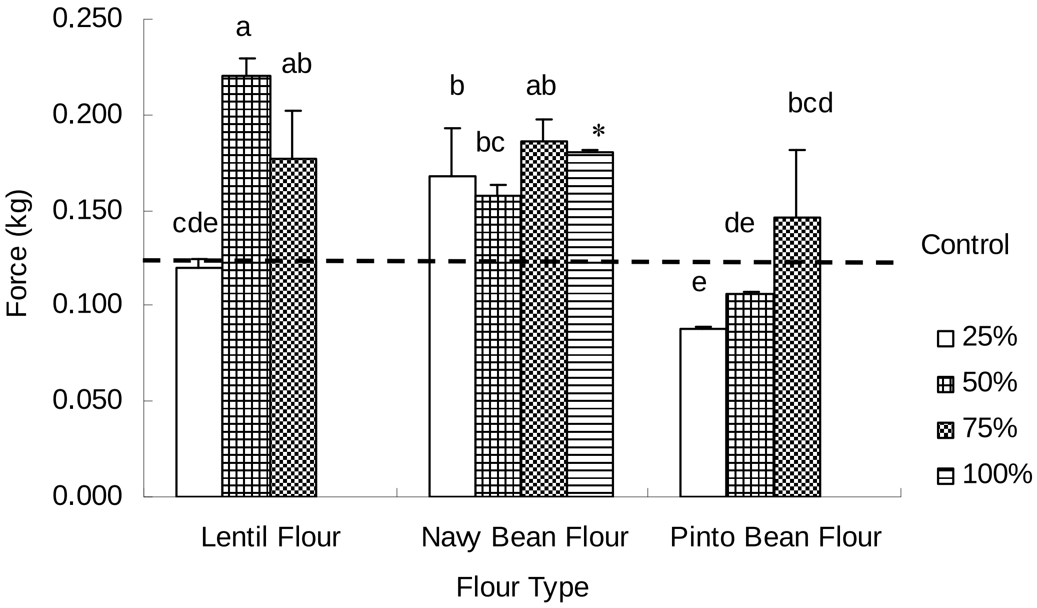

Figure 3.9. Effect of Flour Type and Level of Substitution on Force of the Top Layer of Pita Bread. Bars with the same character are not significantly different (P>0.05)
* - the data was available only for navy bean four and not included in statistical analyses

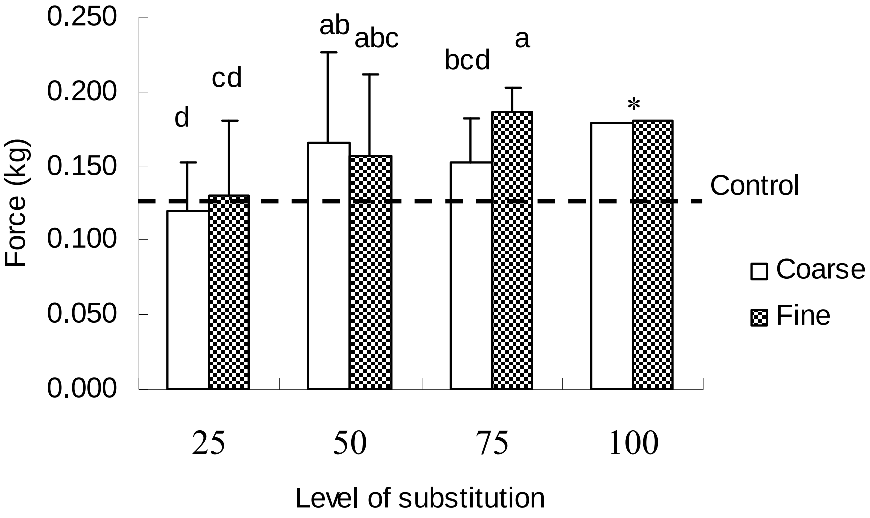

Figure 3.10. Effect of Level of Substitution and Flour Particle Size on the Force of the Top Layer of Pita Bread. Bars with the same character are not significantly different (P>0.05).
* - the data was available only for navy bean four and not included in statistical analyses

Crust and crumb structure of pita bread contribute to its texture, and these parts are developed during the whole process of breadmaking. Wheat gluten plays a main role in texture development. With an increasing level of pulse flours in the formulation, the proportion of gluten is decreasing, and a lower amount of gluten protein is involved in developing the sponge structure of the dough which sets up into a soft crumb when baked. In this study, there was little crumb and the level appeared to decrease as greater levels of pulse flour were incorporated. The products containing 75 and 100% pulse flours appeared to have no crumb structure, and the crust primarily accounted for the texture attributes. Another important observation was that rapid evaporation of moisture from the pita surface during baking occurred, and this resulted in overdrying and a loss of softness. This was more pronounced with 75 and 100% pulse flours. To improve the water holding capacity of the composite flours, a gum system was included in the formulation. The texture of the pitas containing pulse flours at all levels was improved but still not enough to take measurements at 100% level. Only 100% pitas containing navy beans tolerated the cutting action into the upper and lower layers and subsequently into the strips, and readings for texture could be taken. A negative effect of non-wheat ingredients in flat bread formulations on the texture was previously reported; however, the studied materials were of a different nature and at lower levels of substitution in these studies (Hallab et al., 1974; Anton et al., 2008a; Izydorczyk et al., 2007; Basman & Köksel, 1999).

Significant effect of flour particle size, which was revealed at 75% supplementation, needs to be highlighted. It seems that at higher levels of incorporation, composite flours with the coarse particle size produced products with softer texture than those with the fine particle size. That was in agreement with the study conducted by Wang & Flores (2000) where they evaluated the effect of particle size of flours milled from different wheat varieties on the texture of tortillas. They concluded that finer particles produced the tortillas of poor textural properties. The suggested explanation was that the flours with finer particle sizes had the lower protein content than those with coarse particle sizes.

The values for area under the curves, which relate to the toughness of the product, had a similar tendency to the force values and supported the proposed explanations of the texture changes. There was a significant increase in the area under the curve for the pitas containing lentil flour when the amount of added pulse flour increased from 25% (0.165±0.006kg*sec) to 50% (0.256±0.004kg*sec), and then there was a significant drop in the area under the curve value (0.163±0.018kg*sec) when the level of lentil flour increased up to 75% (Table 3.3; Figure 3.11). It was visually observed that the pitas gradually lost their tearing quality when amount of added pulse flours increased, and at a certain level, which was 50% for the lentil flour, the tearing ability was lost completely as the rupture of the pita strips was achieved by cracking but not tearing. For example, Figures 3.12 and 3.13 show the typical curves obtained during the textural measurements for the pitas at lentil flours levels of 25 and 50%, respectively. Based on these graphs, it can be seen that the character of the bending areas changes from curved into very sharp as the way of rupture changes from tearing to cracking.

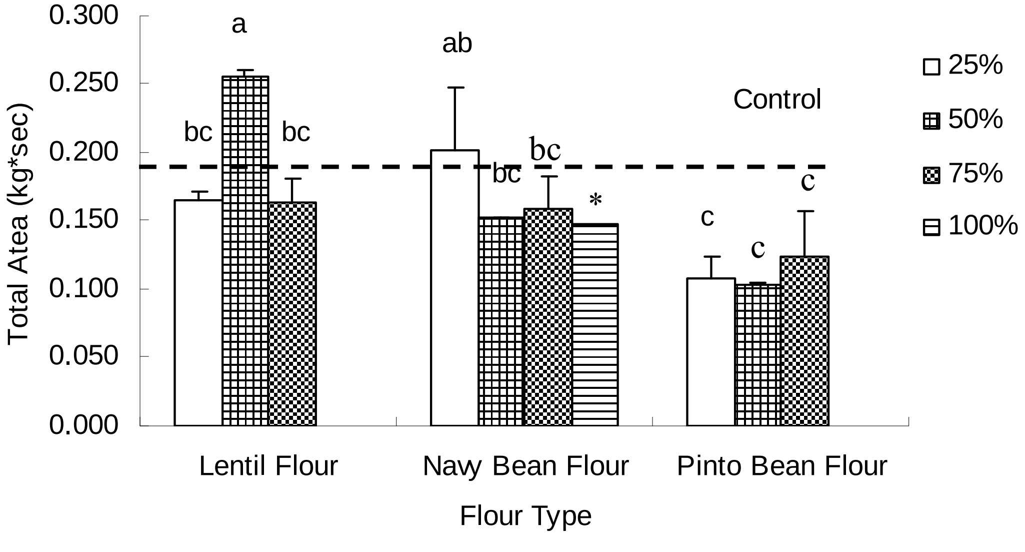

Figure 3.11. Effect of Flour Type and Level of Substitution on the Total Area under the Curve of the Top Layer of Pita Bread. Bars with the same character are not significantly different (P>0.05).

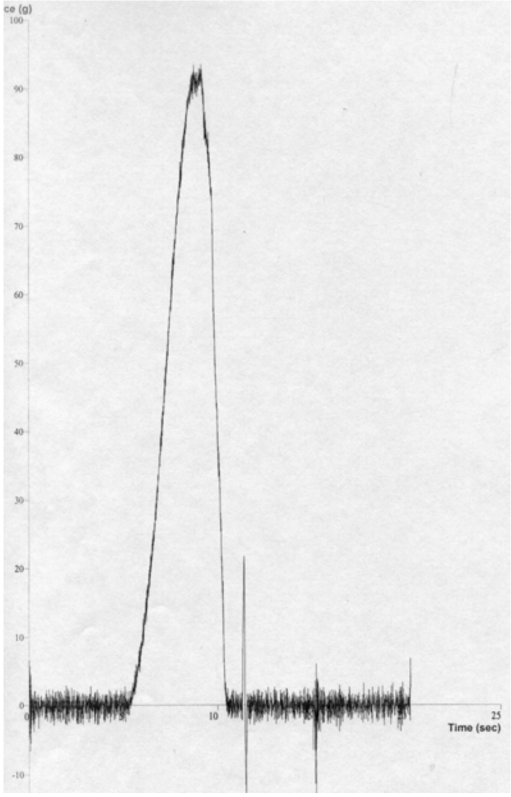

Figure 3.12. The Texture Curve at 25%

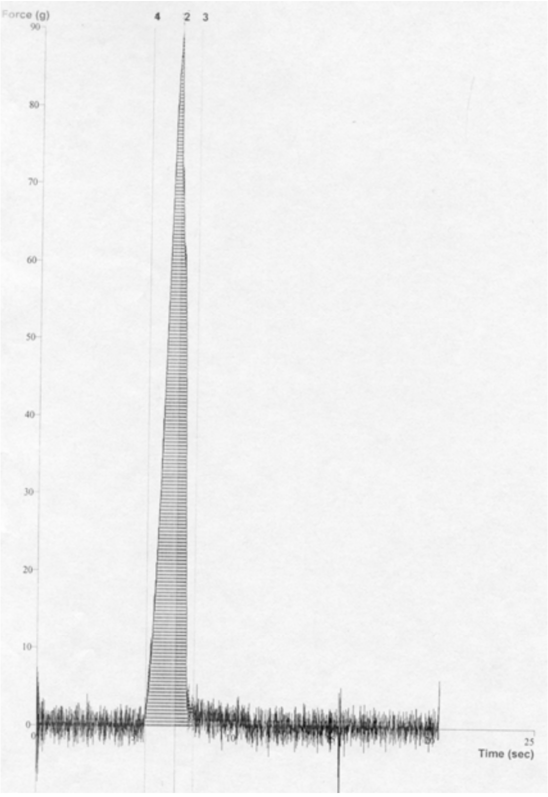

Figure 3.13. The Texture Curve at 50%

For the pitas containing navy bean and pinto bean flours at 25, 50, and 75%, no significant difference was detected for the area under the curve (Figure 3.11). Flour particle size had a significant effect on the area under the curve values, which is in agreement with the results obtained for the force (Table 3.3). Composite flours with the coarse particle sizes resulted in a lower value of the area under the curve (0.150±0.047kg*sec) compared to those with the fine particle size (0.168±0.050kg*sec) regardless of flour type and level of substitution.

Contrast analyses for general comparisons showed that lentil containing pitas were not significantly different from the wheat control in the area under the curve value.

All remaining pitas containing pulses were significantly different from the wheat control and yellow pea control (Table 3.4).

Color

Product color is considered one of the most important characteristics influencing consumer acceptability. In this study, crust color of pita bread was expressed as the whiteness index, which accounted for the lightness of the product and was calculated based on the L*, a*, and b* values. The other color components, such as hue angle, which distinguished a “red” from a “green” from a “blue”, and the chroma index, which represented the color saturation, were also calculated and are included in Appendix 4 for the top crust of pita bread and Appendix 5 for the bottom crust. The whiteness index of the top crust is discussed in detail in this section.

A significant decrease in the whiteness index was detected for the pitas containing lentil flour as the amount of flour increased from 25 to 75%; no difference was observed between pitas containing 75 and 100% green lentil flour (Figure 3.14). For the pitas containing pinto bean flour, a significant decrease in the whiteness index was obtained with 75 and 100% in comparison to the pita with 25% flour. The pitas containing navy bean flour did not vary significantly with the level of substitution, and for levels of substitution of 50% and above had significantly higher whiteness indices than comparable lentil or pinto bean pitas. Overall, there was no significant difference detected in the whiteness index at levels 75 and 100% for all pulse flours. Flour particle size significantly impacted the whiteness index resulting in a higher value for the coarse particle size (57.02±5.86) than for the fine particle size (55.52±5.81) when analyzed for all flour types at all levels (Table 3.3). Based on contrast analysis, all the pitas containing pulses flour were significantly different from the wheat control and yellow pea control in terms of the whiteness index (Table 3.4).

Polyphenolic compounds, which are mostly distributed in the seed coat, are colored and responsible for the color of the seed (Jadhav et al., 1989). Lentils have a relatively high content of polyphenols (490mg/100g in catechin equivalent), whereas the whole pinto beans are lower in the tannin content (264.7mg/100g in catechin equivalent) (Adsule et al., 1989a; Jadhav et al., 1989). Whole peas are very low in the tannins (0.06 – 0.35 % in catechin equivalent), while white-seeded beans contain no detectible amounts of tannins (Adsule et al., 1989b; Jadhav et al., 1989).

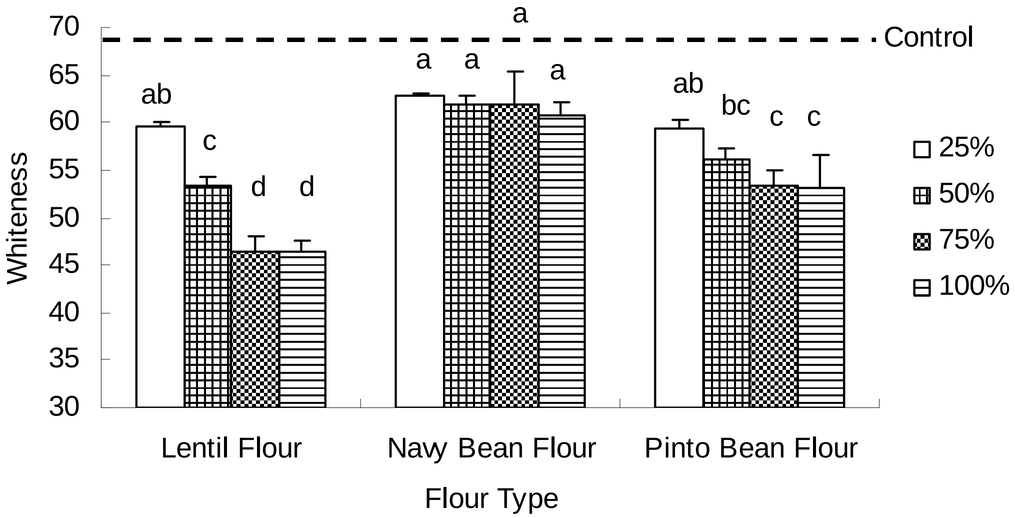

Figure 3.14. Effect of Flour Type and Level of Substitution on the Whiteness Index of the Top Crust of Pita Bread. Bars with the same character are not significantly different (P>0.05)

In this study, even though lentil seeds were dehulled prior to milling, the colored pigments were still present in the flour as a part of the cotyledon thus contributing to the color. Navy beans, being a white colored variety, appeared not to affect the color of the end product even though they were milled with the hull. Such a trend was obvious for the pitas containing navy bean flour. The pigment in the hull of pinto beans contributed to the lower whiteness index at higher levels of substitution. Changes in color were reported by Anton et al. (2008a) and Hallab et al. (1974) when the flours from the colored bean varieties and chickpeas were added into flat breads, respectively. Prasopsunwattana et al. (2009) and Izydorczyk et al. (2008) detected less pronounced changes in the brightness (L* value) when the barley materials of coarser particle size were added into flat breads compared to those of the fine particle size.

3.4.3. Sensory Evaluation

Summary of the mean scores for pitas containing coarse navy bean flour at 25 and 100% supplementation and pitas containing coarse pinto bean flour at 25% supplementation is shown in the Table 3.5. Pitas containing coarse navy bean flour at 25% were not significantly different from the wheat control for all sensory attributes whereas pitas containing coarse pinto bean flour at 25% had significantly higher scores for texture and overall acceptability, and no significant difference for other parameters. In general, these pitas were as good as or better than the control. Pitas made from 100% coarse navy bean flour had significantly lower scores for all the sensory parameters despite personal observation from the laboratory trial that suggest they may be similar. It is possible that large scale production and lower cooking temperature used resulted in some variations in the quality that were not seen at the laboratory scale.

Table 3.5. Mean Scores of some Sensory Attributes for the Selected Pitas*

Sensory Attribute	Wheat Control	% of Pulse Flour			P-value
		25% Navy Bean	25% Pinto Bean	100% Navy Bean	
Aroma	6.0a	6.1a	6.4a	5.1b	<0.01
Appearance	6.5a	6.6a	6.8a	4.7b	<0.01
Color	6.5a	6.6a	6.7a	5.3b	<0.01
Flavor	6.1ab	6.0b	6.5a	2.7c	<0.01
Texture	5.4b	5.6b	6.8a	3.3c	<0.01
Overall	5.9b	5.6b	6.8a	2.4c	<0.01

* Means within the same raw sharing a common letter were not significantly different (P>0.05)

3.5. Conclusions

An interaction between type of pulse flour and level of substitution was significant for all physical parameters of pita bread with the greatest variation in these values occurring for the pitas containing lentil flour. Flour particle size had a significant effect on all parameters except specific loaf volume either as a main effect on an interaction with level of flour. For moisture, the coarse particle size for both pinto and navy bean flours had lower moisture, whereas pitas with a smaller diameter with increased pocket height were only seen for the coarse particle size the navy bean flour. The effect of particle size on texture varied with the measurement used. Only at a substitution level of 75% were higher force values obtained for coarse flours, but the extensibility based on area under the curve was lower for all coarse flours. Whiteness index was also higher for all the coarse flours. Pitas containing navy bean flour demonstrated the lowest variation in color and texture at all levels of substitution, whereas pitas containing lentil flour had the highest variation.

Overall, this study showed that composite flours, regardless the particle size of the flours and level of substitution, were able to produce separation of the top and bottom layers in pita bread, and thus demonstrated their high suitability for this type of baked products. In general the coarse flours had some benefits in terms of pita texture and color. Pitas containing navy bean and pinto bean flours appeared to be superior in the color and texture compared to the pitas containing lentil flour, and addition of 25% pulse flours produced pitas of similar or superior quality to those of the wheat control, as confirmed with the sensory evaluation. Modification of the formulation and processing method during scale up must be undertaken to effectively use higher levels of added pulse flours. In addition, further studies on the effect of particle size are recommended for pita bread baking.

4. Incorporation of Pulse Flours Milled from Green Lentils (*Lens culinars*), Yellow Peas (*Pisum sativum* L.), Navy Beans (*Phaselous vulgaris* L.), and Pinto Beans (*Phaselous vulgaris* L.) of Different Particle Size into Pan Bread

4.1. Abstract

Pulse flours milled from green lentils, yellow peas, navy beans, and pinto beans were evaluated based on their ability to be incorporated into a pan bread formulation. Dehulled yellow pea flour with a fine particle size was of commercial origin; all remaining pulse flours were ground into fine and coarse particle sizes. The pulse flours were blended with wheat flour at different levels (10, 15, and 25%) and baked into pan bread. Baking quality of the composite flours was evaluated based on Farinograph data. Among the pulse flours, coarse navy bean flour demonstrated a superior baking performance as demonstrated by a significantly higher dough stability value and a significantly lower mixing tolerance index value. Navy bean flour with fine particles and pinto bean flour with both particle sized also showed a good baking performance. Addition of lentil flour, regardless of particle size, most negatively affected dough properties. Pan bread quality was estimated according to its specific loaf volume (SLV), oven spring, crumb structure and crumb texture profiles, as well as crust and crumb color. Results of the baking tests were in agreement with farinograph measurements. Overall, the pan bread tolerated well the addition of navy and pinto bean flours resulting in a higher SLV, oven spring, finer crumb structure, and softer crumb texture than the breads

containing lentil flour. Navy bean flour produced the bread with the lightest crumb; however, the addition of pinto bean flour resulted in a crumb with the softest texture. In general, the pulse flours with the coarse particle size demonstrated superior dough handling properties and bread quality, including crumb color and crumb texture, when compared to flours with the fine particle size. This effect was significantly pronounced at the 25% substitution level. Coarse navy bean flour could be incorporated into the bread formulation at 15% level producing the bread with the minor changes in the quality parameters compared to the wheat control, whereas all the remaining pulse flours with coarse and fine particles could be added at a10% replacement level only.

4.2. Introduction

The history of breadmaking goes back to the ancient times when the leavening action of yeast was accidently discovered by the Egyptians (Spencer, 1988). Bread still plays an important role in the human diet in many parts of the world, serving a major source of caloric intake (Abdel-Aal et al., 1993). Within the past 20-30 years, much attention has been paid to the health-related benefits derived by direct consumption of certain foods. Fortification of bread products, which are typically made from refined wheat flour of low nutritional value, with nonwheat materials, is not new. For example, numerous studies revealed that legumes, oilseeds, tubers, other cereals, and rice bran milled into flour or particle sizeated into protein and fiber could be effectively included in the bread formulations for that purpose (Chavan & Kadam, 1993).

Pulses provide the diet with protein, dietary fiber, carbohydrates, vitamins, and minerals and thus possess high nutritional potential for human consumption (Tharanathan& Mahadevamma, 2003). The high protein quality of pulse crops needs to be highlighted as the levels of some essential amino acids, in particular lysine, are significantly higher than the levels in the wheat protein. In addition, the combination of legume and wheat proteins provides complementary levels of other essential amino acids such as sulphur containing methionine and cysteine, and tryptophan (Adsule & Kadam, 1989a). Therefore, a product prepared by a combination of pulse and wheat materials would have a superior biological value associated with the protein compared to a product made from wheat material exclusively.

Most of the studies regarding utilization of the legume crops and their derivatives into baked products have been centered on development of “high-protein” or “high-fiber” bread (Chavan & Kadam, 1993). A variety of the legume crops such as Great Northern beans, mung beans, chickpeas, pigeon peas, faba beans, navy beans, pinto beans, field peas, and lentils were milled into flour and demonstrated a high potential for breadmaking at the levels 10-15% depending on the crop (Chavan & Kadam, 1993; Repetsky & Klein, 1981; Sadowska et al., 2003; Abdel-Aal et al.,1993; D’Appolonia, 1977; 1978). Also, protein particle sizes derived from navy beans, pinto beans, and Great Northern beans have been successfully utilized in bread at the levels not exceeding 10% (Silaula et al., 1989; Sathe et al., 1981); however the protein concentrates extracted from chickpeas and yellow peas produced acceptable bread at 2 % supplementation (Fenn et al., 2010). High-fiber bread of satisfactory quality could be produced with pea fiber addition at 2% supplementation in one study (Gomez et al., 2003), whereas ground pea hulls were effectively added at 15% replacement level in another study (Sosulski & Wu, 1988).

Finney et al. (1982) focused on the effect of some treatments applied to the legume seeds prior to milling on the dough handling properties and bread quality. It was concluded that flour milled from the whole mung beans was unsuitable for breadmaking at a 5% replacement level; however, dehulled mung seeds produced bread of acceptable quality at levels of substitution of up to 15%. Particle size is another flour attribute which has been reported to significantly influence the breadmaking process (Zhang & Moore, 1997 and 1999; Kurimoto & Shelton, 1988; Ozboy & Koksel, 1997). In these relevant studies, wheat bran and wheat flour of varying particle sizes were evaluated; not much research was found regarding that effect when non-wheat supplemented materials of differing particle size were used. Therefore, it is of practical interest to study the particle size effect of the flours milled from the pulses grown in relation to their effectiveness for use in breadmaking.

In this study, the composite flours prepared by blending all-purpose wheat flour with the pulse flours milled from lentils, yellow peas, navy beans, and pinto beans at varying levels (10, 15, and 25%) were evaluated for their baking potential. The main objectives were: 1) to determine the most suitable pulse flour for wheat flour substitution in pan bread; 2) to determine the optimum level of incorporation of the pulse flours resulting in a product of acceptable quality; 3) to evaluate the effect of particle size distribution on the bread quality.

4.3. Materials and Methods

4.3.1. General

Green lentils were obtained from Simpson Seeds in Moose Jaw, SK, Canada. Commercial dehulled yellow pea flour with a fine particle size (Parrheim Foods, Saskatoon, SK, Canada) was used. Navy beans and pinto beans were obtained from Parent Seeds Farm, Ltd. in St. Joseph, MB, Canada. The pulse seeds were ground into fine and coarse particle sizes at the Canadian International Grains Institute, Winnipeg, MB, Canada. Green lentils were dehulled prior to milling using a Buhler pilot scale dehuller and splitter operated at 530 rpm. Navy beans and pinto beans were milled with the hull. Flour with the coarse particle size was obtained using a Jacobson 120-B lab scale hammer mill with a 1.5 screen. To obtain flour with the fine particle size, coarse flour was further milled using a Hosokawa Alpine 100 UPZ pin mill at 18,500 rpm. Parameters of the pulse flours are summarized in Table 4.1. Commercially available enriched pre-sifted Robin Hood all purpose wheat flour (Smucker Foods of Canada Co., Markham, ON, Canada) was used for preparing the composite flours and the controls. Blends containing 10, 15, and 25% of each pulse flour are referred as the composite flours in this study. Commercially dehulled yellow pea flour with a fine particle size (Parrheim Foods, Saskatoon, SK, Canada) was included as a secondary control. The composite flours were stored in the zip-locked plastic bags at room temperature until required for testing.

Table 4.1. Characteristics of Wheat Flour and Pulse Flours

	Wheat flour	Pea flour	Green lentil flour		Navy bean flour		Pinto bean flour	
			Fine	Coarse	Fine	Coarse	Fine	Coarse
Moisture[1] (g/100g)	12.9±1.0	7.92 ± 0.10	6.30 ± 0.01	7.75 ± 0.03	6.70 ± 0.02	10.98 ± 0.03	6.72 ± 0.04	9.90 ± 0.02
Protein[2] (g/100g)	13.4 ± 0.13	22.36 ± 0.09	25.02 ± 0.03	24.43 ± 0.01	22.13 ± 0.33	21.45 ± 0.27	22.04 ± 0.24	21.53 ± 0.19
Fat[3] (g/100g)	1.0 ± 0.07	0.94 ± 0.10	1.09 ± 0.09	0.84 ± 0.11	1.91 ± 0.09	2.24 ± 0.10	2.15 ± 0.02	2.44 ± 0.08
Ash[4] (g/100g)	0.38 ± 0.09	2.83 ± 0.10	2.22 ± 0.04	2.26 ± 0.01	4.03 ± 0.07	3.91 ± 0.02	4.15 ± 0.14	4.23 ± 0.04
Carbohydrates [5] (g/100g)	72.3 ± 0.32	61.95 ± 0.55	65.38 ± 0.08	64.72 ± 0.13	65.23 ± 0.22	61.42 ± 0.13	64.91 ± 0.14	61.82 ± 0.25
Whiteness Index[6]	78.08±0.36	80.83 ± 0.11	80.95 ± 0.09	72.82 ± 0.22	91.16 ± 0.10	87.5 ± 0.17	87.91 ± 0.21	85.22 ± 0.37
D [v,0.1][7](μm)	24.36±1.14	0.92 ± 0.02	0.29 ± 0.01	10.19 ± 0.65	0.38 ± 0.05	12.38 ± 2.63	0.30 ± 0.00	8.37 ± 0.43
D [v,0.5][7](μm)	75.67 ± 0.30	21.69 ± 0.07	16.05 ± 0.08	135.05 ± 10.13	21.73 ± 0.35	58.91 ± 2.63	21.78 ± 0.06	59.83 ± 2.71
D [v,0.9][7](μm)	129.81± 0.35	47.70 ± 0.43	35.52 ± 0.01	438.91 ± 2.91	48.47 ± 0.27	424.18 ± 1.94	48.38 ± 1.05	416.04 ± 2.15
Mean particle size (μm)	77.33 ± 0.30	23.45 ± 0.14	17.09 ± 0.05	189.74 ± 5.33	23.08 ± 0.22	155.28 ± 1.52	23.10 ± 0.05	149.69 ± 2.15

[1] Air Oven Method AACC 44-15A

[2]

[3]

[4]

[5]

[6]

[7]

[8] D[v , 0.1], D[v, 0.5], D[v, 0.9] are particle sized corresponding to the cumulative distribution at 10%, 50% and 90% respectively (e.g. D[v, 0.1] represents the value below which 10% of the cumulative distribution lies). Mean diameter provides the average size of all particles

4.3.2. Pan Bread Preparation

The pan bread formulation is summarized in Table 4.2. The weight of wheat or composite flours was adjusted to 14% moisture content. The amount of added distilled water for baking was based on Farinograph Water Absorption (FAB) corrected to 14% moisture basis as determined with a Brabender Farinograph (Duisburg, Germany) at 500 BU of dough consistency. The Farinograph was equipped with a 50 g bowl, and the constant flour-weight procedure was applied (Method 54-21; AACC, 2000). The amount of added water, required for the optimal dough development, was equal to the FAB value minus three percent.

Table 4.2. Pan Bread Formulation

Ingredient	Weight, g
Flour or blend (14% MB)	100.0
Yeast	1.0
Salt	1.5
Sugar	6.0
Shortening	3.0
Whey	4.0
Malt syrup	0.2
Ascorbic acid	20 ppm
Ammonium phosphate	0.1
Water	variable

The other basic ingredients such as instant dry yeast (Fleischmann’s, Canada) and salt (sodium chloride USP/FCC Granular, Fisher Scientific, Canada) were also used for bread preparation. Also, sugar (Rogers sugar, Lantic Inc., Canada), shortening (Crisco, Markham, ON, Canada), ammonium phosphate (Fisher, Canada), and ascorbic acid (Fisher, Canada) were added to the bread formulation. Malt was provided by the Cereal

Quality Laboratory at the Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg, MB Canada.

Two controls were used in this study. The main one was baked entirely from wheat flour. A second control was made with commercial yellow pea flour at levels of substitution of 10, 15, and 25%.

All the ingredients were placed into the mixing bowl of a 100-g recording pin mixer (National MFG Co., Lincoln, NB, USA) and mixed at 140 rpm until the energy input was just past peak development. Then the dough was allowed to ferment for 180 min at a temperature of 37.5 °C and 85% relative humidity in a fermentation cabinet (National MFG Co., Lincoln, NB, USA). The dough was punched down after 105 min, and again after an additional 50 min, and after an additional 25 min using a sheeter with 6-inch rolls (Somerset Industries, Inc., Billerica, MA). Following these steps, the dough was moulded, put into a lightly greased baking pan, and underwent a final proofing at 37.5 °C at 85% relative humidity until the dough reached 95 mm in height. That proofing time, which was established for the wheat control, was used as a final proofing time for all the samples. The loaves were then baked at 204°C (400 °F) for 25 min in the oven (National Manufacturing Company), and allowed to cool on a wooden rack at room temperature for 30 min. Then the loaves were placed into zip-locked plastic bags and stored at room temperature until physical properties were evaluated on the second day after baking.

4.3.3. Physiochemical Analyses

Determination of the moisture content of wheat flour and the composite flours was carried out based on the AACC one-stage procedure (Method 44-15A; AACC, 2000).

Composite Flours

The effect of substitution of wheat flour with the pulse flours on the dough physical properties was determined using a Brabender Farinograph (Duisburg, Germany) at 500 BU of dough consistency. The Farinograph was equipped with a 50 g bowl, and the constant flour-weight procedure was applied (Method 54-21; AACC, 2000). Dough development time, dough stability, and the mixing tolerance index were determined.

Pan Bread

Physical parameters of interest for the baked bread included oven spring, loaf volume (LV), and specific loaf volume (SLV). Oven spring was calculated as the difference in the loaf height values after baking and before baking using an electronic caliper (Model SDV-6"A, Mitutoyo Corp., Japan) and expressed in mm. LV was determined by a rapeseed displacement method, and SLV was calculated as the ratio between LV and weight and expressed in cm^3/g.

Crust and crumb color (CIE tristimulus system, L*, a*, and b* values) were measured by a Minolta Baking Meter BC-10 (Konica Minolta, Tokyo, Japan) with a 10° standard observer and D65 daylight illuminant calibrated with a white plate. In such a system, L* characterizes brightness, +a* - redness, -a* - greenness, +b* - yellowness, and –b* - blueness. The calibration readings were L*=98.3, a*=0.1, and b*=1.4. Two readings were taken for the crust of each loaf, and two readings were taken for the crumb of two slices of each loaf. Then an average of each corresponding parameter was calculated. The color profile was expressed as the Whiteness Index, Hue Angle, and the Chroma Index based on the following formulas (Al-Hooti et al., 2000):

$$\text{Whiteness}=100 - [(100-l^*)^2+a^{*2}+b^{*\,2}]^{0.5};$$

$$\text{Hue Angle}=\tan^{-1}(b^*/a^*);$$

$$\text{Chroma}=(a^{*2} + b^{*2})^{0.5}$$

Each loaf was sliced, and then two slices of the loaf were chosen near the centre and used for the crumb structure evaluation with image analysis software (CrumbScan, American Institute of Baking, Manhattan, KS). The average cell elongation and average cell width were selected for that purpose. Two other bread slices were used for the crumb texture evaluation as determined by a compression test (TA-XT2 Texture Analyzer, Texture Technologies Corp., Scarsdale, NY, and Stable Micro System, Godalming, Surrey, UK). The cylindrical probe was used, and the following settings were applied - 1.7 mm/sec for the probe speed and 40% for the strain. The values of force and areas under the curve described the crumb texture profile. Two readings were taken for the structural and textural parameters of each loaf, and then the average of the corresponding parameters was calculated for duplicated.

4.3.4. Statistical Analysis

All the composite flours (28 in total) were baked into pan bread in duplicate batches, and all the data were expressed as means ± SD. The statistical analyses were performed using GLM with SAS software (SAS version 9.1.2) with a probability level of less than 0.05 used to identify significant differences. A 3x2x3 factorial experiment was conducted to determine the effect of type flour, flour particle size, and level of substitution respectively on the dough physical parameters and pan bread quality. A series of contracts was performed to make a general comparison of baking suitability between the bread baked from both the wheat flour (the 1st control) and commercial yellow pea flour (the 2nd control) with the remaining pulse flours.

4.4. Results and Discussion

4.4.1. Analyses of the Composite Flours

Farinograph Water Absorption (FAB)

All the composite flours as well as wheat flour were evaluated for their FAB to determine the amount of water to be added to the bread formulation (Appendix 6). Based on statistical analysis, FAB was significantly affected by flour type, flour particle size, level of substitution, and their 2-way interactions (Table 4.3). Overall, addition of lentil flour resulted in a significant decrease in FAB, particularly at 25% replacement, whereas addition of navy bean and pinto bean flours produced doughs with increased FAB (Figure 4.1). This means that the FAB values of different pulse flours depend on the crop type as well as the milling technique used. In this study, the opposite trends in FAB changes might be due to the fact that navy and pinto beans were milled with the hull and lentils were dehulled prior to milling. A higher proportion of fiber, which is the main component of the hull, exists in the navy bean and pinto bean flours than in the lentil flour leading to a greater absorbing capacity. Gómez et al. (2003) concluded that the hydroxyl groups of the fiber components interact intensively with water through hydrogen bonding. Greater water absorption when navy and pinto bean flours, or their protein particle sizes, were added to the bread formulation was reported by D'Appolonia (1977) and Silaula et al. (1989). Similar results were revealed when pea flour was included into bread (Sadowska et al., 2003). However, addition of lentil flour has been reported to decrease FAB (D'Appolonia, 1977).

Table 4.3. Significant Effects of the Main Factors and their Interactions on Farinograph Data of the Composite Flours*

Factor	Moisture	Farinograph Water Absorption	Dough Development Time	Dough Stability	Mixing Tolerance Index
Flour	NS	S	S	S	S
Particle size	S	S	NS	S	S
Level	S	S	S	S	S
Flour*Particle size	NS	S	S	S	S
Flour*Level	NS	S	S	NS	S
Particle size*Level	NS	S	NS	NS	NS
Flour*Particle size*Level	NS	NS	NS	NS	NS

* Results are obtained by SAS (3x2x3 factorial experimental design where Flour –flour type effect, Particle size – flour particle size effect, and Level – level of substitution effect)
S – significant effect (P<0.05);
NS – not significant effect (P>0.05)

The dashed line on the figures, which are included in the following discussions, represents the mean value of each measured or calculated parameter for the wheat control.

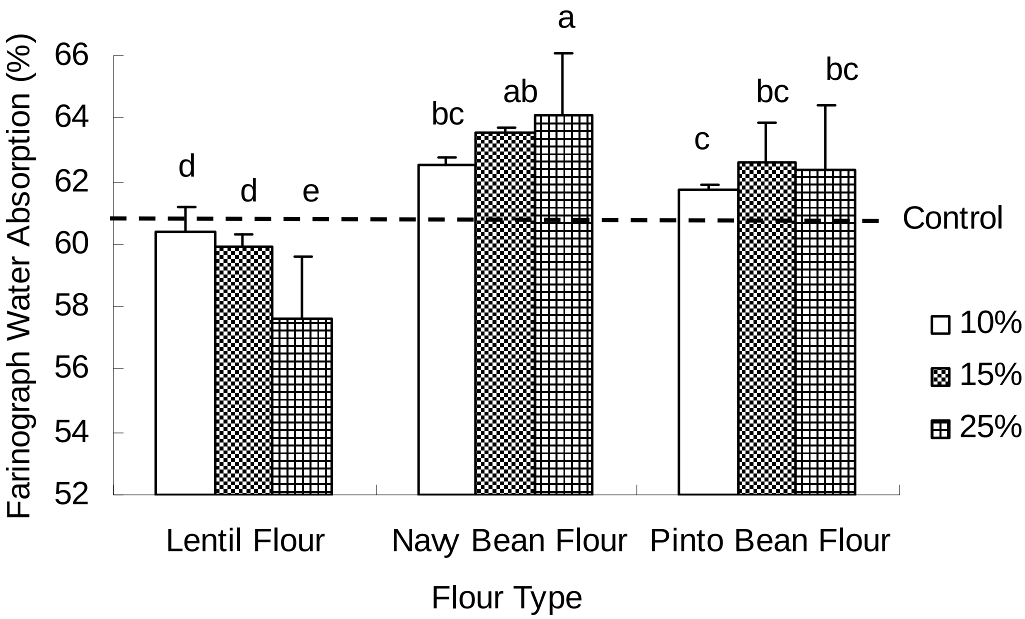

Figure 4.1. Effect of Flour Type and Level of Substitution on the Farinograph Water Absorption of the Composite Flours. Bars with the same character are not significantly different (P>0.05)

Flour particle size significantly affected the FAB values for the doughs containing lentil and pinto bean flours only (Figure 4.2) producing lower FAB values for the doughs with fine particle size and higher FAB values for doughs with the coarse particle size. This effect was more pronounced at a 25% substitution level (Figure 4.3). This could be due to higher level of damaged starch in the fine pulse flours compared to the coarse pulse flours as they were subjected to additional milling. Studies conducted on damaged starch in wheat flour concluded that if the dough contains a high level of damaged starch, it is expected to absorb more water (Holas & Tipples, 1978; Tipples et al., 1978; Farrand, 1972; Okada et al., 1986; Kurimoto & Shelton, 1988). One the other hand, if the level of damaged starch is extremely high (more than 10%), the dough is sticky and difficult to handle (Sluimer, 2005). As a result, FAB, which characterizes the amount of water required to produce the dough with a certain optimum consistency of 500 BU, is lower.

A slight increase in the FAB values was reported by Pomeranz et al. (1977) when wheat bran with coarse rather than fine particles was added to pan bread for wheat flour substitution. Zhang & Moore (1997) concluded that FAB values of the wheat dough containing of 5, 10, and 15% of wheat bran were not affected by particle size of the bran. However, the dough made with coarse wheat bran demonstrated significantly greater water-holding capacity than that with fine wheat bran.

The results obtained for the moisture content of the composite flours confirmed that flour particle size had a significant effect on this parameter (Table 4.3) resulting in an average value of 11.60±0.50% for the composite flours with the fine particle size and 12.14±0.39% for the composite flours with the coarse particle size. The moisture content of all the composite flours and wheat flour are shown in Appendix 6.

Contrast analyses demonstrated that all the composite flours except those containing yellow pea flour produced doughs with FAB values significantly different from the wheat control dough. Also, doughs containing lentil, navy bean, and pinto bean flours were significantly different from those containing yellow pea flour with respect to FAB (Table 4.4).

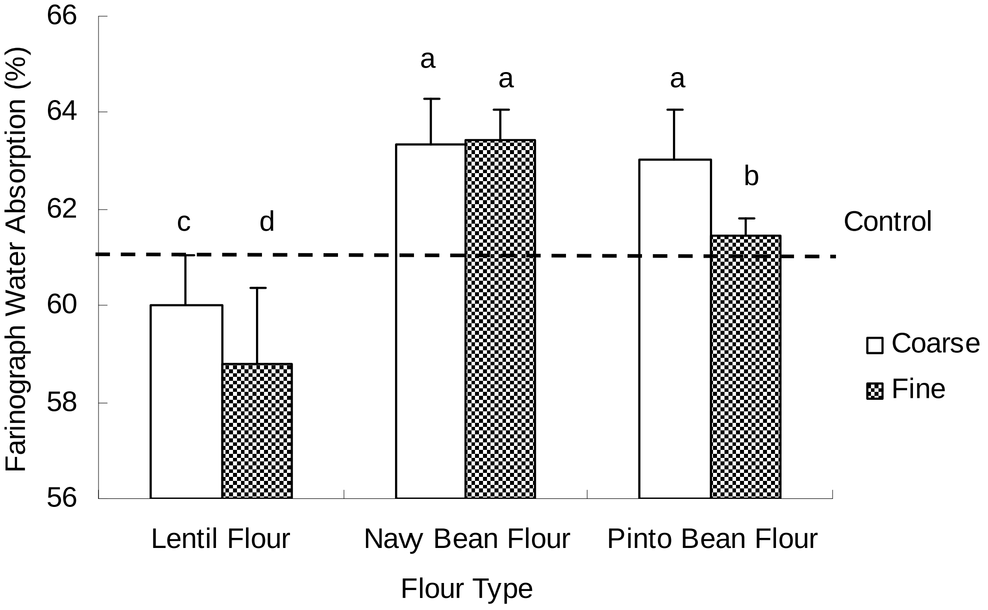

Figure 4.2. Effect of Flour Type and Flour Particle Size on the Farinograph Water Absorption of the Composite Flours. Bars with the same character are not significantly different (P>0.05)

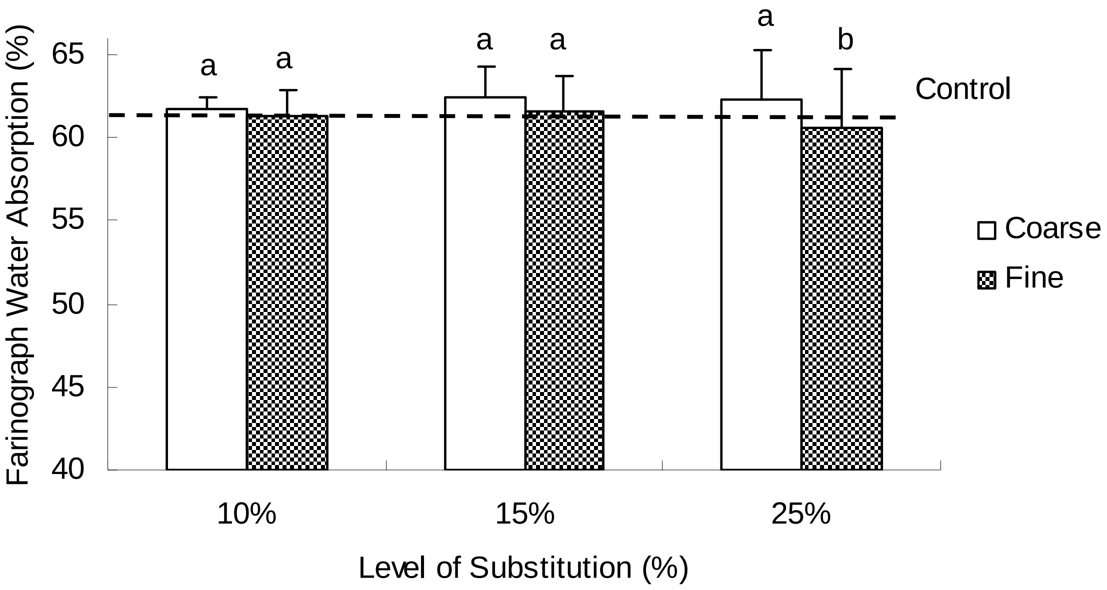

Figure 4.3. Effect of Flour Particle Size and Level of Substitution on the Farinograph Water Absorption of the Composite Flours. Bars with the same character are not significantly different (P>0.05)

Table 4.4. Farinograph Data Comparison of the Composite Flours with Wheat Flour and Commercial Yellow Pea Containing Composite Flours *

Parameter	Wheat Flour				Commercial Yellow Pea Flour		
	Green Lentil	Yellow Pea	Navy Bean	Pinto Bean	Green Lentil	Navy Bean	Pinto Bean
Moisture	NS	NS	NS	NS	NS	NS	NS
FAB	S	NS	S	S	S	S	S
DDT	S	S	S	S	S	NS	S
DS	S	S	S	S	NS	S	S
MTI	S	S	NS	NS	NS	S	S

* Results are obtained by Contrast Analysis;
S – significant effect ($P<0.05$); NS – not significant effect ($P>0.05$).
FAB – Farinograph water absorption (%); DDT – dough development time (min); DS - dough stability (min); MTI – mixing tolerance index.

Dough Development Time (DDT)

DDT in the Farinograph indicates the period of time required for dough to reach its optimum consistency of 500BU. This parameter was recorded for all composite flours to determine the effect of pulse flour addition on dough strength (Appendix 6). In general, DDT was reduced with addition of all the pulse flours (Figure 4.4). The smallest decrease was observed for the doughs containing pinto bean flour, and the largest decrease was seen for the doughs containing lentil flour. Flour particle size had no significant effect on the DDT values for the doughs containing lentil and navy bean flours; however, the doughs containing pinto bean flour with coarse particles were significantly lower in DDT (6.65±0.43min) than those with fine particles (7.83±0.32min). The level of substitution was significant for the doughs made from lentil flour where the DDT was significantly lower at 25% replacement than at 10 and 15% replacement (Figure 4.5).

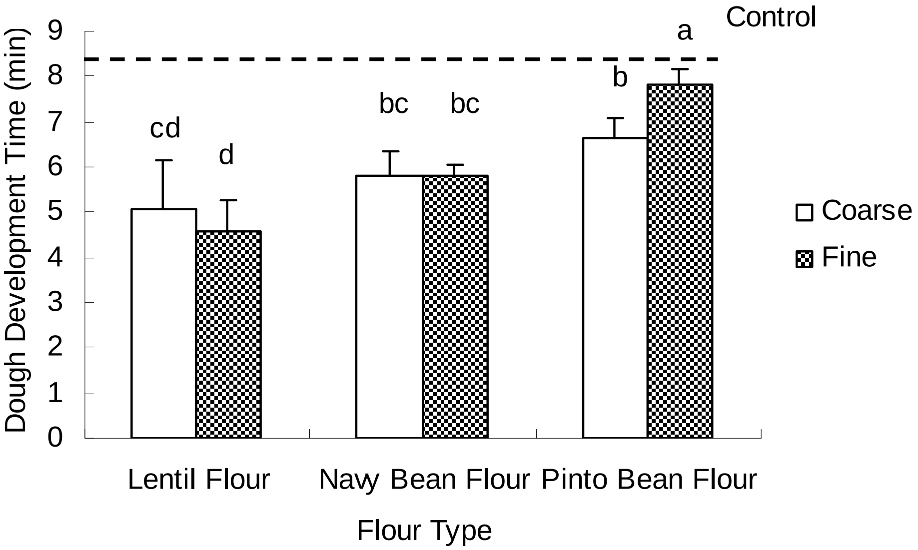

Figure 4.4. Effect of Flour Type and Flour Particle Size on the Dough Development Time of the Composite Flours. Bars with the same character are not significantly different (P>0.05)

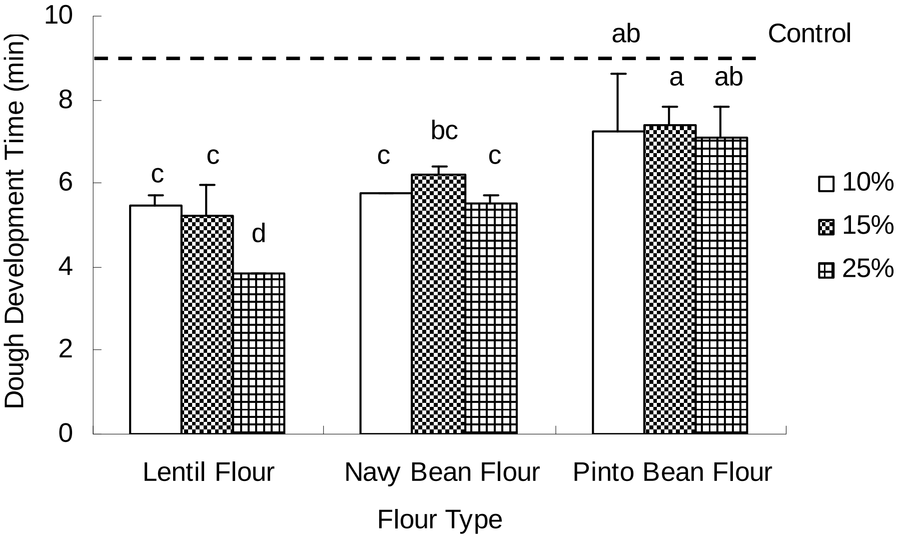

Figure 4.5. Effect of Flour Type and Level of Substitution on Dough Development Time of the Composite Flours. Bars with the same character are not significantly different (P>0.05)

The varied reduction in the DDT values for the doughs containing different pulse flours might be due to different composition for the proteins. For example, Sadowska et al. (2003) concluded that doughs containing pea flour at levels from 5 to 15% had lower DDT values than that for the wheat control; however, with an increasing level of pea flour in the dough, DDT was also increased. A similar tendency was reported by D'Appolonia (1977) for the doughs containing lentil flour at the levels from 5 to 20%. However, the DDT values for doughs containing navy bean were not affected by the level of substitution (D'Appolonia, 1977). The reduced values for DDT of the doughs containing pulse flours compared to the wheat dough might be due to the decreasing level of wheat gluten in the dough with an increased proportion of pulse flour and thus less time might be required to complete dough development.

Contrast analysis showed that all the doughs containing pulse flours were significantly different from the wheat control and yellow pea control with respect to DDT. The only exception was for the doughs from navy bean flour which were not significantly different from the yellow pea control (Table 4.4).

Dough Stability (DS)

Dough stability represents the difference in the times when the dough reaches the consistency of 500 BU the first time and then falls below that value, and is an indicator of dough strength (Sluimer, 2005). The DS values for all the composite flours are summarized in Appendix 6. Level of substitution had a significant effect on the DS (Table 4.3).When the pulse flours were incorporated to the wheat dough, DS decreased gradually with increasing levels of the pulse flours as mean value of DS for all the pulse flours with both coarse and fine particle size at 10% level was 9.84±1.89min, at 15% level – 7.68± 1.93min, and at 25% level – 5.08± 1.49min. The decrease in the DS values was also significantly affected by the interaction between the type of pulse crop and the particle size of the flour (Table 4.3). A significant decrease in DS with regard to the flour particle size (DS was lower for fine particles) was observed for the doughs prepared from navy bean flour only (Figure 4.6). When comparing the flour type, the coarse navy bean flour was more stable than the coarse lentil and pinto bean flours, and the fine pinto bean flour was more stable than the fine lentil flour.

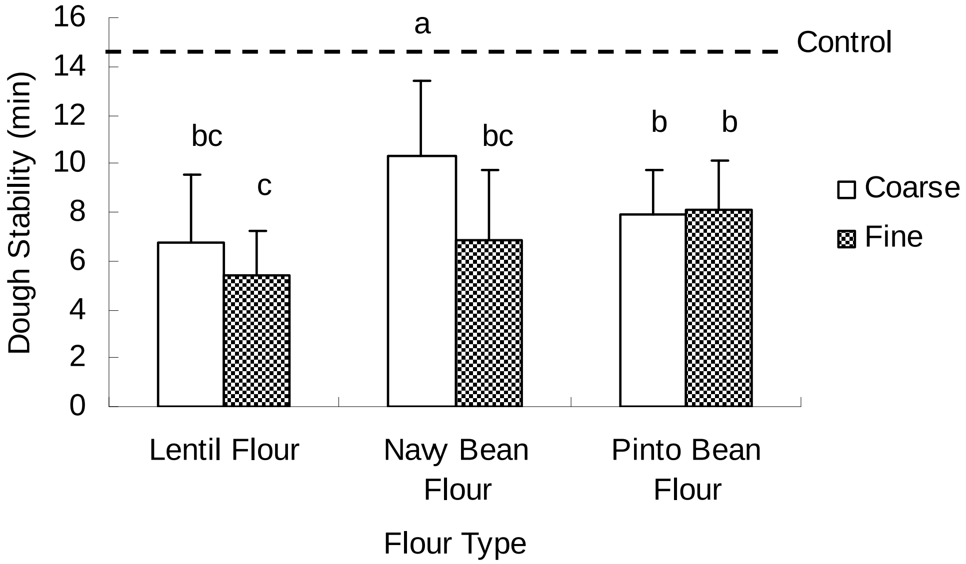

Figure 4.6. Effect of Flour Type and Flour Particle Size on the Dough Stability of the Composite Flours. Bars with the same character are not significantly different (P>0.05)

Based on the contrast analyses, all the doughs containing bean flours were significantly different from the wheat control and yellow pea control with respect to DS.

However, the doughs containing lentil flour were not significantly different from the yellow pea control (Table 4.4).

Mixing Tolerance Index (MTI)

MTI corresponds to the decrease in the dough consistency 5 min after the peak, and it also describes the dough strength (Sluimer, 2005). The raw data regarding MTI for all the composite flours are shown in Appendix 6. Based on statistical analyses, the MTI values are influenced by flour type, particle size, and level of substitution as well as interactions between flour type and particle size, and flour type and level of substitution (Table 4.3). Only the interactions will be discussed. There was a significant increase in MTI for the doughs prepared from lentil flour when the level of lentil flour increased from 10 to 25% while doughs containing navy bean and pinto bean flours were not significantly affected by the level of substitution (Figure 4.7). At a substitution level of 25%, the navy and pinto bean flours had lower mixing tolerances than the lentil flour. The flour particle size significantly influenced the MTI for the doughs prepared from lentil and navy bean flours producing stronger doughs with the coarse particle size and weaker doughs with the fine particle size (Figure 4.8).

Based on contrast analyses, the doughs containing navy bean and pinto bean flours were not significantly different from the wheat control dough in terms of MTI; however, they were significantly different from the doughs containing yellow pea flour (Table 4.4). The MTI of the doughs containing lentil and yellow pea flours were significantly different from the wheat control dough, but they were not significantly different from each other (Table 4.4).

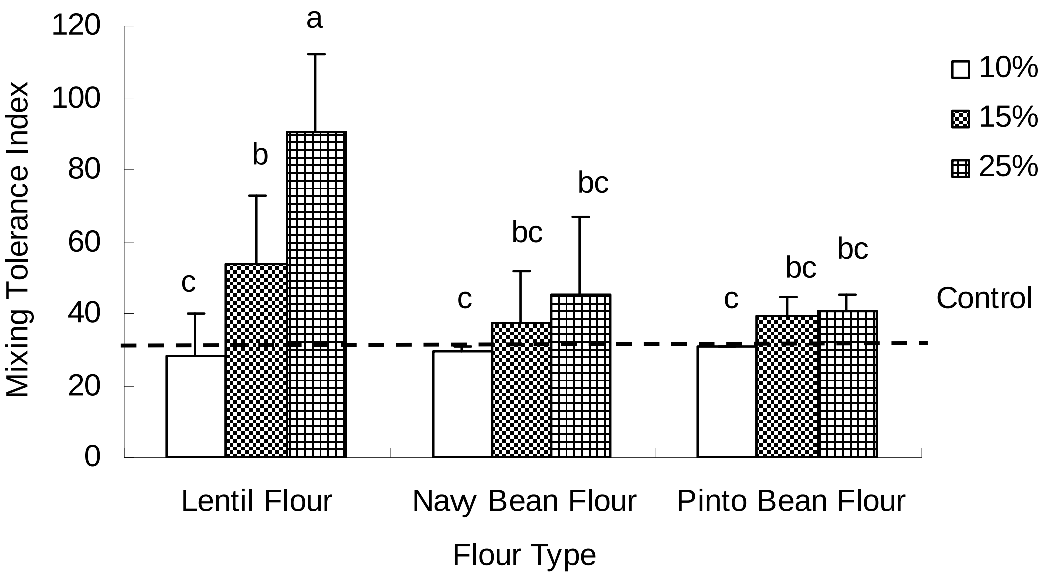

Figure 4.7. Effect of Flour type and Level of Substitution on Mixing Tolerance Index of the Composite Flours. Bars with the same character are not significantly different (P>0.05)

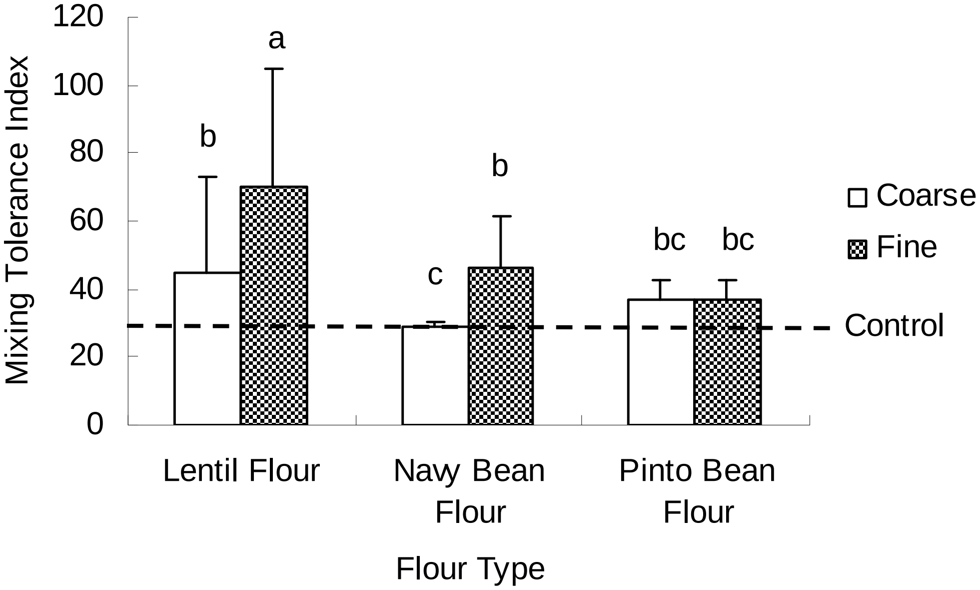

Figure 4.8. Effect of Flour Type and Flour Particle Size on the Mixing Tolerance Index of the Composite Flours. Bars with the same character are not significantly different (P>0.5)

The negative effect of the non-gluten material on the dough strength when incorporated into wheat dough was previously reported and partially explained by dilution of the gluten proteins (Galliard, 1986). The results reported by D'Appolonia (1977;1978), Abdel-Aal et al. (1993), Chavan & Kadam (1993), and Sathe et al. (1981) are consistent with the results observed in this study indicating an overall weakening effect of pulse flours on the physical properties of the wheat dough. The less pronounced adverse changes in the doughs containing navy bean and pinto bean flours compared to the doughs containing lentil flour might be due to the difference in the fiber content. Navy and pinto bean flours were expected to be higher in fiber than lentil flour as they were milled from the whole seeds. Studies examining the effects of fiber on dough rheology and breadmaking revealed that the doughs containing different sources of fiber required longer mixing times and were more tolerant to overmixing indicating stronger physical properties (Pomeranz et al., 1977; Gomez et al., 2003; Wang et al., 2002; Sosulski & Wu, 1988). A possible explanation for this might be the interactions between fibers and gluten (Wang et al., 2002).

With regard to the effect of the particle size on dough strength, similar conclusions were found in the literature. In general, doughs containing coarse wheat bran were stronger and more tolerant to mixing than the doughs containing fine wheat bran as they had higher values of DDT, DS and lower values of the MTI (Zhang & Moore, 1997). The suggested explanation in that study was a possible disruption of the gluten network by the bran particles. With finer particles, a greater number of sites for disruption were available at the same level of replacement compared to the coarse particles, resulting in a greater disruption of the gluten network (Zhang & Moore, 1997). Ozboy & Koksel

(1997) revealed an unexpected strengthening effect when coarse bran was added to the wheat dough, while fine bran constantly demonstrated a weakening effect on the wheat dough. On the other hand, Kurimoto & Shelton (1988) reported no significant effect of the flour particle size on the DDT, DS, and MTI.

4.4.2. Analyses of Pan Bread

Oven Spring

When fermented wheat dough is placed in a hot oven, it expands in volume by about one-third of its size at the final proof stage. This effect, known as “oven spring”, indicates the ability of the gas cells accumulated during dough fermentation to expand upon heating, as well as the ability of the cell walls to keep elasticity and expand under the pressure inside the cells (Pyler, 1985). In addition, the extent of dough expansion during baking affects directly the fineness and uniformity of the crumb structure (Bloksma, 1985). In this study, incorporation of the pulse flours in the bread formulation negatively affected the oven spring. The raw data are included in Appendix 7. The most significant depressing effect was detected for the loaves containing lentil flour, and the least depressing effect was observed for the loaves containing pinto bean flour (Figure 4.9). The oven spring values for the individual pulse flours represent the mean values for both the coarse and fine flours at all the levels of replacement of that flour; this is responsible for the relatively high standard deviations. Also, the level of substitution had a significant effect on the oven spring (Table 4.5). In general, as the proportion of the pulse flours in the bread formulation increased, there was a significant decrease in the oven spring, producing negative values at 15 and 25% levels of substitution when the loaves shrank during baking instead of expanding. The mean values for oven spring were 2.04±3.01 mm at 10% replacement, -4.44±2.82 mm at 15% replacement, and -10.54±5.76 mm at 25% replacement. The high standard deviations were again due to the large variation in the oven spring values among different pulse flours and flours of different particle size.

Contrast analyses confirmed that the loaves containing all the pulse flours were significantly lower in the oven spring than the wheat control. However, they were not significantly different from the yellow pea control (Table 4.6).

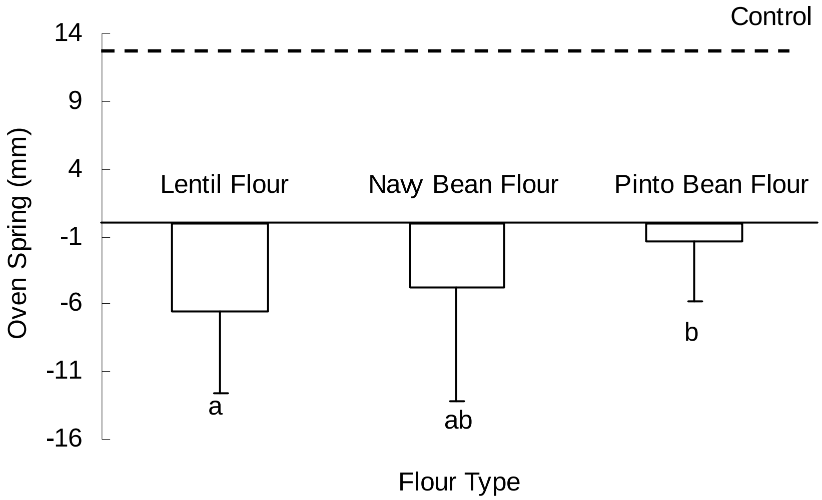

Figure 4.9. Effect of Flour Type on the Oven Spring of Pan Bread. Bars with the same character are not significantly different (P>0.05)

Table 4.5. Significant Effects of the Main Factors and their Interactions on Some Parameters of Pan Bread*

Factor	Oven Spring	Specific Loaf Volume	Crumb Structure		Crumb Texture	
			Elongation	Cell Width	Force	Area
Flour	S	S	S	NS	S	S
Particle size	NS	NS	S	NS	S	S
Level	S	S	NS	S	S	S
Flour*Particle size	NS	NS	S	NS	S	S
Flour*Level	NS	NS	NS	NS	S	S
Particle size*Level	NS	NS	NS	NS	S	S
Flour*Particle size*Level	NS	NS	NS	NS	NS	NS

* Results are obtained by SAS (3x2x3 factorial experimental design where Flour –flour type effect, Particle size – flour particle size effect, and Level – level of substitution effect)
S – significant effect (P<0.05);
NS – not significant effect (P>0.05)

Table 4.6. Physical Parameters Comparison of Pulse Flour-Based Pan Bread with Wheat Pan Bread and Pan Bread Containing Commercial Yellow Pea Flour*

Parameter	Wheat Flour				Commercial Yellow Pea Flour		
	Green Lentil	Yellow Pea	Navy Bean	Pinto Bean	Green Lentil	Navy Bean	Pinto Bean
Oven Spring	S	S	S	S	NS	NS	NS
Loaf Volume	S	S	S	S	NS	NS	S
Specific Loaf Volume	S	S	S	S	NS	NS	S
Crust Color							
Whiteness	S	S	S	S	NS	NS	NS
Hue	S	S	S	S	NS	NS	S
Chroma	S	NS	S	S	NS	S	S
Crumb Color							
Whiteness	S	S	S	S	S	S	S
Hue	S	S	S	S	S	S	S
Chroma	S	S	S	S	S	S	S
Crumb Structure							
Elongation	S	S	NS	S	NS	S	NS
Cell Width	S	S	S	S	NS	NS	NS
Crumb Texture							
Force	S	S	S	S	NS	NS	S
Area	S	S	S	S	NS	NS	S

* Results are obtained by Contrast Analysis;
S – significant effect (P<0.05); NS – not significant effect (P>0.05)

Specific Loaf Volume (SLV)

During baking, the dough continues to expand until the completion of structural changes thus producing a certain shape and volume (Sluimer, 2005). In general, there should be an optimal relationship between the loaf volume and weight, known as SLV, which produces crumb of the optimal structure and texture. A higher SLV does not mean a better crumb characteristics as the crumb can have an open grain and weak texture, and a lower SLV can be due to weak gluten quality or incomplete dough development during fermentation (Pyler, 1985).

In this study, SLV was significantly affected by flour type and level of substitution (Table 4.5). The raw data regarding SLV as well as loaf volume (LV) are included in Appendix 7. Addition of the pulse flours in the bread formulation negatively affected SLV (Figure 4.10). The extent of the decrease was more pronounced for the bread loaves containing lentil and navy bean flours, which were not significantly different in the SLV between each other. In addition, with an increasing level of the pulse flours in the bread formulation, there was a significant decrease in SLV. At 10% substitution, the drop in the SLV was the smallest among the other levels with an average value of 5.43±0.30a cm^3/g; at 15% substitution the SLV 4.61±0.28b cm^3/g, and at 25% there was the greatest drop in the SLV with an average value of 3.19±0.13c cm^3/g. Flour particle size did not significantly effect SLV (Table 4.5).

Based on the contrast analyses, all the breads containing pulse flours were significantly different from the wheat control in SLV. Also, the bread containing pinto bean flour was significantly different from the yellow pea control. However, addition of lentil flour and navy bean flour into the bread formulation produced bread which was not significantly different from the yellow pea bread with regard to SLV (Table 4.6).

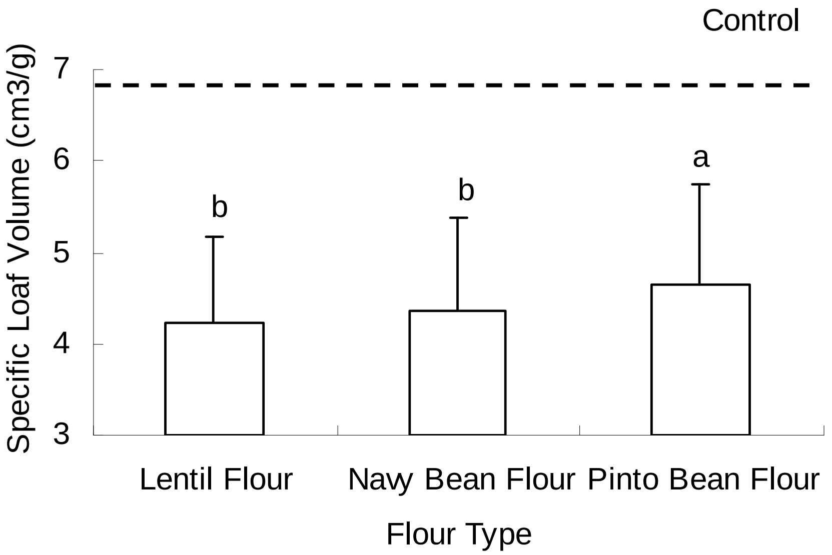

Figure 4.10. Effect of Flour Type on the Specific Loaf Volume of Pan Bread. Bars with the same character are not significantly different (P>0.05)

The negative effect of the pulse flour addition on the dough expansion during baking, responsible for the lower values for oven spring and SLV is due to the decreasing gluten level in the wheat dough with increasing level of the pulse flours in the bread formulation. As the gluten level decreases, the cell walls, which surround the gas cells in the foam-like dough, lose their elasticity and ability to expand during fermentation and baking. An effect of the addition of gluten-free materials to bread products is a decrease in volume-related parameters as has been previously reported (Fenn et al., 2010; Sathe et al., 1981; Abdel-Aal et al., 1993; D’Appolonia, 1977 & 1978; Sosulski & Wu, 1988).

Bread Crumb Quality

Overall, bread quality is highly correlated with its crumb structure and texture which determines the volume of the bread loaf, its resilience, mouthfeel, and freshness. The final crumb forms during baking when the foam-like dough converts into the sponge-like structure due to chemical and physical changes. Depending on the nature of the raw materials and processing conditions, bread can be different in crumb structure and texture (Bloksma, 1985; Scanlon & Zghal, 2001; Lassoued et al., 2008). Typically, crumb structure depends on the size of the crumb cells, their shape, uniformity, as well as the thickness of the cell walls. Smaller cells, which are elongated in shape and have thin walls, are considered to be more desirable as they produce a softer texture (Pyler, 1985). In addition, a crumb which is uniformly fine and elongated is typically ranked as the best overall crumb grain (Rogers et al., 1995). In this study, the crumb structure was evaluated based on the average elongation and average cell width which characterized the shape of the crumb cells; all data are provided in Appendix 8.

Average elongation of the crumb cells was significantly affected by flour type and flour particle size as well as the interaction between those two main factors (Table 4.5). Only the interaction (Figure 4.11) will be discussed. Bread containing lentil flour with fine particle size had the crumb with significantly lower values for cell elongation compared to the values of the bread prepared with coarse particle size flour. However, navy beans and pinto beans of coarse and fine particle size produced the crumb which was not significantly different in cell elongation. The effect of flour type was only evident for the fine flours where the average cell elongation was lower for the lentil flour (Figure 4.11). The average cell width was significantly affected by the level of substitution only (Table 4.5). With increasing levels of pulse flours, there was a significant decrease in the cell width values. The highest cell width values were detected for the bread crumb containing the pulse flours at 10% replacement (0.075a mm on average) followed by at 15% replacement (0.065b mm on average), and the lowest values were observed at 25% supplementation (0.052c mm), where the a, b, and c indicate significant difference at $p<0.05$. The results obtained from the crumb structure analyses were directly related to the results from SLV indicating that overall, bread with decreased volume had a crumb with less pronounced elongation and smaller cell width.

Based on the contrast analyses, navy bean flour was not significantly different from the wheat control in the cell elongation (Table 4.6). Breads prepared from the remaining pulse flours were significantly different from the wheat control for this parameter. However, compared to the yellow pea control, the navy bean breads were significantly different in cell elongation, whereas the lentil and pinto bean breads were not significantly different from the yellow pea control breads. With regard to the cell width parameter, all the pulse containing breads were significantly different from the wheat control; however, they were not different from the yellow pea control (Table 4.6).

Bread crumb, which has fine cells and thin cell walls, is typically soft and elastic in texture (Pyler, 1985). In this study, the crumb texture was evaluated based on the force and area under the curve values obtained by a compression test. The raw data regarding the crumb texture are summarized in Appendix 8.

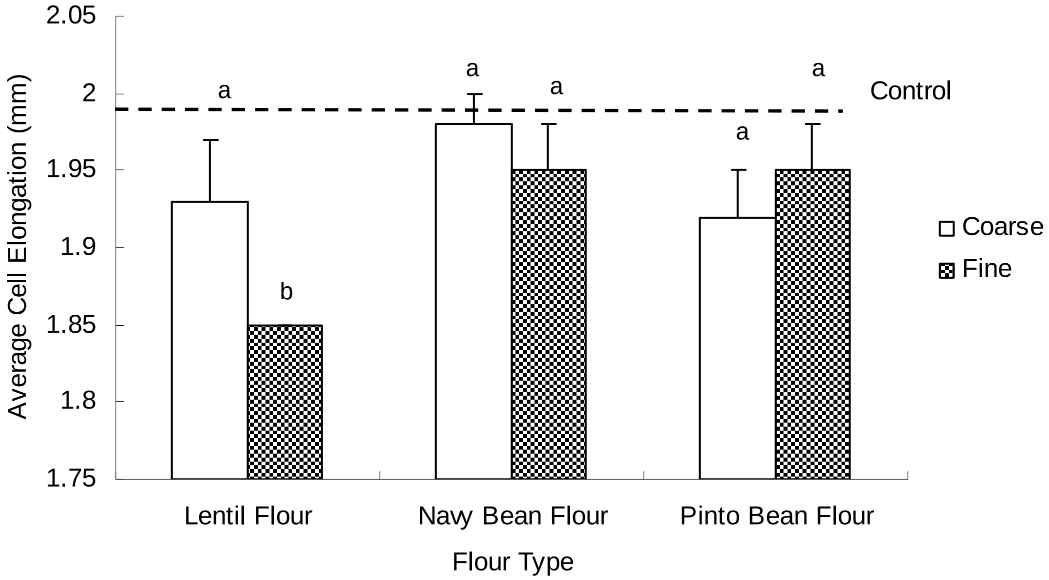

Figure 4.11. Effect of Flour Type and Flour Particle Size on the Crumb Structure (Cell Elongation) of Pan Bread. Bars with the same character are not significantly different (P>0.05)

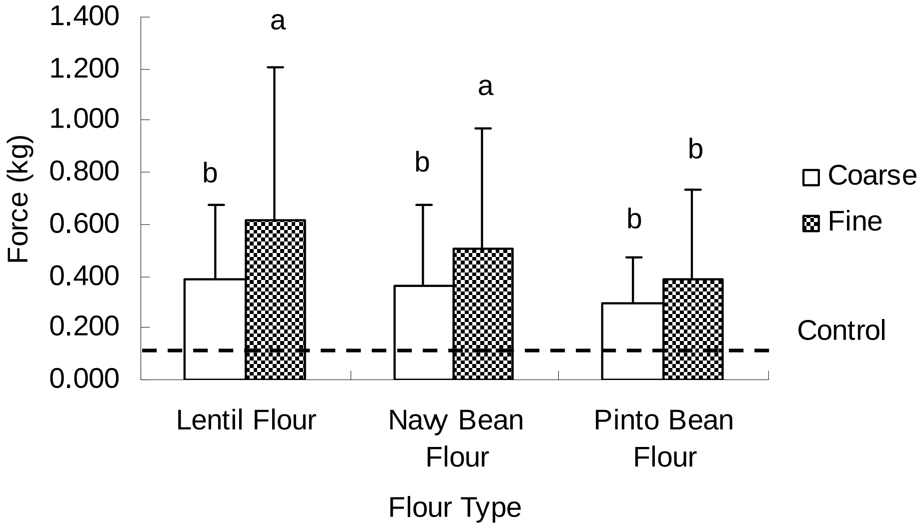

Figure 4.12. Effect of Flour Type and Flour Particle Size on the Crumb Texture (Force) of Pan Bread. Bars with the same character are not significantly different (P>0.05)

The compression force, which is related to the crumb firmness, was significantly affected by all the main factors (flour type, flour particle size, and level of substitution), as well as their two-way interactions (Table 4.5). For the interaction between flour type and particle size, significantly softer crumbs were detected for the breads containing coarse lentil and navy bean flours compared to the breads containing the corresponding flours with the fine particle size (Figure 4.12). The softness of the crumbs for the breads containing pinto bean flour with the coarse and fine particle size was not significantly different.

Considering the interaction between flour type and level of substitution, the crumb of the breads containing the pulse flours at 10 and 15% replacement was not significantly different in softness. A significantly firmer crumb was observed at 25% replacement for all three pulse flours (Figure 4.13). However, at a 25% substitution level, breads from pinto bean flour were softer than the breads from navy bean and lentil flours. The interaction between flour particle size and level of substitution showed that the flour particle size was significant only at 25% replacement resulting in the significantly lower force values for the breads prepared from the coarse pulse flours than those prepared from the fine pulse flours (Figure 4.14).

Contrast analysis indicated that all breads containing pulse flours were significantly different from the wheat control (Table 4.6) with higher force values for the bread crumb (Figures 4.12-4.14) and thus firmer crumb texture. With regard to the yellow pea control, the crumb of the bread prepared from pinto bean flour were significantly different in force values, whereas the breads prepared from lentil and navy bean flour had crumbs which were similar to the crumb of the bread containing pea flour.

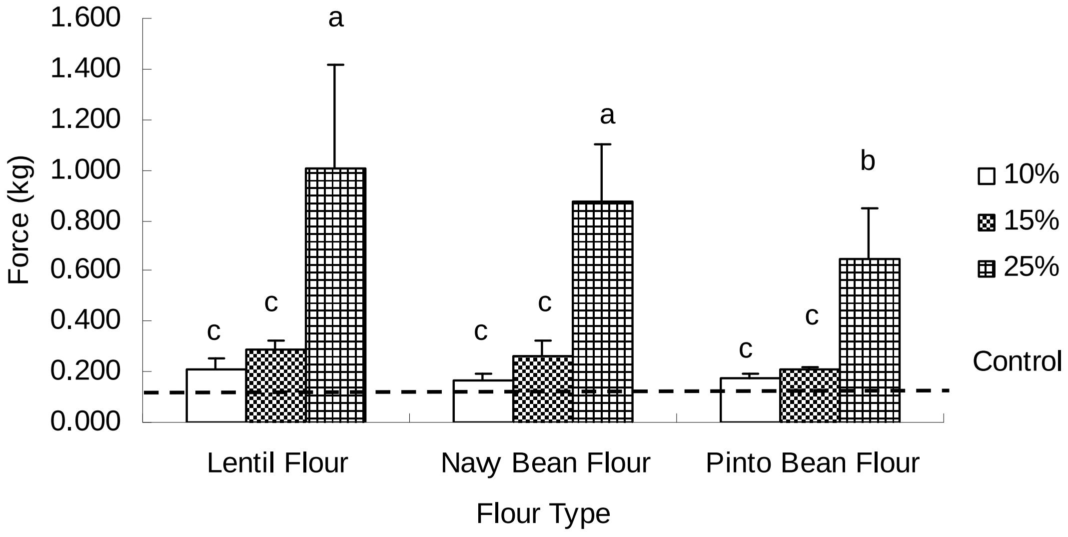

Figure 4.13. Effect of Flour Type and Level of Substitution on the Crumb Texture (Force) of Pan Bread. Bars with the same character are not significantly different (P>0.05)

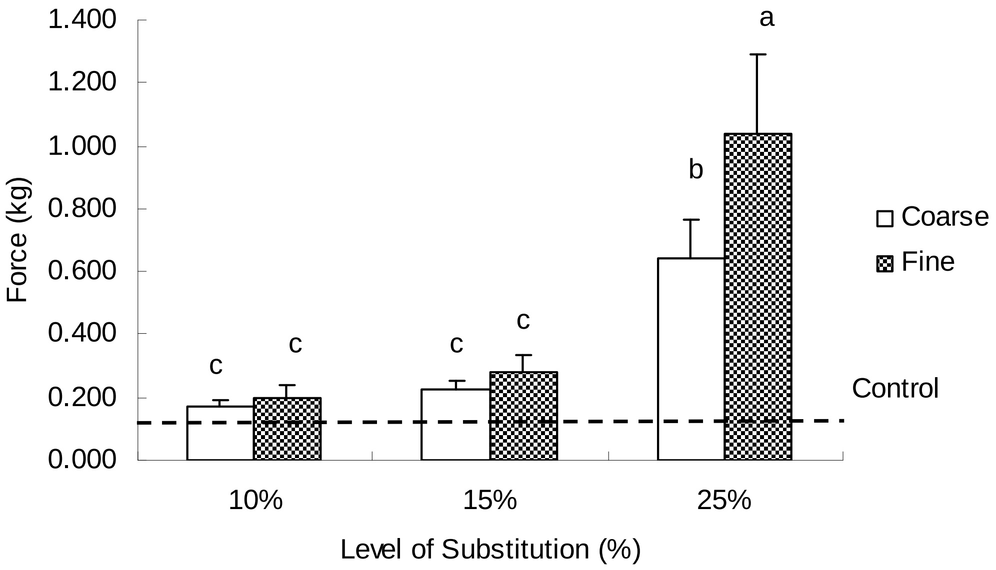

Figure 4.14. Effect of Flour Particle Size and Level of Substitution on the Crumb Texture (Force) of Pan Bread. Bars with the same character are not significantly different (P>0.05)

Area under the curve is another parameter related to the crumb texture. The area values obtained in this study had the same trends as for the force values in relation to all the main factors as well as their interactions (Tables 4.5 and 4.6), indicating force and area both reflect crumb structure. A detailed discussion regarding the area under the curve is therefore not presented. However, all the raw data are summarized in Appendix 8.

The changes in the crumb structure and texture towards firmer crumb cells and less soft texture when the pulse flours are added in bread formulations have been previously reported (D'Appolonia,1977;1978; Abdel-Aal et al., 1993; Repetsky & Klein, 1981; Sadowska et al., 2003). A similar negative effect of pulse protein isolates and pea fiber particle sizes, when added to the bread, have also been reported (Sathe et al., 1981; Silaula et al., 1989; Fenn et al., 2010; Sosulski & Wu, 1988; Gómez et al., 2003). It has been proposed that plant protein concentrates might disrupt the protein-starch complex in the wheat dough system (Fleming & Sosulski, 1977). Sadowska et al. (2003), using light microscopy, revealed that there were differences in the starch structure and protein distribution when pea flour was added to wheat bread. In the dough, the wheat gluten protein and the pea protein formed a hydrated protein matrix which was tightly packed with thick and small filaments. As a consequence of the disrupted gluten network, the protein films surrounding the gas cells in the dough lost their extensibility. The cell walls ruptured, and thus resulted in a coarser and more open crumb grain (Sadowska et al., 2003). A change in the texture profile of the bread crumb, when different fiber materials including pea fiber were incorporated to the bread, was a result of the thickening of the cell walls surrounding the gas cells (Gómez et al., 2003).

Considering the particle size effect, Zhang & Moore (1999) concluded that the bread containing fine bran obtained higher scores for crumb grain and crumb texture than the breads containing coarse bran. The findings of this study were opposite with regard to the particle size of the wheat-pulse composite flours. It appears that more investigation is required to understand the effect of degree of milling of pulses on bread crumb quality.

Crust Color

The color of the bread crust and crumb is an important characteristic affecting consumer acceptability. Crust color develops during baking and depends on the baking temperature and the level of residual sugars which are involved in reactions with polypeptides as part of the Maillard reaction. Caramelization reactions are also involved in crust color formation (Sluimer, 2005). Crumb color mostly depends on the natural color of the flour used for baking (Pyler, 1985). In this study, the color was described as the whiteness index, hue angle, and chroma index. The whiteness index was calculated based on the values of the L*, a*, and b* color components and used as an indicator of the lightness. In the hue angle and chroma index calculations just the a* and b* values were involved. In general, the hue angle identifies the individual color and is expressed in degrees while distinguishing a “red” (0 or 360°) from a “yellow” (90°) from a “green” (180°) from a “blue” (270°) colors (McLellan et al., 1994). The chroma index describes the saturation or purity of a specific color. The raw data for all the color characteristics of the crust are summarised in Appendix 9.

For the crust color, the Whiteness Index was significantly affected by the flour particle size only (Table 4.7). A lighter crust color was detected for the bread loaves containing the coarse particle size for all pulse flours at all levels of substitution, whereas a significantly darker crust color was observed for the bread loaves containing the flours with the fine particle size (Table 4.7). While statistical comparison of all the main effects are shown in Table 4.6, only significant main effects that are not involved in interactions will be discussed.

Table 4.7. Significant Effects of the Main Factors and their Interactions on the Color Characteristics of the Crust and Crumb of Pan Bread

Factor	Crust Color			Crumb Color		
	Whiteness	Hue Angle	Chroma Index	Whiteness	Hue Angle	Chroma Index
Flour	NS	S	S	S	S	S
Particle size	S	NS	NS	S	S	NS
Level	NS	S	NS	S	S	S
Flour*Particle size	NS	S	NS	NS	NS	NS
Flour*Level	NS	NS	NS	S	S	S
Particle size*Level	NS	S	NS	NS	NS	NS
Flour*Particle size*Level	NS	NS	NS	S	NS	NS

* Results are obtained by SAS (3x2x3 factorial experimental design where Flour –flour type effect, Particle size – flour particle size effect, and Level – level of substitution effect)
S – significant effect (P<0.05);
NS – not significant effect (P>0.05)

Among all the color attributes, the hue angle was the only one affected by flour type and level of substitution, as well as flour particle size which was involved in interactions with both flour type and level of substitution (Table 4.7). The effects of flour type, level of substitution, and particle size can be seen by examining these interactions. An interesting trend was noticed for the flour particle size effect where the pulse flours with the coarse particle size did not significantly affect the hue angle values for the crust of the breads when evaluating lentil, navy bean, and pinto bean flours separately (Figure 4.15). In addition, for pulse flours with the coarse particle size, crust color of the breads at 10, 15, and 25% substitution were not significantly different in hue angle values (Figure 4.16). However, with the fine flours the hue angle varied with different flours and varying levels of substitution. Specifically, fine lentil flour produced breads with a crust which had significantly higher hue angle values than those for fine navy and pinto bean flours (Figure 4.15). Also, 10% substitution resulted in a significantly higher hue angle value than those at 15 and 25% substitution for fine flours while no difference due to the level of substitution were seen for the coarse flours (Figure 4.16).

Table 4.8. Comparison of the Color Attributes of the Crust and Crumb of Pan Bread with regard to effects of the main factors

		Whiteness Index		Hue Angle		Chroma Index	
Factor		Crust	Crumb	Crust	Crumb	Crust	Crumb
Flour	Lentil	32.1±0.9a	65.2±1.6b	50.8±4.7a	92.1±1.2a	29.9±1.5a	15.09±3.5a
	Navy Bean	31.9±0.8a	68.7±1.6a	48.5±1.7b	90.7±1.6b	28.1±1.5a	12.9±3.0b
	Pinto Bean	32.2±1.5a	64.9±2.5b	47.9±3.2b	84.0±3.7c	25.9±1.3b	12.0±2.3c
Level	10%	32.3±0.5a	68.2±1.9a	51.0±4.4a	90.7±2.9a	27.4±1.2a	10.9±1.1a
	15%	32.3±1.0a	66.2±2.2b	49.0±1.8ab	89.8±3.5b	27.8±1.9a	12.1±1.2b
	25%	31.6±1.5a	64.4±2.2c	47.2±3.2b	86.3±5.4c	28.8±3.1a	17.0±2.2c
Particle size	Coarse	32.6±1.0a	66.5±2.8a	49.6±0.7a	89.2±3.9a	28.0±1.9a	13.2±3.1a
	Fine	31.5±0.9b	66.0±2.4b	48.5±5.0a	88.6±4.8b	28.0±2.6a	13.5±3.2a

* The average values are obtained by SAS (3 x 2 x 3 factorial experimental designs where Flour – flour type effect, Particle size – flour particle size effect, and Level – level of substitution effect). The number with the same character are not significantly different (P>0.05).

For the individual flour, the value represents an average of the coarse and fine particle size at all the levels of substitution. For the individual level, the value represents an average of all the flour types with the coarse and fine particle size. For the individual particle size, the value represents an average of all the flour types at all the levels of substitution.

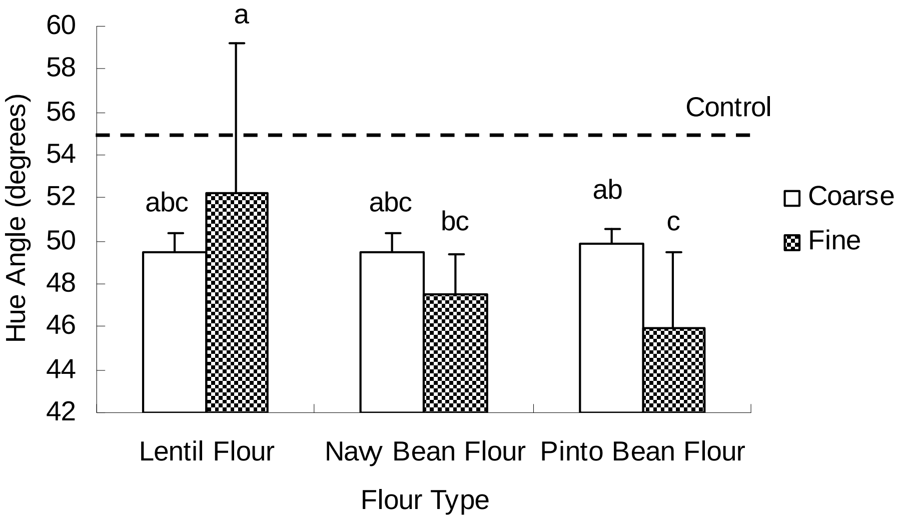

Figure 4.15. Effect of Flour Type and Flour Particle Size on the Crust Color (Hue Angle) of Pan Bread. Bars with the same character are not significantly different (P>0.05)

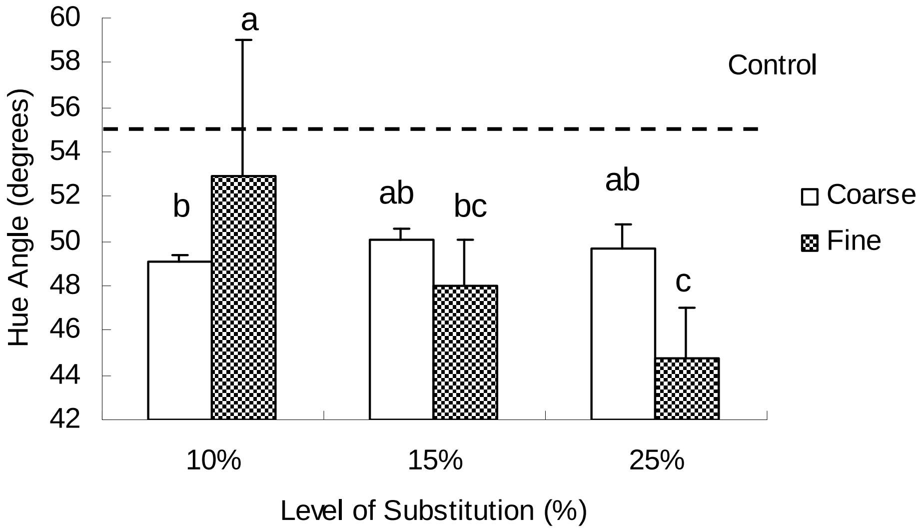

Figure 4.16. Effect of Flour Particle Size and Level of Substitution on the Crust Color (Hue Angle) of Pan Bread. Bars with the same character are not significantly different (P>0.05)

Addition of the various pulse flours into bread formulation affected the crust saturation expressed as the chroma index differently (Table 4.8). The crust of the bread containing lentil flour had the highest saturation followed by navy bean flour while the crust of the bread containing pinto bean flour had a significantly lower saturation (Table 4.8). Chroma index of the crust was unaffected by particle size and level of substitution.

Contrast analyses indicated that all the breads containing pulse flours were significantly different from the wheat control in the whiteness index and hue angle of the crust (Table 4.6). However, they were not significantly different from the yellow pea control in these two color characteristics, with an exception for the loaves containing pinto bean flour which were significantly different from the yellow pea control in the hue angle. In terms of the chroma index of the crust, all the breads containing pulse flours, except those containing yellow pea, were also significantly different from the wheat control. Breads containing pinto bean and navy bean were significantly different from the yellow pea control, whereas the breads prepared from lentil flour were not significantly different from this control with regard to the chroma index of the crust.

Crumb Color

The raw data on the color attributes of the bread crumb are included in Appendix 10. The whiteness index of the crumb was significantly affected by all three main factors (flour type, flour particle size, and level of substitution) as well as their three-way interaction (Table 4.8). Only the three-way interaction will be discussed by looking at individual flour types.

For the lentil flours, there was no significant difference detected for the whiteness index of the bread crumb prepared from the coarse and fine flours at the corresponding levels of replacement (Figure 4.17). Among all the levels of substitution for the coarse lentil flour, the crumb at 10% replacement was significantly lighter than at the 15 and 25% replacement levels. However, level of substitution did not affect significantly the whiteness index for the fine lentil flour.

A similar tendency was observed in the whiteness index values for the crumb of the breads containing coarse and fine navy bean flours where no significant difference due to particle size was detected at all the corresponding levels of substitution (Figure 4.17). Among the various levels of substitution for the coarse navy bean flour, the crumb was significantly lighter at 10% addition than at 25% addition. The whiteness index of the crumb of the bread containing fine navy bean flour was not significantly affected by the level of the added flour.

Similarly, the bread containing pinto bean flours with the coarse and fine particle size had the crumb which was not significantly different in the whiteness index at all the corresponding levels of substitution (Figure 4.17). A significantly lighter crumb was produced by the coarse pinto bean flour at 10% replacement compared to that at 25% replacement while no difference was detected among samples at 15 and 25% of supplementation. Unlike the navy bean flour, the same tendency was observed for the fine pinto bean flour where 10% addition resulted in a significantly lighter crumb than 25% addition. In general, from all the samples analyzed for whiteness index, the lightest crumb was detected for the bread made with 10% addition of coarse navy bean flour, whereas the darkest crumb was observed for the bread made with 25% addition of fine pinto bean flour.

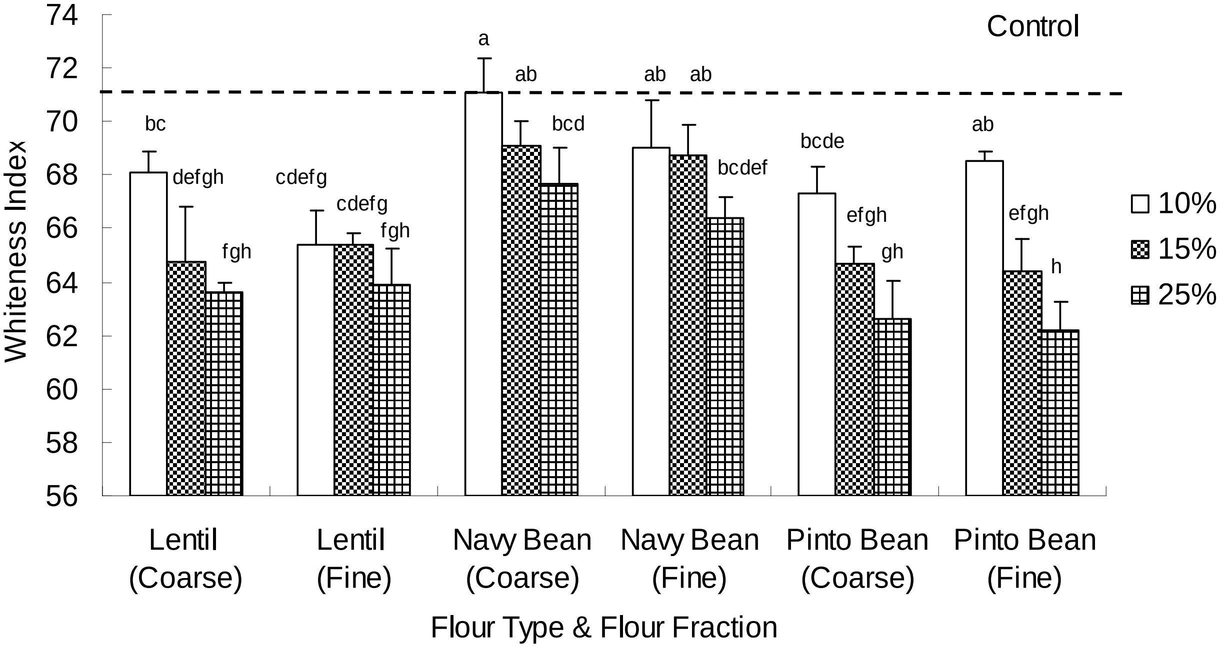

Figure 4.17. Effect of Interaction between Flour Type, Flour Particle Size, and Level of Substitution on the Whiteness Index of the Bread Crumb. Bars with the same character are not significantly different (P>0.05)

Hue angle was another color attribute affected significantly by all the main factors including flour type, flour particle size, and level of substitution as well as the interaction between the two last factors (Table 4.8). The highest crumb hue angle was seen for breads containing lentil flour followed by breads containing navy bean flour, and the lowest hue angles were observed for breads containing pinto bean (Table 4.9).

When considering the interaction between flour type and level of substitution, the breads containing lentil and navy bean flours had similar behaviors at the corresponding levels of substitution resulting in hue angle values that were not significantly different at

10 and 15% replacement levels within individual flours as well as between these two flours (Figure 4.18). However, there was a significant decrease in the hue angle values for the breads containing lentil and navy bean flours at 25% of supplementation compared to those at lower levels of substitution. Addition of pinto bean flour in the bread formulation decreased the hue angle values of the crumb to the greatest extent. Again, no differences in the hue angle values were seen at 10 and 15% supplementation, but there was a significant decrease in the hue angle value at 25% replacement. The hue angle values for the bread containing pinto bean flour were significantly lower than those for the bread containing lentil and navy bean flours at all corresponding levels of substitution (Figure 4.18).

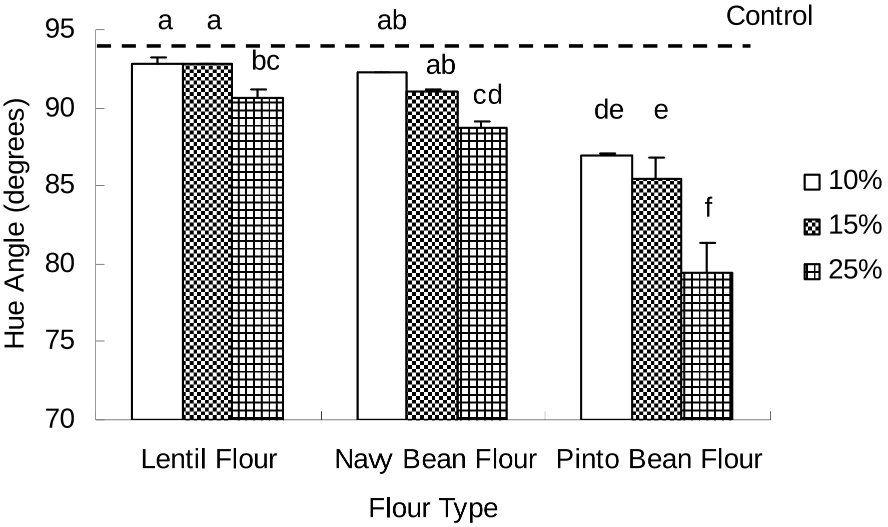

Figure 4.18. Effect of Flour Type and Level of Substitution on the Crumb Color (Hue Angle) of Pan Bread. Bars with the same character are not significantly different (P>0.05)

The chroma index of the bread crumb was significantly affected by flour type and level of substitution, as well as their interaction (Table 4.8). At the maximum supplementation (25%), the pulse flours were significantly different from each other (Figure 4.19). At the minimum level of supplementation (10%), the breads containing navy and pinto bean flours were not significantly different in chroma index, whereas they were significantly lower in this color attribute than the breads containing lentil flour. Breads containing lentil and pinto bean flours at 10 and 15% replacement were not significantly different in the chroma index of the crumb within individual flours; however, a significant increase was detected for the navy bean containing bread when the replacement level increased from 10 to 15%. Flour particle size had no significant effect on the color changes of the crumb related to the chroma index.

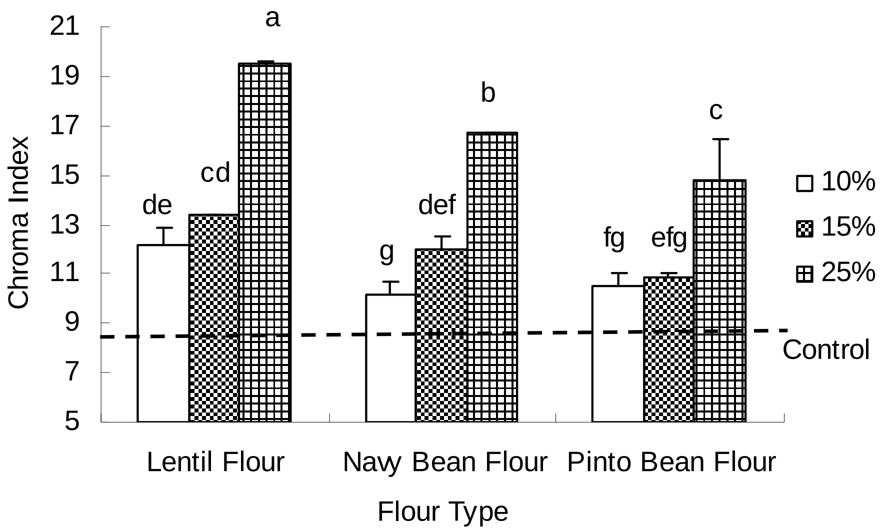

Figure 4.19. Effect of Flour Type and Level of Substitution on the Crumb Color (Chroma Index) of Pan Bread. Bars with the same character are not significantly different (P>0.05)

Contrast analyses indicated that all the pulse flours produced bread for which all the color attributes, including the whiteness index, hue angle, and the chroma index, of the crumb were significantly different from the wheat control as well as from the yellow pea control (Table 4.6).

In an overall comparison of the changes in the crumb and crust color of the bread, the breads crumb was more affected by addition of the pulse flours than the bread crust (Table 4.9). For example, type of flour had no effect on the whiteness of the crust; however, it significantly affected the crumb lightness. The addition of navy bean flour decreased the lightness the least followed by lentil flour, whereas addition of pinto bean flour produced the darkest crumb among all the pulse flours. The whiteness index of the crust was not significantly different at all the levels of substitution; however, the whiteness index of the crumb decreased with increasing levels of the pulse flour addition. Flour particle size had a significant effect on both the crust and crumb color resulting in a lighter color for the breads containing coarse flours and a significantly darker color for the breads containing fine flours.

The hue angle attribute of the crust and crumb experienced the most pronounced changes (Table 4.9). Among all the pulse flours, the breads containing lentil flour had the highest hue angle values for both crust and crumb, followed by navy bean flour. The breads containing pinto bean flour had the lowest hue angle values for both crust and crumb. For both the crust and crumb, increasing the level of pulse flours in the bread formulation resulted in a gradual decrease in the hue angle values. Similar to the whiteness index, higher hue angle values were detected for the coarse flours, although some exceptions were noted for the crust hue angle values (Figures 4.15 and 4.16). For example, the crust of the breads prepared from coarse navy and pinto bean flours at 15 and 25% replacement demonstrated a particle size effect which was similar to that seen for the crumb. However, the crust of the bread containing lentil flour had higher hue angle values for the fine particle size than for the coarse particle size. Also, 10% supplementation with the fine flours produced crusts with the higher hue angle values than with the coarse flours.

Crust color was more saturated than crumb color resulting in the higher values of the chroma index probably because of excessive browning reactions on the surface of the bread (Appendixes 9 and 10). A loss of saturation of the crust and crumb was dependent on the flour type. Among all the pulse flours, incorporation of the lentil flour produced the crust and crumb color with more pronounced saturation as evidenced by the higher values of the chroma index. This was followed by the addition of the navy bean flour. The least saturated color of the crust and crumb was observed when pinto bean flour was added in the bread formulation. The level of substitution significantly affected the chroma index of the crumb only. When a higher proportion of the pulse flour was used in the bread formulation, a more pronounced saturation (higher the chroma index values) was detected. Coarse and fine pulse flours were not significantly different in the chroma index of the crust and crumb.

The detected changes in the crust and crumb color of the bread can be probably attributed to the presence of the colored pigments and other components in pulse flours which might be involved in interactions with the pulse and wheat proteins. Each of the pulse flours used in this study was different in the amount and composition of the colored polyphenolic compounds which were mostly distributed in the seed coat (Jadhav et al., 1989). It is logical that when a white-colored pulse crop, such as navy beans, is milled into the flour (even with the seed coat) and incorporated into a bread formulation minimal changes in the color result. On the other hand, pinto beans, the most colored variety among all the pulse crops used in this study, tend to affect the color to a greater extent, especially when milled with the hull. That was in agreement with the results obtained from this study as well as from the other studies where an addition of different pulse flours or their derivatives in the pan bread formulation produced similar changes in the crust and crumb color (Fenn et al., 2010; D'Appolonia, 1977 and 1978; Silaula et al., 1989).

The amount of added pulse flours in the bread formulation directly affected the changes in the color resulting in more pronounced alterations at the higher levels of substitution supporting the presence of the higher amounts of the colored compounds in the composite flours as well as the end products as being responsible for the color differences.

Interestingly, the coarse pulse flours tended to produce breads of superior crust and crumb color than the fine pulse flours. This might be due to a lower physical number of the particles in the coarse flours than that of the fine flours at the same level of supplementation. An assumption can be made that the surface of the crust might be less disrupted by the coarse flour particles due to their larger physical size and lower number thus producing superior light reflection than the fine flours. However, Zhang & Moore (1999) concluded that the bread prepared with fine bran had lighter crust color and more uniform crumb color. Also, Kurimoto & Shelton (1988) concluded that the finer flour produced the brighter (higher the L* values) and less yellow (lower b* values) bread color. Further investigations regarding this particle size effect is required to understand the mechanism of color changes in the bread with and without added pulse flour.

4.5. Conclusions

Overall, flour type and level of substitution as well as an interaction between these factors had a significant impact on most of the Farinograph parameters of the composite flours. Also, flour particle size as a main factor significantly affected the baking quality of all the wheat-pulse composites with an exception for the DDT, and it was involved in significant interactions with flour type for all the Farinograph parameters and with the level of substitution for FAB only. The composites blended with navy and pinto bean flours had higher FAB than those blended with lentil flour due to the presence of the hull. The quality of the composite flours can be ranked in the following order - pinto bean containing blends, navy bean containing blends, and then lentil containing blends where the first one demonstrated the highest values of the DDT and the lowest values of the MTI. However, the navy bean composites had the highest values of the DS among all the pulse flours. With regard to the particle size effect, the blends containing coarse lentil and pinto bean flours had higher FAB values than the corresponding fine flours; the impact was significantly pronounced at 25% replacement. The composites containing the coarse pinto bean flour had a significantly lower the DDT value than those containing the fine pinto bean flour. However, navy bean flour with the coarse particles produced a higher DS value than that with the fine particles. When more pulse flour was blended with wheat flour, there was a greater decrease in DS.

Similar to the dough characteristics, flour type as a main factor significantly affected most of the bread parameters excluding crumb structure (cell width) and the crust color (whiteness index). The effect of the level of substitution was also significant for all parameters except crumb structure (cell elongation) and crust color (the whiteness and chroma indices). Flour particle size as a main factor was significant for the crust color (whiteness index) as well as for the crumb color (whiteness index and hue angle). Also, it significantly affected the crumb structure (cell elongation) and all the crumb texture measurements. All the main factors were involved in two-way interactions for some of the bread characteristics and three-way interaction for the crumb Whiteness.

The results obtained for the bread physical analysis were in agreement with the results obtained with Farinograph evaluation of the composite flours. Navy bean and pinto bean flours demonstrated their superior suitability for breadmaking compared to lentil flour. Among the pulse flours, incorporation of navy bean flour in bread produced the lightest colored crumb. However, the bread containing navy bean was lower in oven spring and SLV than bread containing the pinto bean. Crumb structure and texture of the breads containing navy and pinto bean flours were not significantly different. On the other hand, as the hull of the pinto bean contains a purple pigment, the addition of pinto bean flour to bread significantly affected crumb color. The bread containing lentil flour had the lowest oven spring and SLV and most negatively affected crumb structure and texture. However, among all the pulse flours, lentil flour produced the bread with the highest Hue Angle and Chroma Index values for the crust and crumb.

Flour particle size affected the crumb characteristics of the bread containing lentil flour only where the coarse particles resulted in more elongated crumb cells than the fine particles. In addition, bread containing coarse lentil and navy bean flours had softer crumb than the bread containing the corresponding flour with the fine particles. The crust color was significantly lighter and hue angle values higher for breads prepared from coarse flours rather than fine flours.

Increasing the level of pulse flours in bread resulted in more pronounced changes in bread physical parameters, especially the hue angle and saturation of crust and crumb color. In general, navy and pinto bean flours with coarse particle size could be incorporated at the 15% substitution level to the bread formulation with only relatively small changes in the bread quality. However, the bread could tolerate coarse and fine lentil flours as well as navy and pinto bean flours with the fine particle size at 10% replacement only.

Additional studies focusing on the particle size effect of the pulse flours on the characteristics of the composite flours and bread quality are recommended to better understand the functionality of the pulse flours in breadmaking. Also, studies on the physical state and composition of starch in the pulse-wheat composites as well as its pasting properties are desirable as they would provide more insight on the behavior of the pulse flours in breadmaking. Shelf-life studies on the pulse-containing bread are also suggested. Use of a stronger wheat flour, as well as addition of the baking improvers and modification of the processing conditions during scale up could improve the quality of breads containing pulse-wheat composite flours.

5. DISCUSSION

In this study, the type of pulse flour, level of substitution and particle size, all influenced the properties of doughs and breads. The type of pulse flour significantly affected most of the physical parameters of the doughs for both pita and pan breads prepared with the pulse flours. In most cases, flour type was involved in a significant interaction with the level of substitution. This was seen for FAB and all quality parameters for pita bread (Tables 3.3). For pan bread, that interaction was significant for FAB, DDT, MTI and crumb texture. For DS, SLV, and the crumb structure profile, flour type and level of substitution significantly affected these parameters as main factors (Tables 4.3; 4.5). This clearly showed that both parameters were important in determining the quality characteristics of the breads studied in this investigation. These findings agree with what has been published previously where the level of substitution for pulse flours in breads was limited (Hallab et al., 1974; D'Appolonia, 1977; Repetsky & Klein, 1981; Chavan & Kadam, 1993; Anton et al., 2008a).

Less information is available on the effect of particle size of pulse flours in bread formulations. In this study, flour particle size had a significant impact on most of the physical parameters of the experimental doughs. In the case of pita bread, the FAB values were significantly higher for the coarse flours than for the fine flours (Table 3.3). The same was observed for the FAB values of the doughs in the pan bread study; however, flour particle size was also involved into significant interactions with either flour type and/or level of substitution for DDT, DS, and MTI (Tables 4.3; 4.5). In general, the extent of the changes in these parameters was more pronounced at higher levels of substitution.

With regard to the end-product parameters, flour particle size significantly affected pita texture (area under the curve) as well as the whiteness index of the crust. This factor was also involved into significant interactions with flour type for diameter and pocket height of pita bread. In addition, the interaction between flour particle size and level of substitution was significant for force to tear the pita (Table 3.3). In the pan bread study, flour particle size had significant effects on crumb structure (average cell elongation), crumb texture profile, as well as crust and crumb color profiles either as a main factor or as an interaction with flour type and/or level of substitution (Tables 4.3; 4.5). However, some of the parameters, such as oven spring, SLV, crumb structure (cell width) as well as the chroma index of the crust and crumb were not affected by flour particle size. In general, better dough and bread characteristics were obtained with the coarse particle sizes as has been reported previously for work on tortillas using wheat flours with different particle sizes (Wang & Flores, 2000).

Compared to the wheat control, most of all the experimental doughs and breads in the pita bread study, where the substitution levels were higher than those in the pan bread study, had quality characteristics that were significantly different from the corresponding parameters of the wheat control (Table 3.3). There were a few exceptions including the pita pocket height for all breads made from pulse flours and diameter of pitas made from yellow peas which were not significantly different to pitas made from the wheat control. Similarities to the wheat control were also seen for texture where pitas containing pinto bean flour were not significantly different in force values, and pitas containing lentil flour were not significantly different in area under the curve values (Table 3.4). In the pan bread study, only doughs containing yellow pea flour were similar to the wheat control with regard to FAB, and the doughs containing navy bean flour were similar to the wheat control with regard to MTI. All the remaining pulse doughs had parameters which were significantly different from the wheat control (Table 4.4). Similar to the pita bread study, most of the experimental pan breads had parameters, which were significantly different from the wheat control (Table 4.6).

Compared to the yellow pea control, all pita parameters except pocket height and diameter (for both green lentil and pinto bean flours) were significantly different from the corresponding parameters for the yellow pea control (Table 3.4). For the pan breads, addition of green lentil flour produced doughs, which were not significantly different from those made with yellow pea flour in DS and MTI (Table 4.4). Also, addition of navy bean flour did not significantly affect DDT compared to those made from yellow pea flour. The remaining dough parameters for all the pulse flours were significantly different from those of the yellow pea control. When comparing the bread quality parameters with the breads made from yellow, all the breads containing the pulse flours were significantly different in the crumb color profile (Table 4.6). For breads containing lentil flour, all other bread quality parameters were not significantly different from those obtained with yellow pea. Except for chroma index of the crust and cell elongation, the breads containing navy bean flour were not significantly different from those made with yellow pea flour. The breads containing pinto bean flour, however, exhibited significant differences compared to the breads made with yellow pea flour in several parameters including LV, SLV, hue angle and chroma index of the crust as well as force and area under the curve (Table 4.6).

When pulse flours were added to the pita or pan bread formulations, changes in the dough and end-product parameters occur due to the fact that pulse proteins do not contain gluten which contributes to visco-elastic properties of the dough and accounts for about 80-90% of the total protein content in wheat (Schofield, 1988). With an increased level of the pulse flours in the dough, the proportion of the gluten is subsequently reduced. This is known as a gluten-dilution effect. As a result, less gluten is involved into development of the dough to optimum consistency. Therefore, water uptake by the dough is reduced as was confirmed in the pita and pan bread studies. The greater decrease in FAB for the doughs containing lentil flour than those for the doughs containing navy bean and pinto bean flours was due to the difference in the crop type as well as the milling technique used. Navy beans and pinto beans were milled with the hull, whereas lentils were dehulled prior to milling. The hull has the highest proportion of fiber, and therefore navy bean and pinto bean flours had a greater water uptake than lentil flour. Also, doughs prepared from the pulse-wheat blends had less strength resulting in breads with lower volume, coarser crumb grain, and firmer crumb texture (Galliard, 1988). Logically, the negative changes were more pronounced at higher levels of substitution.

Not only flour gluten, but also flour starch attributes to the bread quality (Jongh, 1961; Blanshard, 1986). In particular, the composition and structure of starch granule, nature of crystalline and amorphous regions within the granule, and starch gelatinization determines its functionality in breadmaking (Blanshard, 1986). Biliaderis et al. (1980)

investigated starch gelatinization of some pulse crops, and some of the results of this study are summarized in Table 4.7.

Table 4.9. Some Characteristics of Pulse Straches Compared to Wheat Starch

Starch	Amylose content (%)	Gelatinization Temperature[1] (°C)
Smooth pea	33.1	65-(67)-69
Lentil	45.5	58-(59)-61
Navy bean	36.0	68-(71)-74
Mung bean	34.9	63-(65)-69
Faba bean	32.5	61-(63)-66
Wheat	26-31[2]	58-(61)-64[3]

[1] Temperatures correspond to loss of birefringence by 5, 50, and 95% of the granules
[2] Adopted from Blanshard, 1986
[3] Adopted from Olkku & Rna, 1978

Wheat and pulse starches are of different botanical source. It appears that pulse starch has higher level of amylose in starch than wheat starch. Gelatinization temperature of lentil starch is lower, and gelatinization temperature of pea and bean starch is higher than that of wheat starch. Kusunose et al. (1999) concluded that the starch in bread should gelatinize and set when the dough is completely expanded. It seems that lentil starch, for example, with its lower gelatinization temperature among the other starches shown in Table 4.7, gelatinized earlier and did not allow the dough to expand. That is in agreement with the results of this study as the breads containing lentil flour had the lowest oven spring and the firmest crumb texture compared to the breads containing navy and pinto flours as navy bean and pinto bean starches appeared to have higher gelatinization temperature.

Overall, structure and texture of the bread products were significantly influenced by the particle size of the pulse flours. This might be because plant proteins, when incorporated to wheat dough, disrupt the protein-starch complexes in the dough system, and the protein films surrounding the gas cells lose their extensibility and rupture leading to coarse crumb grain (Sadowska et al., 2003). Overall, coarse flours produced pitas and pan bread of superior quality to those from fine flours. Logically, the coarse flours have a lower physical number of the particles than that of the fine flours at the same level of supplementation. Therefore, an assumption could be made the protein films surrounding the gas cells in the sponge-like dough and the surface of the product crust might be less disrupted by the coarse particles due to their larger physical size and lower number resulting in superior crumb and crust quality.

Product color was also significantly affected by the type of the pulse flour used. For example, navy beans being white in color (average whiteness index for navy bean flour was 89.8) produced the pitas and pan bread with the highest whiteness index for crust and crumb color respectively, whereas pinto beans being a colored bean type (average whiteness index for pinto bean flour was 86.6) produced a pan bread products with the lowest whiteness index, hue angle and chroma index for the crumb color.

Flour particle size also affected the color profile. The larger particle sizes and fewer particles in the coarse flours clearly had an impact on product color.

6. CONCLUSIONS

The findings obtained from this study showed that the pulse flours milled from green lentils, yellow peas, navy beans, and pinto beans can be utilized in bakery products such as pita bread and pan bread. In general, it appears that the blends containing navy and pinto bean flours produced stronger doughs and pita and pan breads with superior physical parameters than the blends containing lentil flour. Among all the pulse flours, the products containing navy bean flour were of the lightest color, whereas the products containing pinto bean flour had the softest texture. The products containing lentil flour had the greatest variation in the dough and end-product quality parameters.

Flours with a coarse particle size is more desirable than a fine particle size as products prepared from the pulse flours with the coarse particle size demonstrated improved quality for both pita bread and pan bread.

All the pulse flours can be incorporated into the pita bread formulation at the level of 25% and thus producing the pitas of acceptable quality. The pitas containing coarse pinto bean and coarse navy bean flours at 25% level were selected for a sensory evaluation which confirmed that these pitas were of similar or superior quality to the wheat control. With regard to pan bread, 15% addition of navy and pinto bean flours with the coarse particle size can be recommended as the maximum tolerant level to produce bread of satisfactory quality. Navy bean and pinto bean flours with fine particle sizes as well as lentil flour with the both particle sizes can be added to the bread formulation at 10% substitution only. To successfully utilize the pulse flours at higher levels, modifications of the formulations as well as the processing methods during scale up are recommended.

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8. APPENDICES

Appendix 1. Farinograph Data of Wheat Flour and the Composite Flours*

Flour Type	Flour Particle Size	Level of Pulse Flour (%)	Moisture (%)	FAB (cm^3)	Dough Development Time (min)	Dough Stability (min)
Wheat	Fine	0	12.5±0.4	61.4±0.9	7.1±2.3	14.7±2.1
Green Lentil	Coarse	25	11.9±0.8	60.3±1.6	4.0±0.4	3.4±0.2
		50	10.5±0.4	52.6±0.5	4.8±0.0	2.5±0.1
		75	9.0±0.5	45.2±0.1	5.1±0.3	1.8±0.2
		100	8.2±0.6	38.9±0.6	2.1±0.1	1.8±0.1
Green Lentil	Fine	25	11.6±1.2	58.4±1.4	4.2±0.3	3.0±0.3
		50	10.1±1.0	49.9±1.2	4.9±0.2	1.7±0.2
		75	8.6±0.4	43.3±0.4	4.6±0.9	1.8±0.4
		100	6.9±0.6	38.3±0.8	0.9±0.0	1.1±0.1
Yellow Pea	Fine	25	12.5±1.3	60.9±1.7	5.0±0.3	2.8±0.4
		50	11.6±0.6	54.3±0.6	5.2±0.2	1.4±0.0
		75	11.0±0.8	48.5±0.9	4.4±0.2	1.5±0.0
		100	10.2±0.5	44.8±0.2	0.8±0.3	0.9±0.1
Navy Bean	Coarse	25	11.7±0.9	65.0±1	4.7±0.7	6.5±0.4
		50	11.5±1.0	66.2±0.9	5.5±0.6	2.4±0.5
		75	11.0±0.7	64.5±0.4	5.2±0.3	1.8±0.1
		100	10.5±0.7	60.2±0.1	10.1±0.9	11.0±1.1
Navy Bean	Fine	25	11.2±0.9	64.6±1.2	5.8±0.6	4.6±0.9
		50	9.500.3	63.9±0.8	5.7±0.0	1.9±0.2
		75	8.1±0.7	62.0±0.0	4.8±0.0	1.3±0.3
		100	6.8±0.8	56.8±0.3	6.1±2.3	15.0±0.6
Pinto Bean	Coarse	25	12.6±0.4	65.1±1.3	6.1±0.2	5.5±0.3
		50	10.9±0.4	62.6±0.9	7.3±0.6	3.5±0.2
		75	10.2±0.5	57.9±0.7	5.3±0.4	5.2±1.6
		100	8.9±0.6	54.7±0.7	3.5±2.3	10.3±11.2
Pinto Bean	Fine	25	10.8±1.3	62.5±1.9	7.5±0.3	6.0±0.6
		50	9.9±1.3	58.7±1.4	8.6±0.6	4.9±0.7
		75	8.6±0.6	56.0±0.8	1.5±0.0	1.7±0.2
		100	6.4±0.9	55.7±0.7	1.7±0.4	1.9±0.6

* Data is recorded as the mean ± standard deviation

Appendix 2. Physical Properties of Pita Bread*

Flour Type	Flour Particle Size	Level of Pulse Flour (%)	Diameter (mm)	Pocket Height (mm)	Loaf Volume (cm^3)	Specific Loaf Volume (cm^3/g)
Wheat	Fine	0	88.9±3.3	37.8±7.3	90±24	4.1±1.1
Green Lentil	Coarse	25	87.9±4.1	38.9±2.8	94±8	4.3±0.5
		50	88.6±4.5	36.8±9.4	153±33	7.9±1.0
		75	85.5±1.9	41.4±3.2	164±12	8.3±0.8
		100	87.4±4.2	35.2±5.5	143±10	7.0±0.8
Green Lentil	Fine	25	87.2±1.2	37.2±1.9	129±36	6.2±1.2
		50	89.3±4.3	37.8±5.0	143±31	7.6±0.7
		75	86.0±2.7	42.8±7.3	162±21	8.2±0.5
		100	87.6±5.4	32.5±12.0	124±39	5.8±1.7
Yellow Pea	Fine	25	87.9±2.2	37.1±5.3	133±16	6.0±0.8
		50	89.5±4.0	40.9±7.9	163±23	8.5±1.5
		75	87.1±2.3	41.8±4.6	148±10	7.7±0.6
		100	84.4±1.2	41.6±3.9	155±14	7.8±0.6
Navy Bean	Coarse	25	92.8±3.5	36.3±6.9	139±25	5.4±0.8
		50	84.4±2.4	40.6±2.0	147±13	7.3±1.0
		75	83.1±2.7	39.1±4.1	144±16	7.1±0.6
		100	86.0±5.4	33.6±4.9	116±25	6.3±0.9
Navy Bean	Fine	25	88.5±3.8	40.0±7.9	127±35	6.2±1.2
		50	84.1±1.9	41.3±3.8	146±5	7.3±0.5
		75	82.6±2.2	41.5±3.7	141±11	6.9±0.4
		100	82.2±1.2	42.3±3.4	138±14	6.0±0.5
Pinto Bean	Coarse	25	88.7±2.0	39.2±3.0	146±48	6.9±0.3
		50	85.8±1.2	36.8±1.3	123±35	6.5±1.1
		75	86.1±3.9	38.1±5.7	149±15	7.2±0.8
		100	81.2±5.9	42.0±2.6	155±7	7.1±0.3
Pinto Bean	Fine	25	85.9±1.8	40.0±2.9	114±40	5.3±1.3
		50	86.7±2.7	38.6±4.3	133±21	6.3±1.0
		75	86.2±2.1	36.8±2.7	136±7	6.6±0.5
		100	86.3±2.4	38.8±3.0	147±8	6.2±0.4

* Data is recorded as the mean ± standard deviation.

Appendix 3. Texture Parameters of Pita Bread*

Flour Type	Flour Particle size	Level of Pulse Flour (%)	Force Top Layer (kg)	Area under the Curve Top Layer (kg*sec)	Force Bottom Layer (kg)	Area under the Curve Bottom Layer (kg*sec)
Wheat	Fine	0	0.122±0.049	0.214±0.149	0.122±0.049	0.213±0.105
Green Lentil	Coarse	25	0.124±0.050	0.161±0.079	0.115±0.036	0.160±0.061
		50	0.227±0.093	0.258±0.130	0.263±0.105	0.330±0.141
		75	0.160±0.038	0.151±0.031	0.183±0.037	0.207±0.057
Green Lentil	Fine	25	0.118±0.020	0.169±0.030	0.126±0.023	0.186±0.031
		50	0.214±0.042	0.254±0.081	0.241±0.038	0.325±0.069
		75	0.195±0.028	0.175±0.035	0.268±0.053	0.354±0.082
Yellow Pea	Fine	25	0.184±0.047	0.267±0.111	0.184±0.051	0.293±0.107
		50	0.359±0.131	0.414±0.171	0.264±0.035	0.338±0.061
		75	0.187±0.022	0.161±0.050	0.241±0.074	0.237±0.068
Navy Bean	Coarse	25	0.151±0.076	0.168±0.094	0.095±0.021	0.130±0.033
		50	0.161±0.064	0.153±0.067	0.130±0.027	0.126±0.020
		75	0.178±0.045	0.142±0.045	0.124±0.041	0.109±0.038
		100	0.180±0.080	0.133±0.072	0.154±0.059	0.125±0.055
Navy Bean	Fine	25	0.186±0.062	0.234±0.096	0.127±0.033	0.184±0.050
		50	0.155±0.028	0.151±0.034	0.177±0.069	0.200±0.069
		75	0.195±0.022	0.177±0.022	0.161±0.032	0.171±0.043
		100	0.181±0.084	0.162±0.074	0.161±0.039	0.158±0.055
Pinto Bean	Coarse	25	0.087±0.008	0.119±0.034	0.078±0.007	0.110±0.032
		50	0.107±0.010	0.103±0.007	0.085±0.014	0.149±0.144
		75	0.119±0.019	0.100±0.018	0.098±0.027	0.101±0.016
Pinto Bean	Fine	25	0.089±0.031	0.097±0.038	0.076±0.011	0.103±0.021
		50	0.106±0.032	0.103±0.035	0.091±0.024	0.101±0.036
		75	0.170±0.045	0.148±0.046	0.124±0.051	0.119±0.052

* Data is recorded as the mean ± standard deviation.

Appendix 4. Color Characteristics of the Top Crust of Pita Bread*

Flour Type	Flour Particle Size	Level of Pulse Flour (%)	Whiteness Index	Hue Angle	Chroma Index
Wheat	Fine	0	68.9±3.4	91.0±1.2	14.5±1.5
Green Lentil	Coarse	25	60.0±4.3	91.7±1.4	21.7±2.1
		50	54.0±2.2	87.7±2.6	31.3±2.5
		75	47.5±3.8	79.5±5.9	40.2±3.2
		100	45.7±4.2	76.7±5.1	44.0±3.3
Green Lentil	Fine	25	59.2±1.4	89.2±1.5	22.8±1.6
		50	53.7±3.8	84.6±5.7	33.0±4.9
		75	45.3±10.0	73.4±14.2	35.4±6.2
		100	47.3±5.3	74.0±7.6	41.6±3.3
Yellow Pea	Fine	25	60.2±3.3	88.8±2.1	19.9±2.2
		50	52.8±3.9	80.4±5.3	32.3±2.9
		75	42.4±2.5	70.0±5.9	40.6±3.6
		100	42.3±4.7	71.0±6.1	41.2±3.4
Navy Bean	Coarse	25	62.6±2.4	92.0±1.3	14.9±1.1
		50	61.3±5.1	91.6±1.3	16.6±1.2
		75	64.4±2.2	91.0±1.0	19.7±1.7
		100	61.7±2.5	88.5±1.3	22.7±1.5
	Fine	25	62.9±2.3	91.7±1.5	16.0±1.2
		50	62.6±0.9	89.4±2.2	21.0±2.7
		75	59.3±4.8	85.5±2.3	26.0±2.2
		100	59.7±2.4	83.8±3.3	28.8±2.1
Pinto Bean	Coarse	25	60.2±6.0	82.6±1.3	16.3±1.1
		50	56.9±2.3	78.8±1.4	18.0±1.2
		75	54.6±3.9	75.7±1.2	18.8±1.3
		100	55.6±4.0	74.0±1.5	20.0±1.8
Pinto Bean	Fine	25	58.6±4.4	80.6±1.5	17.0±1.4
		50	55.5±3.6	75.4±1.8	21.2±2.2
		75	52.3±1.9	74.0±3.2	24.4±2.9
		100	50.8±1.9	73.5±3.7	25.6±3.3

* Data is recorded as the mean ± standard deviation.

Appendix 5. Color Characteristics of the Bottom Crust of Pita Bread*

Flour Type	Flour Particle Size	Level of Pulse Flour (%)	Whiteness Index	Hue Angle	Chroma Index
Wheat	Fine	0	70.2±5.8	90.7±1.3	15.3±1.4
Green Lentil	Coarse	25	62.4±1.0	91.6±0.7	22.5±2.1
		50	53.1±2.5	83.2±4.2	35.0±2.3
		75	46.1±2.4	79.1±3.8	42.4±2.3
		100	43.0±2.7	74.7±5.0	45.4±2.0
Green Lentil	Fine	25	57.7±5.2	85.4±6.7	25.7±3.5
		50	54.7±3.9	84.5±5.2	33.0±1.3
		75	41.4±4.1	70.5±4.7	43.5±3.4
		100	38.5±3.5	65.4±4.7	45.4±2.6
Yellow Pea	Fine	25	60.8±2.9	87.6±2.9	19.7±3.4
		50	50.2±2.6	77.0±2.8	35.7±3.6
		75	42.1±6.9	70.0±8.1	42.3±3.7
		100	40.4±2.5	68.6±3.1	45.6±2.0
Navy Bean	Coarse	25	65.5±1.0	89.3±2.2	17.4±1.46
		50	63.5±2.0	89.4±2.8	19.8±2.28
		75	64.8±1.5	89.5±1.3	22.1±1.41
		100	61.2±2.4	87.4±1.9	23.9±1.96
	Fine	25	64.4±2.0	86.9±3.2	20.1±2.5
		50	61.9±3.3	86.0±4.5	24.2±4.0
		75	60.8±2.9	85.7±3.1	26.3±2.5
		100	57.1±4.9	83.3±6.0	31.1±5.1
Pinto Bean	Coarse	25	64.4±4.7	83.5±1.1	16.6±1.8
		50	60.2±1.9	78.6±1.0	18.9±1.2
		75	57.7±1.9	76.4±0.7	19.9±1.5
		100	64.4±4.7	74.0±0.8	21.4±1.8
Pinto Bean	Fine	25	61.7±1.4	79.6±1.3	18.3±2.5
		50	57.5±1.0	74.7±1.3	22.7±1.9
		75	53.4±2.0	72.0±1.4	24.0±1.8
		100	48.4±3.7	68.3±2.5	27.8±5.4

* Data is recorded as the mean ± standard deviation.

Appendix 6. Moisture Content and Farinograph Data of Wheat Flour and the Composite Flours*

Flour Type	Flour Particle size	Level of Pulse Flour (%)	Moisture (%)	FAB (cm^3)	Dough Development Time (min)	Dough Stability (min)	Mixing Tolerance Index
Wheat	Fine	0	12.9±1.0	60.8±0.1	8.5±0.4	14.7±2.1	27.5±10.6
Green Lentil	Coarse	10	12.6±0.8	61.0±0.5	5.7±0.2	9.3±0.8	20.0±8.5
		15	12.0±0.7	60.2±0.7	5.8±0.4	7.2±0.7	40.5±6.4
		25	11.7±0.6	58.9±0.4	3.9±0.2	3.7±0.1	75.0±18.4
Green Lentil	Fine	10	12.1±0.4	59.8±1.1	5.3±0.1	7.3±1.4	36.5±16.3
		15	11.6±0.6	59.6±0.6	4.7±0.2	5.2±0.4	67.5±7.6
		25	11.2±0.5	57.0±0.6	3.9±0.8	3.6±1.1	106.0±9.9
Yellow Pea	Fine	10	12.6±1.3	60.9±0.2	6.0±0.6	9.5±2.5	15.5±14.8
		15	12.7±1.4	61.1±0.1	5.4±0.2	5.9±1.1	60.0±31.1
		25	11.8±0.3	59.5±0.3	4.8±0.1	2.9±0.6	88.5±0.7
Navy Bean	Coarse	10	12.1±1.0	62.4±0.4	5.8±0.1	13.1±1.8	28.0±4.2
		15	11.8±0.7	63.5±0.1	6.4±0.2	10.8±0.7	27.5±0.7
		25	11.7±0.8	64.3±0.1	5.4±0.2	7.0±0.4	30.5±0.7
Navy Bean	Fine	10	12.0±0.4	62.7±0.0	5.8±1.3	9.9±1.8	30.5±3.5
		15	11.6±0.4	63.7±0.2	6.1±0.2	6.6±1.2	47.5±9.2
		25	11.2±0.9	63.9±0.3	5.7±0.5	4.1±0.2	60.5±0.7
Pinto Bean	Coarse	10	12.6±0.2	61.9±0.1	6.3±0.4	9.2±1.7	31.0±11.3
		15	12.7±0.1	63.5±0.3	7.1±0.1	8.8±0.9	35.5±7.8
		25	12.3±0.1	63.8±0.5	6.6±0.6	5.8±0.7	44.0±9.9
Pinto Bean	Fine	10	12.4±0.6	61.7±0.8	8.2±0.1	10.4±0.9	31.0±5.7
		15	11.7±0.9	61.7±0.4	7.7±0.7	7.6±0.6	43.0±9.9
		25	10.9±1.3	61.1±0.1	7.6±0.1	6.4±0.0	37.0±1.4

* Data is recorded as the mean ± standard deviation.

Appendix 7. Physical Properties of Pan Bread*

Flour Type	Flour Particle Size	Level of Pulse Flour (%)	Oven Spring (mm)	Loaf Volume (cm^3)	Specific Loaf Volume (cm^3/g)
Wheat	Fine	0	13.7±0.8	968±8	6.8±0.1
Green Lentil	Coarse	10	3.3±1.4	785±50	5.4±0.3
		15	-5.6±1.0	639±6	4.5±0.0
		25	-13.1±0.8	467±33	3.3±0.3
Green Lentil	Fine	10	-3.3±1.8	713±32	5.0±0.3
		15	-8.8±3.3	616±16	4.3±0.2
		25	-11.8±3.6	423±4	3.0±0.0
Yellow Pea	Fine	10	2.5±1.5	790±4	5.5±0.1
		15	-6.9±1.4	622±12	4.3±0.1
		25	-10.2±2.2	456±4	3.1±0.0
Navy Bean	Coarse	10	4.1±0.1	807±9	5.5±0.1
		15	-4.9±4.6	685±28	4.7±0.1
		25	-20.3±10.8	478±25	3.3±0.2
	Fine	10	1.1±1.8	769±23	5.3±0.1
		15	-2.8±12.5	640±85	4.4±0.6
		25	-5.6±0.9	455±71	3.0±0.4
Pinto Bean	Coarse	10	1.9±5.4	808±67	5.6±0.4
		15	-1.8±2.9	725±21	5.0±0.2
		25	-6.4±0.4	490±28	3.3±0.2
Pinto Bean	Fine	10	5.2±0.1	845±11	5.8±0.1
		15	-1.4±3.5	710±28	4.9±0.2
		25	-6.0±0.3	485±14	3.3±0.1

* Data is recorded as the mean ± standard deviation.

Appendix 8. Crumb Structure and Texture Characteristics of the Pan Bread*

Flour Type	Flour Particle size	Level of Pulse Flour (%)	Crumb Structure		Crumb Texture	
			Cell Elongation (mm)	Cell Width (mm)	Force (kg)	Area under the curve (kg*sec)
Wheat	Fine	0	1.993±0.062	0.093±0.012	0.119±0.01	0.367±0.039
Green Lentil	Coarse	10	1.983±0.031	0.075±0.007	0.183±0.039	0.574±0.136
		15	1.904±0.071	0.059±0.013	0.259±0.024	0.815±0.069
		25	1.920±0.094	0.053±0.009	0.712±0.213	2.427±0.741
Green Lentil	Fine	10	1.851±0.027	0.074±0.011	0.245±0.065	0.783±0.199
		15	1.849±0.078	0.057±0.008	0.316±0.027	1.013±0.083
		25	1.858±0.070	0.057±0.014	1.293±0.163	4.707±0.800
Yellow Pea	Fine	10	1.921±0.026	0.074±0.019	0.179±0.027	0.578±0.091
		15	1.972±0.119	0.061±0.008	0.338±0.115	1.074±0.433
		25	1.871±0.075	0.045±0.006	0.946±0.085	3.354±0.321
Navy Bean	Coarse	10	1.984±0.049	0.078±0.013	0.153±0.013	0.477±0.063
		15	2.005±0.072	0.078±0.008	0.217±0.023	0.720±0.089
		25	1.965±0.096	0.064±0.021	0.721±0.162	2.477±0.510
Navy Bean	Fine	10	1.971±0.079	0.076±0.014	0.182±0.018	0.591±0.062
		15	1.963±0.026	0.060±0.010	0.309±0.035	0.994±0.089
		25	1.918±0.051	0.044±0.007	1.037±0.070	3.746±0.324
Pinto Bean	Coarse	10	1.931±0.026	0.069±0.013	0.187±0.028	0.616±0.111
		15	1.959±0.027	0.067±0.007	0.201±0.011	0.655±0.065
		25	1.890±0.044	0.052±0.008	0.505±0.174	1.701±0.615
Pinto Bean	Fine	10	1.944±0.073	0.079±0.014	0.170±0.017	0.556±0.066
		15	1.982±0.015	0.070±0.014	0.216±0.024	0.679±0.063
		25	1.930±0.016	0.042±0.006	0.789±0.050	2.834±0.260

* Data is recorded as the mean ± standard deviation.

Appendix 9. Color Characteristics of the Pan Bread Crust*

Flour Type	Flour Particle Size	Level of Pulse Flour (%)	Whiteness Index	Hue Angle (degree)	Chroma Index
Wheat	Fine	0	34.7±1.6	54.9±1.2	31.8±1.3
Green Lentil	Coarse	10	32.2±0.8	49.4±1.4	27.6±1.3
		15	33.1±0.7	50.4±2.8	29.2±2.1
		25	30.8±0.8	48.6±2.3	31.9±1.8
Green Lentil	Fine	10	33.2±4.5	60.0±6.2	29.5±2.1
		15	31.8±2.8	50.4±3.6	30.5±2.4
		25	31.4±1.2	46.3±4.9	31.1±6.3
Yellow Pea	Fine	10	32.6±0.4	49.4±0.7	28.4±0.3
		15	31.6±0.5	45.3±1.1	26.2±1.8
		25	31.8±0.7	56.5±2.9	35.4±4.4
Navy Bean	Coarse	10	32.1±0.5	48.8±0.4	26.6±0.2
		15	33.2±1.6	49.4±2.5	28.1±2.3
		25	32.3±0.5	50.4±5.1	29.3±5.3
			31.6±1.0	49.5±0.8	27.7±0.6
Navy Bean	Fine	10	31.6±0.7	47.1±0.9	26.7±1.3
		15	30.8±0.8	45.8±3.2	30.3±2.8
		25			
Pinto Bean	Coarse	10	32.4±1.2	49.1±0.7	25.9±0.7
		15	33.1±0.6	50.3±0.5	26.9±0.5
		25	34.3±2.9	50.2±5.0	26.7±5.9
Pinto Bean	Fine	10	32.1±0.8	49.2±0.4	27.0±0.5
		15	31.0±1.9	46.4±3.0	25.4±2.1
		25	30.1±0.6	42.0±1.7	23.6±2.3

* Data is recorded as the mean ± standard deviation.

Appendix 10. Color Characteristics of the Pan Bread Crumb*

Flour Type	Flour Particle Size	Level of Pulse Flour (%)	Whiteness Index	Hue Angle (degree)	Chroma Index
Wheat	Fine	0	71.1±1.2	94.3±1.1	8.9±0.5
Green Lentil	Coarse	10	68.1±0.8	92.5±0.7	12.6±1.1
		15	64.82.1	92.8±0.8	13.4±0.6
		25	63.6±0.3	91.0±0.7	19.4±0.8
Green Lentil	Fine	10	65.4±1.3	93.1±1.4	11.7±1.5
		15	65.4±0.4	92.7±0.5	13.3±1.1
		25	63.9±1.4	90.1±0.9	19.6±0.3
Yellow Pea	Fine	10	69.7±0.8	91.5±1.1	10.9±1.0
		15	65.4±1.2	89.0±0.4	14.3±0.4
		25	65.0±0.8	87.4±0.7	17.8±0.5
Navy Bean	Coarse	10	71.1±1.3	92.3±1.1	9.7±0.3
		15	69.1±1.0	91.1±0.3	11.6±0.8
		25	67.7±1.3	89.0±0.2	16.7±1.4
Navy Bean	Fine	10	69.0±1.7	92.2±1.2	10.5±0.1
		15	68.7±1.1	90.9±0.4	12.4±0.5
		25	66.4±0.8	88.5±0.8	16.7±0.8
Pinto Bean	Coarse	10	67.3±1.0	87.0±2.1	10.8±1.6
		15	64.6±0.7	86.4±0.9	10.7±0.4
		25	62.6±1.4	80.8±1.7	13.7±1.7
Pinto Bean	Fine	10	68.5±0.4	86.9±1.9	10.1±1.1
		15	64.4±1.3	84.6±1.3	11.0±1.0
		25	62.2±1.1	78.2±0.7	15.9±0.7

* Data is recorded as the mean ± standard deviation.