Application of Yellow Pea (*Pisum Sativum*) Flour into Baked Goods

A Thesis

Presented in Partial Fulfilment of the Requirements for the

Degree of Master of Science

with a

Major in Food Science

in the

College of Graduate Studies

University of Idaho

by

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August 2020

Authorization to Submit Thesis

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Abstract

Legumes and pulses are increasingly viewed as a superfood and sustainable future protein source. Yellow pea flour produced in large quantities in North America is high in protein and fiber, and low in lipids. The objective of this thesis is to study the effect of incorporating dry split yellow pea flour into baked goods like bread and pancakes and identify the threshold of maximum incorporation at which physical and sensorial attributes are not affected significantly.

The section titled "the physical and sensorial characterization of yellow split pea flour incorporated pancakes" in the thesis tested the effect of pea flour addition on pancake physical and sensorial properties by instrumental analyzes and a trained descriptive panel at levels of 1%, 2%, 5%, 10%, and 20% w/w basis. Sodium metabisulfite (SMB) was added as the reducing agent to evaluate the hypothesis that changes to protein conformation will impact the flavor profile of the pea flour. All the pancake batters prepared with pea flour, with pea flour and SMB, and with only SMB were optimized to have the same viscosity. It was observed that viscosity optimization was advantageous in attaining pancakes with similar physical attributes, like height, weight, and diameter. There were no significant differences in the measure of weight, height, and specific volume of pancake amongst all the treatments with the value of control at 244.73 g, 2.22 cm^3/g, and 4.97 cm, respectively. However, the deviation was not avoidable at a higher level of pea flour incorporation (i.e., 20%) for diameter and texture, which ranged from 12.18 to 13.13 cm and 2637.52 to 3316.86 g, respectively. Sensory attributes did not show any drastic improvement with the addition of SMB. Nevertheless, some interesting observations on the overall sensorial attributes of pancakes were made.

The “Incorporation of yellow pea flour into white pan bread” section of this thesis investigates the bread quality of pea flour incorporated bread. Pea flour was added at 1%, 2%, 5%, 10%, and 20% levels, and the resulting bread was evaluated for the physical and sensory quality. For sensory analysis, control (100% wheat flour), 5%, and 20% of bread were made and evaluated by a consumer panel. It was observed that the bread made with 10% pea flour was not significantly different from control in terms of height, specific volume, and firmness. Bread incorporated with 5% and 20% pea flour was not perceived to be different by the consumer panel. However, the control was significantly different for flavor, after-taste, willingness to buy, and overall acceptability from the pea flour incorporated treatments. On the other hand, control was similar to 10% pea flour bread in terms of texture and appearance. The panelists were not able to differentiate between the appearance of the bread across all treatments.

Acknowledgments

I would like to acknowledge the tireless efforts of Dr. Brennan Smith for his guidance and patience throughout the process as well as for the opportunity to pursue my Master of Food Science in the United States. Furthermore, I would like to thank my committee, Drs. Craig Morris, Alecia Kizonas, and Armando McDonald for their guidance and support. I would like to acknowledge USD-ARS staff in the Western wheat quality baking and quality lab unit and especially Doug Engle and Mary Baldridge, for their unconditional support and advice while conducting the bread and pancakes trials. I would like to thank my lab members, especially Drs. Gamze Yazar and Ali Sadeghi for allowing discussion, listening to my problems, and helping me in scheduling, planning, and conducting my experiments. I would like to thank Halle Choi for giving me firsthand experience in making pancakes and bread preparation, and Chelsea Price for her assistance in pancake making trails. I would like to acknowledge the help from Dr. Carolyn Ross, for guidance and suggestions on scheduling, and conducting my descriptive sensory panel. I thank Dr. Clifford Hall (North Dakota State University), and Beata Vixie, for helping me identify sensory descriptors, and Victoria Minette for acquainting me with sensory science. I would like to thank the Descriptive panel members without the corporation of whom the sensory section of Physical and sensorial characterization of Yellow split pea flour incorporated pancakes section of this thesis would not have been possible. I am grateful to Dr. William Price for help in understanding the statistical design of sensory data. Lastly, a special thanks to the US Dry Pea and Lentil Council for providing financial support for the completion of my degree.

Dedication

This work is dedicated to my parents, who have been my force to work towards my dreams

and

my friends in Moscow, Idaho, USA, who have always supported me and made me feel at home during my master's degree.

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Chapter 1: Literature review

1.1 Introduction

Consumers are becoming increasingly aware of the food products they choose to buy. With global warming and an increasing emphasis on saving the planet, people are looking for sustainable and greener sources of food to meet their nutritional needs. Protein, a macronutrient, is required in relatively large quantities for the average person. In developed countries, this demand is met by animal products, like dairy and meat (Rochfort & Panozzo, 2007). Legumes and pulses provide a solution in the pursuit of a greener future by providing a cheap and sustainable source of protein (Pimentel & Pimentel, 2003). To share the burden of filling the nutritional needs of humans, legumes, and pulses can be further incorporated into the diet (Bresciani & Marti, 2019). Here, the challenge lies in manufacturing food products like bread and pastries with partial or complete replacement of wheat flour by ingredients derived from legumes and pulses.

Legumes belong to the family of *Leguminosae*, also known as *Fabaceae*. Pulses like beans, peas, and lentils fall under this family. Fresh beans and fresh peas are not considered to be pulses. In general, the dried seeds from leguminous crops are called pulses except for those crops which are used for oil production, like peanuts and soybeans (Maskan & Altan, 2016). According to US Dry Pea and Lentil Council (USDAPLC, 2020), pulses are categorized into dry peas, lentils, chickpea, and beans based on growing conditions, growth structure, maturation, and morphology. Pulses have a separate health benefit apart from soy and peanut; that is, they are low in fat and high in protein and fiber.

Legumes are considered low-glycemic-index foods (Bornet et al., 1997). Selecting low glycemic index food is crucial in the diet for patients with diabetes mellitus. In a healthy individual, legumes will increase satiety, facilitating reduced food intake, and provide other health benefits concerning postprandial (after meal) glucose and lipid metabolism (Rizkalla et al., 2002). Most dieticians and corresponding organizations encourage regular consumption of legumes (Leterme, 2002). This can only be possible if the food industry and professional organizations, which shape and hugely influence the diet pattern of the public, take on the responsibility to encourage consumption of leguminous grains in one form or another into healthy and convenient food products (Schneider, 2002). The supplementation of legumes into cereal-based products or the production of alternative meat are two potential alternatives in this regard.

To take advantage of these health benefits, one must first determine new and creative applications of pulse crops into foods. Incorporation of pulse flours into baked goods is one example of this, where milling pulses into flour is a crucial step. In the case of wheat flour, milling is known to determine the quality of the final product (Kihlberg et al., 2004). Understanding the effect of different milling operations on some of the functional properties like particle size distribution, pasting properties, water holding capacity, and damaged starch of resulting flour will help to identify the best milling procedure for a given use. Pea flour and other pulse flours pose a hurdle in attaining optimum quality in baked products, which can be moderated to an extent by a selection of appropriate milling and stream from milling operation (Kerr et al., 2000). To this end, pea flour and its derivatives, like pea protein, are having trouble in broad-scale application because of objectionable flavors associated with raw dried peas (Owusu-Ansah & McCurdy, 1991).

1.2 Yellow pea

The yellow pea (*Pisum sativa*), a pulse, and a member of the legume family is seeing growing interest. Yellow peas are a cool-season leguminous crop grown throughout North Dakota, Montana, and Palouse region of Pacific Northwest, US (Dyck, 2019). One main reason for the increasing interest is unlike soy, which is among the big eight common food allergens; pea allergy is rare, making it a better alternative in plant-based foods (Wensing et al., 2003).

Carbohydrate and fiber make a considerable amount of the yellow pea seed. Starch is the major carbohydrate and is 46% of dry matter of seed on average. Pea starch has been shown to consist of simple and compound starch granules (Bertoft et al., 1993). Amylose content in pea starch from six pea cultivars from North Dakota has been reported to range from 32.2% to 41.1% (Simsek et al., 2009). It is seen that wrinkled pea has about 65-75% less starch content compared to smooth pea. In addition, the starch in wrinkled pea is high in amylose content compared to starch from smooth pea. It was also observed that the pasting properties of the starch were significantly different between the cultivars indicating phenotypical variability (Ratnayake et al., 2001). Pasting properties of pea flour do not result in a distinct pasting curve. Viscoamylograms often show low breakdown, setback, and final viscosity, a possible reason identified is the smaller amylose chain length (Ratnayake et al., 2002). Pea starch digestibility is slower than its cereal counterparts due to high amylose content, making it a low glycemic index food (Ring et al., 1988).

Fiber accounts for roughly 20% of dry matter of pea seeds. The seed coat has an insoluble dietary fiber like cellulose, and cotyledons contain soluble dietary fiber like hemicellulose and pectin (Dahl et al., 2012). Fiber may help in reducing blood cholesterol by decreasing reabsorption of bile acids, colon cancer, and weight control (Mathers, 2002;

McCrory et al., 2010). Fiber is one of the prime sources of deterioration in the quality of baked goods (Gómez et al., 2003), as mentioned in the later sections.

With an average of ~25% protein, peas, and other pulses are highly regarded for their protein content (Owusu-Ansah & McCurdy, 1991). Unlike their cereal counterparts, peas provide greater amounts of lysine and tryptophan. However, pea protein can be more deficient in methionine when compared to other legumes like soybeans (Owusu-Ansah & McCurdy, 1991).

Peas also are an ample source of minerals and vitamins. Dehulled yellow peas from Saskatchewan were shown to be rich in potassium, phosphorus, magnesium, and calcium at a level of 1.04% 0.39%, 0.10%, and 0.08% weight basis respectively (Reichert & MacKenzie, 1982). Though peas are rich in minerals, the presence of antinutrients like phytate can lower the bioavailability of these minerals, especially iron and zinc (Sandberg et al., 1993). Pulses are high in B vitamins, but a good amount can be lost during the processing (Hall et al., 2017). Field peas contain 101 µg of folate per 100g (Dang et al., 2000). Han and Tyler, 2003 reported lesser concentrations of folate in pea from Saskatchewan, ranging from 23.7 to 55.6 µg/100g on a dry matter basis. In this study, it was also seen that the location of cultivation had a greater effect on folate content than the crop year.

Just like whole cereals, seeds, and nuts, legumes contain antinutrients. Antinutritional factors present in legumes include phytate, chymotrypsin inhibitors, enzyme inhibitors (trypsin inhibitors [TIs], and a-amylase inhibitors), polyphenolics (including tannins), saponins, and lectins (Patterson et al., 2017). These affect the nutritional quality of legumes by decreasing the digestion and absorption of nutrients like protein (Silva-Cristobal et al., 2010). Phytate has also been reported to have a negative effect on the protein bioavailability of faba beans and peas (Carnovale et al., 1988).

Lakkakula et al. (2017) reported a drastic increase in the value of production of dry peas from less than $50 million in 2000 to nearly $351 million in 2016 in the United States. Dry peas are generally cheaper than lentils. This, coupled with increasing consumer demand for plant-based protein, is likely the driving force for the increasing number of products containing pea launched in the last decade.

1.3 Milling Background

Milling, a unit operation of size reduction, is the most important and crucial step in the production of flour. It is a unit operation for size reduction. During milling, seeds are broken down into smaller particles. The size of the resulting flour particles can vary depending on the type of mill, the operating speed of the mill, and grain moisture content (Maskus et al., 2016; Kaiser et al., 2019; Scanlon et al., 2018). Unlike wheat, there is no single commercial or standard methods for milling pulses. While there are many kinds of milling operations, the most commonly applied milling types for cereals and legumes are pin milling, hammer milling, roller milling,

Pin milling consists of two discs opposing each other, with each disc having concentric pin-like protrusions. Pin milling works by centrifugal impact when the seeds enter the center of the discs and hurl to the periphery, hitting against the pins. It is best suited to produce fine flour. Trappey et al. (2015) studied the effect of pin milling on sorghum flour and gluten-free bread quality. Sorghum flours were extracted at rates of 60%, 80%, and 100% were re-milled with a pin mill and processed at low and high speed. It was observed that high-speed pin milling leads to a sorghum flour with more starch damage, finer particle size, and higher water absorption properties. It was reported that the 60% extraction rate sorghum flour when pin milled at high speed gave the softest bread among all treatment combinations. Lower extraction rates, resulting in low fiber and mineral content and small particle size from the high-speed pin milling, were attributed to this. Hoseney (1994) found that pin milled wheat flour with finer particle size along with corrected water absorption made a cohesive dough. Though prolonged milling to achieve finer particle sizes will result in more starch damage in flour (Nowakowski et al., 1986). Barrera et al. (2007) studied the effect of starch damage on bread quality and concluded that more starch damage results in bread with lower quality attributes.

Hammer milling consists of hammers or hammer-like metal plates attached to a central shaft. As the hammers rotate at high speed, it hits the grain and breaks them apart with impact, and the particle size of the resulting flour is determined by mill speed and screen mesh size. (Saravacos & Kostaropoulos, 2002). Kaiser et al. (2019) reported that hammer milling of pea flour resulted in more starch damage with low-speed milling (1.1%) in comparison to high-speed milling (0.7%) with smaller screen apertures. Because the mesh size and rotational speed of the hammers ultimately determine the flours dwell time inside the mill, the increased starch damage reported by these authors can likely be attributed to this.

Stone milling uses compressive and abrasive force to mill grain. This results in coarser and more variable particle size when compared to other milling operations. Maskus et al., 2016 studied the effects of different milling and found that pea flour milled with a stone mill resulted in flour with larger particle size, greater water absorption capacity, and lower pasting properties. This could be attributed to the high amount of fiber

Roller mills resulted in the highest starch damage among the four kinds of milling (Hammer, pin, stone, and roller milling). This is because the roller mill uses compressive force on the flour particle, and the gap size keeps decreasing as the number of rollers increase. Every time the flour particle goes through the pair of rollers, the starch damage in the flour increases, and the flour goes through a series of rollers with reducing gap size resulting in greater starch damage in flour as the number of rollers increases. Thus, the least starch damage is observed in flour coming out from the first break.

Table 1.1 The effect of different milling on starch damage in pea flour compared to wheat flour. (Maskus et al., 2016; Kaiser et al., 2019)

	Wheat flour	Pea flour (Hammer mill)	Pea flour (Roller mill)	Pea flour (Fine pin mill)	Pea flour (Stone mill)
Starch damage (%)	7.5-8.0	1.0-1.4	2.8	1.0-1.4	1.1
Water absorption capacity(g/g)	0.60	1.57	1.41	1.34	1.88

1.4 Bread and influence of composite flours on bread, making, and quality

Making Bread involves many steps and factors that determine the end-quality of the bread. Basic bread making processes include mixing ingredients, dough resting, shaping, proofing, and baking with variations in the intermediate stage depending on the type of product being made (Rosell, 2011). Due to yeast activity, temperature, and water hydration during mixing, proofing, and baking, the dough is subjected to shear and large extensions (Rosell & Collar, 2008). Evaporation of water, expansion of volume, development of a porous structure in the dough, gelatinization of starch, denaturation of protein, and crust formation are some of the major physical and chemical changes that the dough undergoes during production (Faridi & Faubion, 2012).

Gluten network formation in the dough is the key factor that imparts structure in bread while starch provides bulk, and texture. Hence, many studies making composite bread (bread made by partial replacement of wheat flour by non-wheat flours (legume, potato, cassava flour, etc.) generally add gluten or dough conditioner like glycolipids, sucrose monolaurate, potassium bromate, etc. externally or choose a wheat flour with greater protein content to attain the desirable structural characteristics, which in turn, leads to better quality bread (Fenn et al., 2010)

During initial mixing and kneading, the dough is exposed to large axial deformations. This disrupts the native protein structures and hydrates all the flour components. This helps in the formation of gluten networks from two functional classes of proteins, gliadin and glutenin present in raw wheat flour. When enough mixing is done, the dough becomes smooth and elastic. Undermixing results in a dough with patches and overmixing will lead to the weakening of the protein network (Rosell, 2011).

Fermentation allows for yeast activity, which consumes sugars present in the dough to produce carbon dioxide, resulting in a rise or and increase dough volume (Rosell, 2011). Yeast acts as the centre for carbon dioxide release. Air cells incorporated during mixing, provide an anchor, and act as air nuclei for the accumulation of carbon dioxide (Romano et al., 2007). Proofing is followed by punching were dough is remixed to break larger gas cells into smaller ones while distributing them evenly throughout the dough (Charley and Weaver, 1998). During fermentation, punching can be done once or a greater number of times. This is followed by molding the dough into a loaf, followed by a final proofing the pan used for baking (Delcour & Hoseney, 2010).

Baking is the last step in the process of bread making. This step transforms the dough into an aromatic, light, porous and digestible product. Placing the dough into the oven results in a relatively sudden rise in the loaf volume called oven spring which, is induced several factors. First, higher metabolism in yeast cells leads to a rapid increase in carbon dioxide production. Second, the soluble carbon dioxide becomes less soluble with increasing temperature causing more carbon dioxide to move into air cells. Third, the formation of vapors of water, ethanol, and their azeotrope. Finally, the expansion of all the gases and vapors being formed (Delcour & Hoseney, 2010). As heat flows from the outside to inside, and the temperature increases gradually, the yeast gets inactivated at ~45°C (Rosell, 2011). Slowly, the outer layer of the dough exposed to high oven temperatures turns into a rigid dark layer that forms the crust of bread. The thickness of the crust is influenced more by the temperature of the oven than the steps prior to baking (Jefferson et al., 2006). Sugar present in the flour and those produced by enzymes react with protein in a non-enzymatic browning reaction called the Maillard reaction to produce aromatic and reddish-brown colored compounds, which imparts a brown color to the crust (Purlis, 2010). As inner crumb temperatures reach 60°C or above, the inactivated yeast cells start to die. The bread, crumb structure starts to develop from outside, moving to the core as the temperatures reach 99°C (Pyler & Gorton, 1988). As this happens, the protein starts to denature, and starch swells and gelatinizes, forming a semi-rigid structure. The structure and quality of the inner crumb are determined by the biochemical properties of the wheat, milling operations, and the processing steps that the dough has undergone. The crumb structure of baked cereal products is essential for tactile sensorial properties (Traynham, 2006).

Composite flours for baking are generally made my blending wheat flour with a legume, other cereals, tuber, or root flour. Composite flours can also be made with no wheat flour involved. These blends are prepared to take advantage of the flours being either economical or to acquire a specific nutritional or functional benefit (Mohammed et al., 2012; Carson et al., 2000; Eduardo et al., 2013).

The addition of legume flour to wheat flour is of interest because of two main reasons. One is for the overall increase in the protein and fiber content and the other being complementary nature of cereal and pulse protein in terms of their amino acid makeup, the high lysine in pulses and methionine in cereals together make a complete protein (Duodu & Minnaar, 2011).

It is reported that the addition of legume flours leads to a reduction in loaf volume, increased hardness, and unacceptable physical and sensorial attributes. Crumb structure, texture, the color of crust and crumb, flavor, and aroma of the bread have been reported to be affected by composite flours. Two main reasons responsible are 1) interruption and disordering of the protein-starch matrix in a regular wheat bread, 2) dilution of gluten protein in the composite bread (Fenn et al., 2010). The extent of effect legume flour addition has on the final bread depends on the type of legume flour being added and its physicochemical properties in addition to the quality of the wheat flour being used (Fenn et al., 2010).

Composite flours containing 10% w/w pulse flours have resulted in acceptable yeast-leavened rolls (Kohajdová et al., 2013). Researchers also reported that with increase pulse flour, there was a decrease in loaf volume, height, with dense and compact crumb structure, and increased darkening of crust (Kohajdová et al., 2013; Mohammed et al., 2012; Portman et al., 2018). The darker coloration of curst is attributed to the higher amount of reducing sugar in the flour and lysine in the pulse protein, both of which are reactants in the Maillard reaction (Bertram, 1953). In terms of tactile properties, firmness of bread crumb increases with pulse flour addition; this is probably due to higher amylose and fiber content (Bresciani & Marti, 2019) and formation of thicker cell walls with the coalescence of small gas cells into larger ones. Mohammed et al. (2012) reported that the sensorial attributes like appearance, crumb texture, crumb grain, crust color, taste, and odor were not affected significantly with chickpea flour addition of up to 10% w/w, but the addition of 20% w/w of chick-pea flour produced a noticeable difference in all attributes. It was also observed that chickpea flour addition increased the farinograph water absorption of dough. This is attributed to the ability of pulse proteins to absorb water and compete with other constituents in a dough system, which can weaken the dough (Mohammed et al., 2012). Also, Dabija et al. (2017) reported that the addition of pea flour could result in the long shelf life of the bread

The effects of protein isolate addition, germinated, and fermented flours addition has been detailed by Boukid et al. (2019). Germination is known to enhance nutrient availability and reducing complex indigestible carbohydrates and antinutrients (Acevedo et al., 2017). Fermentation results in higher soluble fiber, higher free amino acids, antioxidants, total phenols, and phytase activity (Curiel et al., 2015). It is seen that bread made with fermented and germinated flours results in a sticky dough, which is difficult to handle and shape due to the hydrolysis of complex carbohydrates into simpler short-chain carbohydrates. (Hallén et al., 2004). Also, the bread showed low loaf volume, compact crumb structure, and darker crust (Hallén et al., 2004; Ouazib et al., 2016). Ouazib et al. (2016) observed that there was a drastic deterioration in the above-mentioned characteristics as the pulse flour incorporation was increased from 10% to 20%.

1.5 Cakes, cookies, and influence of wheat and non-wheat flour components

In many soft wheat flour products like cookies, pancakes, and crackers, gluten formation is not of high importance for product quality (Bresciani & Marti, 2019). This broadens the range for a higher level of pulse flour incorporations. An increase in hardness due to the addition of pulse is not a major concern in products like cookies were firmness can be advantageous. Research has also shown that adding green lentils, yellow lentils, navy bean, pinto bean, cowpea, pigeon pea, and chickpea have caused more browning and affected spread, texture, and width of cookies (Zucco et al., 2011; Thongram et al., 2016). It was observed that the addition of pulse flour increased the protein content of cookies and proportionally increased hardness. It is also worth mentioning in the same study that the particle size of the pulse flour affected the spread of the cookie, it was seen that cookies entirely made with or by incorporation of fine pulse flour had less spread and more thickness compared to those made from coarse pulse flour. Thongram et al. (2016) reported that cookies with 25% chickpea, pigeon pea, green lentil, or cowpea flour were acceptable in terms of sensory evaluated by a consumer panel.

For cakes, it is a well-known fact that the viscosity of the batter is of critical importance (Shelke et al., 1990). Viscosity undergoes substantial changes during baking of a cake. Singh et al. (2015) studied the effect of particle size and protein content (11%, 18%, and 21%) on cake batter and final cake quality of 100% w/w navy bean flour cake. It was seen that navy bean flour batter was more viscous than that of wheat flour, but reducing protein content by adding navy bean starch decreased the viscosity. For the cake quality, the volume index was affected by the particle size of bean flour, yet total protein did not affect the volume. It is reported that the type of protein has more effect on the cake volume than the concentration (Ronda et al., 2011). The reason behind this could be the different biochemical and denaturation properties of proteins (Mohamed et al., 1995). The firmness of cakes was not affected by any other factor studied, but springiness of the cake was significantly lower for navy bean flour cakes compared to wheat flour cake. Cakes with higher protein content also showed more Maillard browning. In another study pertaining to the quality of cake made form wheat-chickpea flour blends, cakes showed a decrease in volume with the incorporation of chickpea flour (Gómez et al., 2008). Adding chickpea flour also leads to the darker crust, increased firmness and gumminess, and decreased cohesiveness. Soy and many other legumes, improve moisture retention in cake due to the better water holding capacity of legume proteins (Liu, 2004; Mohammed et al., 2012; Bourré et al., 2019).

1.6 Flavors and aromas associated pea flour

The various sensory attributes of pulses are a key component for achieving consumer acceptability. Pulses have been described to have objectionable off-flavors and aromas, which are inherent or develop during harvesting, processing, and storage (Roland et al., 2017). The lack of consumption of pea flour and its derivatives by consumers is due to the strong off-flavors of peas (El Youssef et al., 2020). A total of 47 compounds have been identified in headspace analysis of pea, of which many are degradation products of fatty acids, saturated and monounsaturated six-carbon aldehydes, alcohols, ketones, and their ester derivatives. (Jakobsen et al., 1998). However, neither the primary source of the problem nor the solution has been documented.

In terms of taste, consumers have rated pea protein high for bitterness in sensory ratings. Saponins are considered to be the main cause of bitterness in these products (Heng et al., 2006). Two types of saponins have been identified, these being 2,3-dihydro-2,5-dihydroxy-6- methyl-4H-pyran-4-one (DDMP) and saponin B. Though both the saponins are perceived to be bitter, saponin B is perceived to be less bitter than DDMP, which could be detected at the threshold of 2mg L^{-1} (Heng et al., 2006). Varieties of dry peas have varying amounts of saponins DDMP, and saponin B, ranging from 0.7 to 1.5 g kg^{-1} and 0 to 0.4 g kg^{-1} (dry matter)

(Heng et al., 2006). With varietal differences, a possible solution might be to select dry peas with fewer saponins. On heating, DDMP gets converted to saponin B, indicating that another possible solution to reduce the bitterness would be to give some form of heat treatment, which could convert DDMP to the less bitter saponin B (Heng et al., 2006). These saponins have also been associated with astringency, a key sensory issue of yellow peas (Price et al., 1985). Astringency can be described as the general drying or puckering of the mouth in response to food intake (Lee & Lawless, 1991).

There are many flavor descriptors associated with peas. Some of these are beany, green, grassy, hay-like, and rancid flavors (Roland et al., 2017). Though hexanal is suspected to be causative of hay-like off-flavors in peas, no strong evidence has been found. It is suggested that mono and di-saturated carbonyls and saturated and mono-unsaturated alcohols formed at the end of alcohol dehydrogenase and lipoxygenase activity can be responsible (Murray et al., 1976). Green pea aroma in dry peas is attributed to three pyrazines; 3-isopropyl-2-methoxypyrazine, 3-sec-butyl-2-methoxypyrazine, and 3-isobutyl-2-methoxypyrazine (Murray et al., 1970; Jakobsen et al., 1998). Murat et al. (2013) reported that 2-methoxy-3-isopropyl-(5 or 6)-methyl pyrazine, a flavor compound present in raw pea flour, was present even after protein extraction. This tells us how closely bonded these compounds with pea protein are. Heng et al. (2004) studied vicilin and legumin the two main pea proteins for their affinity to saponins, aldehydes, and ketone. It was found that the vicilin proteins bound to aldehydes and ketones at both pH 7.6 and 3.8. Heating resulted in a dissociation of vicilin and subsequent loss of bound aldehydes and ketones (Heng et al., 2004). Legumin, on the other hand, did not bind to either of these compounds at pH 3.8 and bound only aldehydes at pH 7.6.

Fermentation has been used to reduce undesirable sensory attributes and to enhance the sensory profile of pulses. Heng (2005) mentioned that saponins could be modified potentially through fermentation for the addition of Carbonyl at C11, which will make it sweet or at least neutral in taste. El Youssef (2020) reported that leguminous and green flavor notes of pea protein-based products decreased with fermentation by lactic acid bacteria and yeast. This process generated new ester compounds which gave fruity and floral flavors note. Schindler et al. (2011) and Schindler et al. (2012) have studied fermentation and its effect on pea and lupin protein and found that fermentation changed the aroma profile of these proteins, causing masking of reduction of off-flavors. Many of the flavor compounds found were degradation products of fatty acids or amino acids. It was seen that Fermented pea protein extract (PPFE) had a decreased amount of n-hexanal compared to untreated pea protein extract (PPE). The odor of PPFE was found to be more pleasant compared to PPE.

Much like cereal flours, the sensory properties of pea flour have been found to be sensitive to aging. Sopiwnyk et al. (2020) investigated whole navy bean, whole Kabuli chickpea, commercially milled whole and split yellow pea, and decorticated red lentil flours for the effect of storage from 1 month to 24 months on sensory attributes. With this, it was reported that the flour color and the crumb color of bread made from aged flour changed significantly. Bitterness, crumb firmness increased. The water absorption capacity of the flour also increased with storage except for chickpea flour, which decreased with storage. Overall, it was observed that the whole pulse flours were more affected by storage time than the split pulse flour. It is inferred that hull fraction had a major effect on storage stability, which is explained to an extent by the polyphenols and tannins found in the seed coat. In a study by Chapman et al. (2010) observed that split peas stored in a sealed container for over 34 years had increased values of L*(brightness), a*(+red to -green), b*(+ yellow to -blue). In this study, it was hypothesized that chlorophyll might have degraded to pheophytin, which is darker (greenish-gray) in color than chlorophyll.

1.7 Conclusion

Legumes and pulses are considered a healthier and sustainable source of protein. With relatively low allergenicity, high production volume, the yellow pea is a relatively better option compared to soy and is presently underutilized in America, with the majority of the produce being exported. Incorporation of these into existing baked goods presents a potential way to add value to these crops and, at the same time, increase the nutritional quality of the baked product. However, when it comes to consumer acceptability, pea flour and its derivatives face aversion or resistance. To fully tap the benefits of a yellow pea, future research needs to be done on understanding, reducing, or masking these objectionable flavors.

The primary aim of this research was to identify the threshold of pea flour addition into pancakes and bread and is covered in chapters two and three, respectively. The secondary aim was to potentially mask the off-flavors from pea flour. Chapter two of this thesis investigates pea flour incorporation into batter-based soft wheat flour system - pancakes, where gluten network is not of prime importance. At the same time, the chapter explores the use of chemical reductants in masking or reducing the flavors from pea flour. Pancakes were measured for physical characteristics, and a trained sensory panel assessed the pancakes for 15 sensory attributes categorized into visual, odor, texture, taste, and flavor. Chapter three examines the pea flour addition in hard wheat flour product – Bread, where gluten network is essential for the end-product quality. The bread was evaluated for physical characteristics and scored by consumers for acceptability of pea flour in bread in terms of appearance, after taste flavor, texture, willingness to buy, and overall acceptability.

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Chapter 2: Physical and sensorial characterization of yellow split pea flour incorporated pancakes.

2.1 Abstract

Pancake is a quick and easy breakfast enjoyed by many. Like many soft wheat flour products, health-conscious individuals may not opt for it. Supplementation of pea flour into pancakes can give these products a new acceptance among the consumers. The primary objective of this chapter has been to facilitate the incorporation of pea flour into pancakes and to understand the effect of pea flours on soft wheat flour-based bakery products. The second objective was to identify the potential of improvement in the flavor profile of yellow pea flour when applied to a pancake system to enhance consumer acceptance. Sodium metabisulphite was used to study the effect of a reducing agent on protein and resulting changes in flavors attributes of pancakes containing pea flour. Pancakes were made with 1%, 2%, 5%, 10%, and 20% pea flour incorporation with and without corresponding levels (500 ppm to pea flour) of SMB and with only corresponding levels of SMB with no pea flour. The pancake formulations were adjusted for water content so that the resulting batter had the same viscosity. Pancakes were accessed for physical quality attributes like dimensions, specific volume, hardness, color, and gas cell and crumb structure. A trained descriptive panel was conducted to evaluate the effect of pea flour and SMB addition on visual, aroma, texture, taste, and flavor attributes of pancakes. It was found that despite adjusting the viscosity, the pancakes with 20% pea flour incorporation showed significant deviation in diameter, texture, and gas cell formation. Changes in visual, aroma, and taste attributes were observed as the amount of pea flour addition increased. SMB addition was not perceivable by the panelist.

2.2 Introduction

Baked goods made from wheat flour are popular all over the world. Pancakes, cakes, and pastries are few baked goods made from soft wheat flour. In order to attain high-quality flour, wheat is refined to remove bran and endosperm containing soluble, insoluble fiber, minerals, and fatty acids (Dewettinck et al., 2008). With high levels of refined wheat flour and sugar, cakes and pastries are likely to be a high glycemic index food and also regarded as unhealthy. Though wheat is a good source of carbohydrates, its protein contains a limiting amount of essential amino acids, lysine, tryptophan, and threonine (Fenn et al., 2010). As pulses are higher in these essential amino acids, a blend of wheat flour and pulse flour will complement each other and produce products with higher protein quality (Boye et al., 2010).

Yellow pea (*Pisum sativum* L.) is a leguminous plant that originates mainly from the near east (Ljuština & Mikić, 2010). The total world dry pea production in 2018 was 13,535,765 metric tonnes. Of this, Canada, Russia, and China were the top producers (Pea, Dry statistic, FAO, 2018). The USA was ranked as the 6th largest producer of dry yellow peas with a production of 722,530 metric tonnes in 2018. Declaration of 2016, as the year of pulses by the United Nations along with beneficiary health effects, has increased the focus of diet-conscious consumers to explore the benefits of plant-based proteins since then (Hillen, 2016). Though traditional sources of protein, like animal protein, are superior in nutritional quality, their utilization raises sustainability and ethical issues. For this reason, alternative foods with complete proteins are needed (Singh, 2017). Yellow pea, with its high protein content of 16.6% to 26.4% (Thavarajah & Thavarajah, 2013), can be a major source of plant-based protein. Pea, like all pulses, is rich in lysine and complements cereals, which are high in sulfur-containing amino acids like methionine (Hall et al., 2017). Hence, blending cereals and pulses together to produce a product with a complete amino acid profile can improve the nutritive value of products (Hall et al., 2017). Pea protein has low allergenic potential (Wensing et al., 2003). Apart from protein, dried peas are a rich source of fiber and folate (Hall et al., 2017; Maskus et al., 2016). Pea being devoid of gluten, and rich in protein and fiber, pea flour and derivatives have been studied for their potential incorporation into everyday foods and to make healthier and gluten-free products (Malcolmson et al., 2013).

Reducing agents are commonly used in wheat bread, cracker, and biscuits as a dough conditioner or relaxer. It is used to overcome seasonal variability in wheat and to make the dough more extensible by reducing the disulfide bonds between proteins (Pečivová et al., 2008). When cleaved, the disulfide bonds in proteins are converted to a free thiol group on cysteine (Fort, 2016). Among reducing agents, sodium metabisulphite is a powerful and unique reducing agent. In the presence of water, bisulfite ions from sodium metabisulphite will lead to the formation of aqueous SO_2 (Shandera et al., 1995). This will react to cysteine residues, creating S-sulfocysteine residues in the protein, essentially capping the thiol group, limiting its future reactivity in oxidation-reduction reactions (Fort, 2016). In a native state, disulfide bonds act as local centers where hydrophobic residues often cluster (Wedemeyer et al., 2000). For the scope of this work, it is hypothesized that the reduction of these bonds will release disulfide-linked sulfur compounds and expose hydrophobic parts of the protein. These hydrophobic parts of protein will bind off-flavor compounds onto them and may potentially mask the off-flavor from pea flour.

Sodium metabisulphite is generally regarded as safe (GRAS) by the FDA, but people have been found to be sensitive to it (Fort, 2016). This has decreased its usage, but its mechanism of action and efficacy of SMB has led its selection over other reducing agents.

The objective of the study was to characterize the effect of replacement of wheat flour by pea flour at rates of 1%, 2%, 5%, 10%, and 20% on physical quality parameters of pancakes and the efficacy of SMB addition in combating the off-flavor of pea flour.

$$Na_2S_2O_5 + H_2O \longleftrightarrow 2NaHSO_3 \qquad (1)$$

Metabisulfite hydration/dehydration Bisulfite

$$NaHSO_3 + RS\text{-}SR \longleftrightarrow RS\text{-}SO_3 + RSH + Na^+ \qquad (2)$$

Bisulfate Protein with disulfide Protein with S-Sulfocysteine Protein with thiol Sodium ion

Equation 1. Reaction of sodium metabisulfite to sodium bisulfate and its reaction with Protein disulfide bond (Bailey & Cole, 1959)

2.3 Material and methods

2.3.1 Materials

Wheat flour used for the study was a super fine cake flour obtained from Bob's red mill Natural food, Inc. Yellow peas were donated by the Spokane Seed Company (Spokane, WA, USA) and were milled using a Miag mill. Pea flour was made by blending all streams except the 4th middling, which is shown to have high water absorption, higher protein, and ash content in wheat milling (Wang & Flores, 1999; Ramseyer et al., 2011). Sugar and salt of WinCo Foods (Boise, ID), Crisco vegetable oil of the J. M. Smucker Company (Orrville, OH), and Baking powder of Clabber Girl Corporation (Terre Haute, IN) were obtained from the local market. Dextrose used was corn sugar dextrose of Brewcraft USA (Vancouver, WA), and Sodium Metabisulphite was from the LD Carlson company (Kent, OH).

2.3.2 Experimental Design

The research was organized to examine the effect of SMB in the elimination of off-flavors arising from the incorporation of pea flour into pancakes and to obtain pancakes close to a control formula in terms of quality attributes. There were three treatments evaluated at multiple levels in the study: 1) pea flour varied as 1%, 2%, 5%, 10%, and 20%; 2) pea flour varied as 1%, 2%, 5%, 10%, and 20%, + SMB equivalent to 500 ppm of corresponding amounts of Pea flour; and 3) Wheat with SMB added at equivalent amounts as the pea-wheat flour blend treatments (Table 2.1). Water addition levels for each treatment was optimized based on batter viscosity so that all treatments matched the viscosity of wheat control pancake batter of 4.683±0.468 Pas. Viscosity experiments were done using DVE viscometer (AMETEK Brookfield, USA) with RV04 spindle at 12 rpm.

2.3.3 Pancake Procedure

A modified AACC Method 10-80.01 was used for pancake production. All dry ingredients: wheat flour, sugar, baking powder, salt, dextrose, pea flour (when indicated) were mixed in a kitchen aid mixer with a whisk attachment at speed 2 for 1 min to make a dry mix. The dry mix was mixed for one more minute after scraping the sides of the bowl with a rubber spatula to ensure homogeneity. For pea flour treatment, a dry mix containing pea flour and the respective amount of water was added. For five SMB + pea flour treatments, five corresponding SMB solutions containing SMB equivalent to 500ppm of pea flour levels were made. The pea flour, 1 ml of corresponding SMB solution, and the required amount of water were mixed using a rubber spatula until all the lumps were dispersed. The mixture was rested for 5 mins to allow the SMB to react with the pea flour. Later, the dry mix prepared (with no pea flour), as mentioned above, was added along with the rest of the water. For SMB treatments, without pea flour, 1 ml of corresponding SMB solution was added into the dry mix along with respective amounts of water (Table 2.1). It was ensured that 1ml of SMB solution was part of the total amount of water added to the dry mix.

After adding all the ingredients into the mixing bowl as mention above, the mixture was mixed for 10 s and stopped to scrape down the ingredients and further mixed for 50 s. Then, oil was added into the mixture and mixed for a total of 1 min with the sides of the bowl scraped down after the first 20 s of mixing. After resting for 2 mins, 60 mL of batter was pulled into a 60 mL syringe and dispensed from a height of 2.54 cm above a Krampouz (Pluguffan, model CECIF4, France) commercial griddle maintained at 190 °C. The syringe was used over the suggested scooping device as outlined in the AACC Method 10-80.01 because the application of the scoop provided inconsistent quantities of batter and non-uniform pancake shapes. The tip of the syringe was removed, and the hole was widened with a 12 mm drill bit. After 75 s the pancake was flipped and let cook for another 75 s. After cooking, pancakes were cooled for 20 mins on a cooling rack prior to analysis. Four pancakes were made from a batch of batter.

2.3.4 Quality attributes

Quality attributes were modified from those described by Finnie et al. (2006). After cooling, weight, and height of a stack of four pancakes were recorded. Three pancakes were randomly chosen for measuring the diameter at three different points, roughly 0°, 120°, 240° apart, and averaged. The pancakes were subjected to a 2-bite texture profile analysis, as described later in this section. The volume of the remaining pancake was analyzed by rapeseed displacement. The specific volume of the pancakes was calculated by dividing the pancake volume by its mass. Color measurement (L*, a*, b*) was completed using a Minolta colorimeter (CR 310, Japan). Three measurements were recorded for each pancake at different locations and averaged. The pancake was then cut in half across the pancake circumference, separating the top from the bottom, to observe the gas cell structure. The layers were scanned using Ricoh Aficio MP C3002 copier (Lionville, PA). Texture profile analysis was performed using a texture analyzer (TA-XT2i, Stable Micro Systems, Scarsdale, NY) equipped with a 5-kg load cell and a round 75-mm diameter compression platen probe (P/75). A stack of three pancakes, with first bake side up, was placed on the platform. The pancake stack was compressed to 25% strain at a constant rate of 1 mm/s with a trigger force of 20 g. After the initial compression, the probe came back to the initial position and remained stationary for 5 s and was followed by the second compression of 25% strain. The TPA software, Texture Exponent 32 (Stable Micro Systems), was used to analyze the graphs. The hardness of pancakes recorded by the peak force in the first compression is analyzed in the study.

2.3.5 Trained sensory panel

All treatment levels and combinations were tested by a trained panel for the characterization of sensory attributes. A descriptive panel consisting of 9 panelists with 5 females and 4 males between 19 to 35 years of age was used. The panelists were trained over six 2 h (12 h total) evening sessions, following both the ballot and consensus method (Bize et al., 2017). Participation was voluntary and was rewarded with a nonmonetary incentive (gift cards) at the end of every training session and at the end of all the formal sessions. The study was reviewed by the University of Idaho, Institutional Review Board, and participants signed an informed consent form.

In the training sessions, the ballot method was used to present panelists with references for attributes of interest. The attributes and references were evaluated and compared to the pancake provided. Discussions were encouraged to understand the definitions of the attribute and identify the fit of presented descriptor terms to the pancake sample. A consensus was used to identify attributes that concerned the panelists. Accordingly, descriptor terms and references were added or eliminated, as suggested by the group of panelists. For this, panelists were given pancake samples with varying levels of some attributes for practice. Panelists were trained to evaluate an attribute on a continuous 15 cm scale with anchors at 1.5 and 13.5 cm. Continuous feedback was provided to the panelists in every session based on their performance in the previous session. The final list of attributes used for the sensorial analysis of pancakes is presented in Table 2.2.

Eight formal sensory sessions were conducted in individual sensory booths. One-sixth of a pancake was presented to the panelists on a disposable plate with a three-digit randomized coding. Panelists were asked to cleanse their palate between samples with unsalted soda crackers (Nabisco Premium, Nabisco, East Hanover, NJ), and filtered water. Only four pancake samples were presented in each session to avoid panelist fatigue (Bize et al., 2017). Treatments were distributed over eight sessions randomly without having two samples of the same treatment occurring in the same session. All descriptive references and final list of attributes with their definition were available for the panelist to review during sessions. Pancakes were prepared 1 to 3 h before the session began. Pancakes were made in the same manner as mentioned previously, except that a commercial griddle was used. The griddle was modified with a PID (proportional-integral-derivative) controller, and a surface thermal coupler was used to ensure the griddle surface was maintained at 190 ± 0.1 °C. After cooling, pancakes were placed on Styrofoam plates and sealed in Zip-Lock bags, which were placed in a proof cabinet maintained at 40 ℃ and 90% relative humidity. Pancakes were cut into wedges at the beginning of the session and placed back in the proofer. Panelists were asked to come in a time slot of 2 h for evaluating the pancake sample.

2.3.6 Statistical analysis

For physical attributes, with three treatments and 5 levels of pea flour incorporation, 15 combinations of pancake batches were studied in triplicates, making a total of 45 batches of pancakes. The study was conducted with all 45 batches randomly assigned over three days with a control conducted at the beginning and end of each day. Three controls out of the total six were randomly selected for the statistical analysis. ANOVA followed by Tukey's test was performed to determine if treatment combinations were significantly different at $P<0.05$. All the statistical tests were done on SAS 9.4 (SAS Institute Inc, Cary, NC, USA).

For the trained panel, data was analyzed using a 3-way Anova in R software (version). In this model, the dependent variables were sensory attributes, and independent variables were panelist, replicate, and treatment. Tukey HSD was used to see differences among the pancake treatments at a significance level of $P<0.05$. Additionally, sensory data was analyzed using Principal Component Analysis (PCA) to visualize differences among the samples using the FactoMineR package (Husson et al., 2017).

Table 2.1 Pancake ingredients amounts (in grams) for different levels of treatment

Ingredient	**Control**	**SMB**					**SMB + Pea flour**					**Pea flour**				
	-	1mg	2mg	5mg	10mg	20mg	1%	2%	5%	10%	20%	1%	2%	5%	10%	80%
Wheat flour	200	200					198	196	190	180	160	198	196	190	180	160
Pea flour	-	-					2	4	10	20	40	2	4	10	20	40
SMB*	-	1	2	5	10	20	1	2	5	10	20	-				
Sugar	21.32	21.32					21.32					21.32				
Baking powder	10	10					10					10				
Dextrose	6.64	6.64					6.64					6.64				
Oil	6.64	6.64					6.64					6.64				
Salt	1.32	1.32					1.32					1.32				
Water*	230	229.2	228.9	226.6	225.2	221.2	230.8	230.4	235.2	233.9	232.9	230.7	232.1	234.3	236.2	236.1

*SMB reported in milligrams

** water content calculated with an 11% flour moisture basis.

Table 2.2 Table of attributes, their definitions, and standards for taste, flavor, and aroma attributes used for evaluation of ready to eat chicken pasta meals by the trained sensory evaluation panel. Standards used in panel training for sensory evaluation (n=10) of white Cheddar cheese samples for appearance, aroma, flavor, and taste attributes.

Descriptive term/Attribute	**Definition**	**References/standards**
Visual terms		
Yellow Color*	The hue between orange and green	Creme brulee (2022-70) = 2 Light yellow (2022-60) = 7 Sundane (2022-50) = 12
Golden Brown color*	The hue associated with the surface/crust of bread and pancakes.	Apple crisp (2159-30) = 4 Venetian gold (2158-20) = 8 Penny (2163-30) = 13
Odor terms		
Sweet (odor)	Aromatic stimulation associated with sucrose and honey	Great Value extra fine granulated sugar = 1 Nabisco Honey Maid graham cracker = 8 Great Value clover honey = 14
Pea (odor)	The smell associated with cooked pulses.	15% pea flour pancake = 7 30% pea flour pancake=14
In-hand terms		
Toughness	Amount of force felt while pressing on the pancake	Bread = 4 Bagel = 14
Mouth terms		
Hardness	Amount of force required to bite	Cream cheese =1 Pretzel =12
Cohesiveness of mass	The degree to which sample deforms rather than crumble, crack, or break	Pillsbury Grands homestyle canned biscuit dough =10 Starburst = example
Taste terms		
Sweet	A fundamental taste factor of which sucrose solution is typical	1.0% sucrose solution = 3 2.0% sucrose solution = 6 8.0% sucrose solution = 15
Astringency	A sensation of drying in the mouth.	0.175g/L Potash alum =7 0.35g/L Potash alum = 14

Bitter	A fundamental taste factor of which caffeine solution is typical	0.02% caffeine =2 0.04% caffeine =10
Flavor terms		
Cooked pea flavor	Flavor commonly associated with cooked pea.	10% pea flour pancake = 7 30% pea flour pancake=14
Cardboard	The smell of a wet cardboard	Old fashioned oatmeal =5 Grapenut cereal Breakfast =10
Nutty	A sweet, light brown, slightly musty and/or earthy flavor	Roasted peanut=14
Doughy	A flavor associated with wet flour or dough	King’s Hawaiian savory butter roll = 5 Pillsbury Grands homestyle canned biscuit dough = 13
Sulfur	Flavor associated sulfites and here with sodium metabisulphite	Sodium metabisulfite = 15

*Color chips by Benjamin Moore, 5 cm x 5 cm

2.4 Results and discussion

2.4.1 Pancake dimensions

The weight of the control pancakes was 244.73±2.77 g. The pancakes were not significantly different (P<0.05) among all treatment combinations, implying that the amount of batter dispensed and the rate of evaporation was consistent among all the combinations (Figure 2.1).

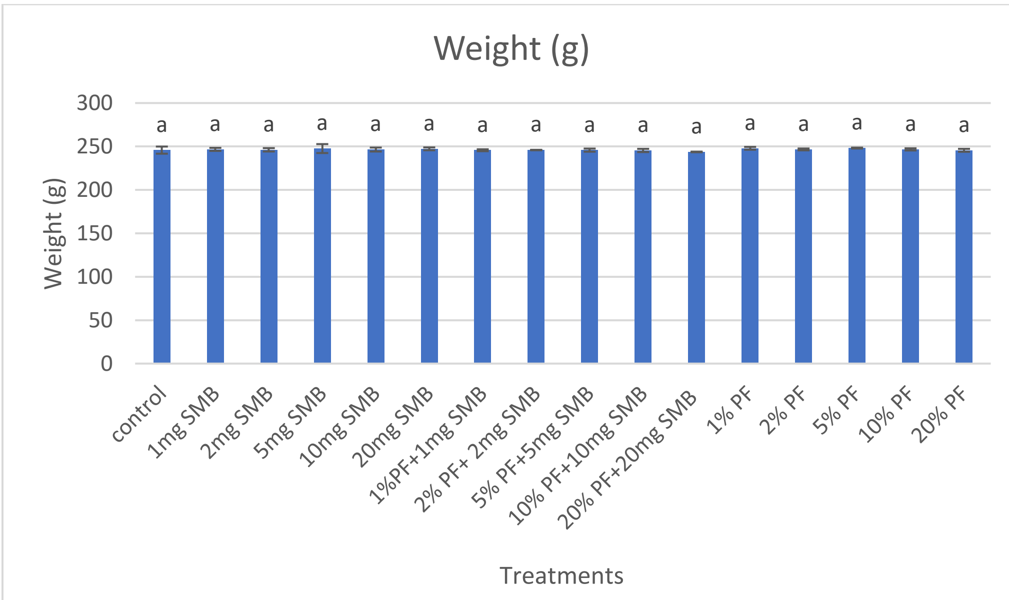

Figure 2.1 A graphical representation of weight (y axis) of four pancakes baked at five different concentrations of SMB, or Pea Flour + SMB, or Pea Flour treatment (x axis). Different lowercase letters represent significant difference (P<0.05) and error bars represent standard deviation.

The pancake stack height across all combinations was not significantly different (P<0.05) from the control (4.97 cm) (Figure 2.2). However, based on the trend in stack height, a further increase in SMB addition might decrease the height of the pancakes. Since SMB is known to cleave the disulfide bonds between cysteine in gluten and damage its functionality, it can be implied that gluten has a role in defining the physical quality attributes of soft wheat flour products like pancakes.

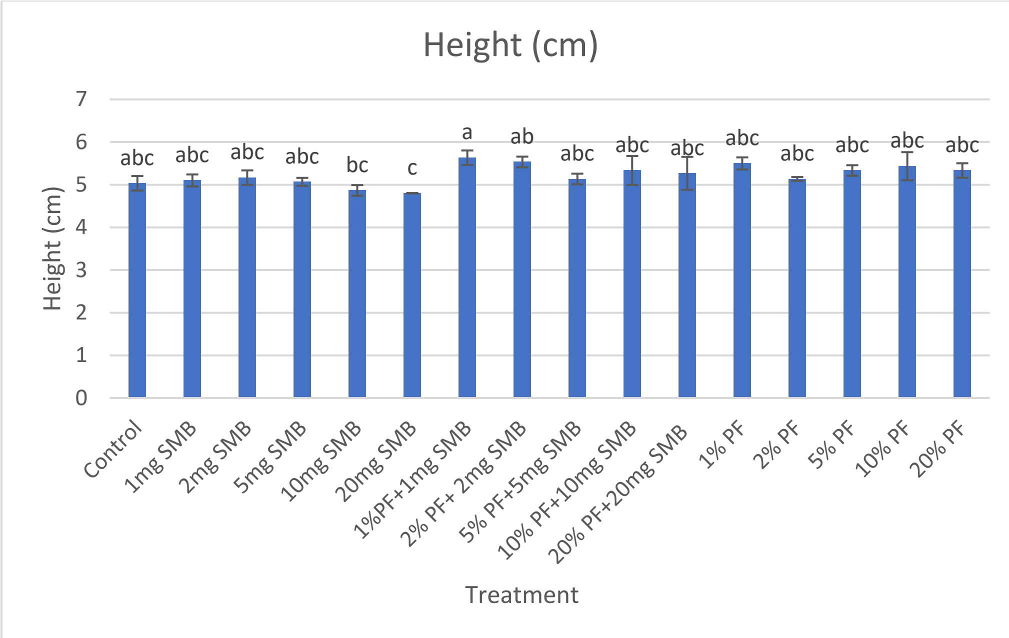

Figure 2.2 A graphical representation of height (y axis) of stack of four pancakes baked at five different levels of SMB, or Pea Flour + SMB, or Pea Flour treatment (x axis). Treatments with similar letters (a-c) show no significant differences between means (P<0.05).

The diameter of the pancakes ranged from 12.18 to 13.13 cm (Figure 2.3). All combinations of pancakes, except 20% pea flour and 20% pea flour + SMB, have diameters not significantly different (P<0.05) from the control. The greater diameter of 20% pea flour (13.06±0.06 cm) and 20% pea flour + SMB (13.13±0.12 cm) can be attributed to an increase in the amount of fiber, decreased gluten, and increased pea flour (Repetsky & Klein, 1982). Weight, height, and diameter of most of the pancake combinations were not significantly different from the control, indicating that water optimization by standardizing batter viscosity is an apt approach to obtain pancakes with similar physical quality attributes. It should be noted that the uniformity in pancake diameters was also a direct result of using a syringe, rather than a scoop as the AACC Method 10-80.01 suggests. In preliminary trials, the utilization of a scoop produced pancakes with a total lack of uniformity (data not shown). It is therefore recommended that future works pertaining to pancake quality testing, utilize the syringe method outlined in the material and methods section, rather than the scoop, as indicated in AACC Method 10-80.01.

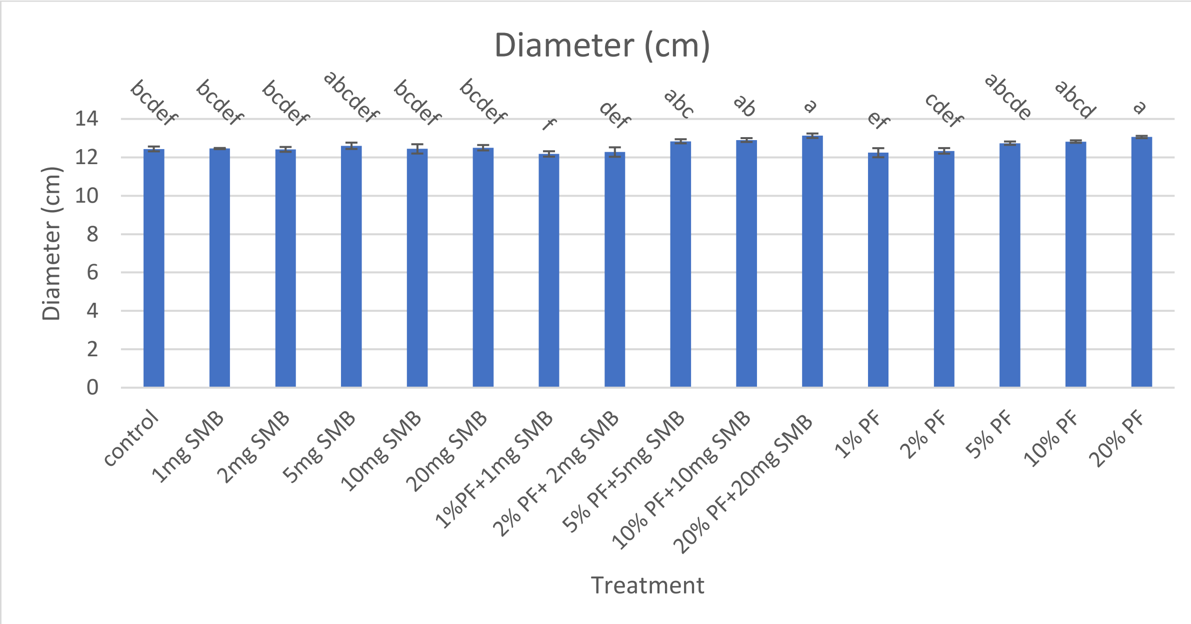

Figure 2.3 A graphical representation of Diameter (y axis) of pancakes baked at five different levels of SMB, or Pea Flour + SMB, or Pea Flour treatment (x axis). Treatments with similar letters (a-f) show no significant differences between means ($P<0.05$).

Even with water optimization, the deviation in the 20% pea flour pancake indicates that there is a tolerance limit to this technique, after which constituents of the pea flour (fiber and lack of gluten) affect the physical attributes notably. Furthermore, the specific volume of all pancake treatments and controls were not significantly different ($P<0.5$) (Figure 2.4). The specific volume of the 100% wheat flour was 2.22±0.07 cm^3/g. These results indicate that pea flour can be added into pancakes at a rate of 20% without a major impact on quality if water addition levels are optimized based on final batter viscosity. Furthermore, since it is the results of this research indicate the importance of standardizing batter viscosity, it should be noted that specific volume is a better indication of treatment response than weight and diameter. This is because specific volume accounts for any variability in flour mass being applied to the griddle.

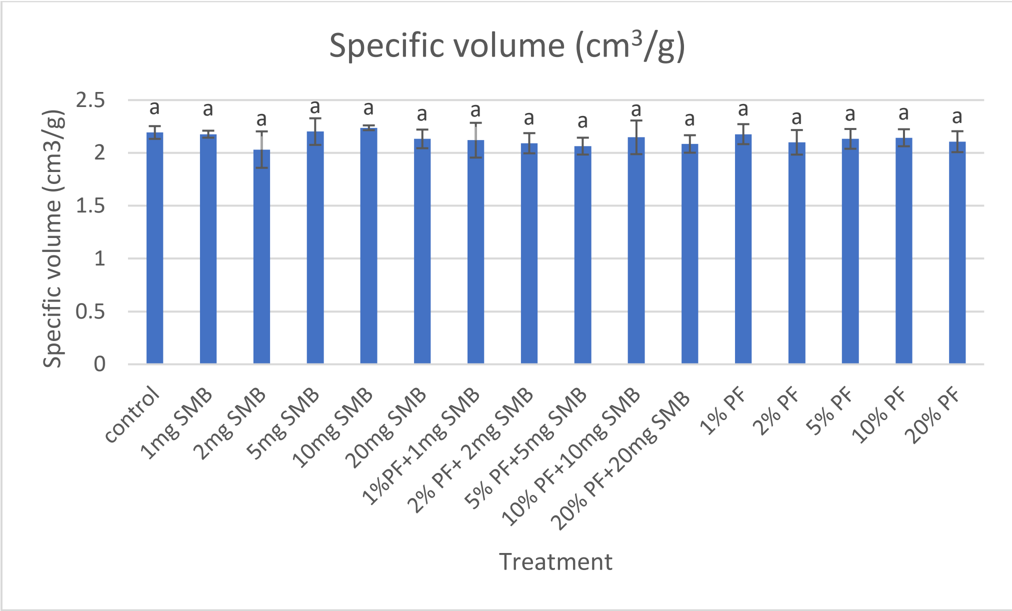

Figure 2.4 A graphical representation of Specific volume (y axis) of pancakes baked at five different levels of SMB, or Pea Flour + SMB, or Pea Flour treatment (x axis). None of the treatment means show significant difference from one another (P<0.05).

2.4.2 Texture analysis

The hardness of pancakes increased with increasing pea flour incorporation and SMB addition (Figure 2.5). As the amount of SMB increased, the amount of water required decreased to attain the same viscosity (Table 2.1). This made the pancakes with higher pea flour, and SMB incorporation levels have batters with higher solids content when compared to control. This may be the reason for harder/firmer pancakes with increasing pea flour and/or SMB levels. Furthermore, higher fiber with increasing pea flour made the pancakes more rigid due to the presence of larger, yet fewer gas cells (Appendix I).

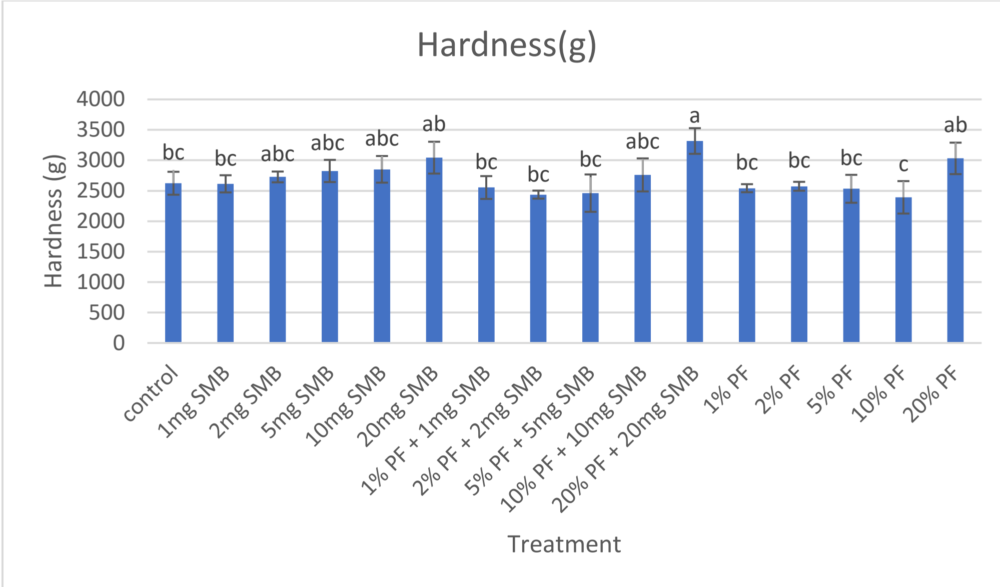

Figure 2.5 A graphical representation of hardness (y axis) of pancakes baked at five different levels of SMB, or Pea Flour + SMB, or Pea Flour treatment (x axis). Different letters(a-c) indicate significant differences in treatment means (P<0.05).

2.4.3 Color

L* value, which is a measure of the brightness of the pancake surface, remained the same with increasing amounts of SMB and decreased with increasing pea flour (Table 2.3). Higher levels of reducing sugars in pea flour compared to wheat flour likely led to increased browning on the pancake surfaces and thus reduced L* value. Whereas a* value, is a measure of redness (+) to greenness (-) and b* value, a measure of yellowness (+) to blueness (-) of the surface increased and decreased respectively due to the Maillard reaction, which produces red-brown pigments (Bize et al., 2017). SMB addition did not have a significant effect on a* and b* values.

Table 2.3 Color measurements (L*, a*, b*) of pancakes made at different treatment levels of SMB, or SMB + pea flour, or Pea flour.

Treatment	**L***	**a***	**b***
Control	66.81±1.66[a]	10.14±0.87[c]	37.67±0.61[ab]
1% SMB	66.72±0.37[a]	10.16±0.31[c]	37.33±0.49[ab]
2% SMB	65.58±1.29[ab]	10.68±0.67[bc]	37.26±1.07[ab]
5% SMB	65.90±0.84[ab]	10.56±0.56[bc]	37.46±1.24[ab]
10% SMB	66.39±1.15[ab]	10.69±0.40[bc]	38.59±1.82[a]
20% SMB	66.24±0.52[ab]	10.46±0.27[bc]	37.76±0.87[ab]
1% PF+SMB	65.13±0.32[abc]	10.47±0.35[bc]	37.21±0.52[ab]
2% PF+SMB	65.22±0.40[abc]	10.68±0.71[bc]	36.82±1.36[ab]
5% PF+SMB	64.79±0.82[abc]	11.06±0.60[bc]	36.38±0.53[abc]
10% PF+SMB	62.59±0.39[cd]	12.05±0.32[ab]	35.03±1.38[bcd]
20% PF+SMB	60.14±0.89[d]	12.85±0.12[a]	32.99±1.03[dc]
1% PF	66.06±0.26[ab]	10.14±0.21[c]	36.85±0.63[ab]
2% PF	65.56±0.47[ab]	10.94±0.14[bc]	37.90±0.91[ab]
5% PF	65.07±0.30[abc]	11.11±0.16[bc]	35.61±0.28[abcd]
10% PF	63.68±0.59[bc]	11.66±0.28[abc]	36.00±0.06[abc]
20% PF	59.97±0.23[d]	13.02±0.16[a]	32.32±0.57[d]

Means are replicates from 3 batches. Means followed by different superscript letters are significantly different ($P<0.05$).

2.4.4 Gas cell structure

It could be seen (Appendix I) that the size of Gas cells in 20% SMB, 20% pea flour, and 20% pea flour + SMB pancake was larger compared to control. The increased amount of fiber and decreased amount of gluten due to pea flour addition, coupled with reduced gluten functionality due to SMB addition resulted in puncture of gas bubbles formed and the batter to be less cohesive. This led to the formation of fewer and large gas cells in pancakes with a higher percentage of pea flour incorporation compared to pancakes with lower or no percentages pea flour or/and SMB, which resulted in numerous amounts of gas cells. It is known that gas cells within cakes are responsible for fluffy textures (Pycarelle et al., 2018). Therefore, it can be in the pancakes with higher pea flour addition resulted in harder pancakes due to a decrease in gas cells.

2.4.5 Trained sensory panel

Different factors and their influence on the visual, odor, physical, and sensory attributes of pancakes are shown in Table 2.4. The influence of taste and flavor attributes is presented in Table 2.5. The effect of panelists can be attributed to complexity in recognition of certain attributes and self-bias that panelists had due to their preferences and food habits. Replication has shown no effect indicating that individual panelist was consistent with their scoring. Even with the panelist effect, the panel was able to differentiate among the pancake's samples.

To further access how the samples scored in intensity rating of sensory attributes, values are reported in Table 2.6. It can be seen that the intensity of both the visual attributes yellow color of crumb and golden-brown color on the surface of the pancake increased with an increase in pea flour addition, whereas SMB addition did not result in any significant change in visual attributes. For physical attributes, toughness, hardness, and cohesiveness of mass did not present any significant difference ($P > 0.05$) among the treatments.

In taste and flavor (Table 2.7), it seems that SMB addition did not alter the taste and flavor perception of the pea flour incorporated pancakes significantly ($P > 0.05$). It is evident that the pea odor and pea flavor increased as the amount of pea flour addition increased. Nutty and cardboard flavor attributes are perceived to be unappealing in pea flour and pea protein (Swanson, 1990; Sessa & Rackis, 1977). Yet, these two Flavors were not perceived to be intensified with an increasing amount of pea flour. Zhoa et al. (2005) reported that nutty flavor increased as the amount of yellow pea flour was increased in spaghetti made from wheat. Cooked wheat flour is attributed with sweet aromatic and doughy flavor. (McWatters et al., 1995). No significant difference ($P > 0.05$) in doughy flavor, sweet odor, and sweet taste over the 16 treatments indicate that pancakes with even 20% pea flour will be acceptable when considering these sensory qualities. Lack of distinguishment of the sulfur flavor between the treatments indicates that SMB addition at a level of 500 ppm to pea flour was not detectable.

Table 2.4 Degrees of freedom and F -ratios from ANOVA of trained panel evaluations of pancakes for visual, odor, and physical attributes. A ∗ represents a significant difference at $p \leq 0.05$

Source	df	Visual		Odor		Physical		
		Yellow color	Golden brown color	Sweet odor	Pea odor	Toughness	Hardness	Cohessiveness of mass
Treatment	15	7.2*	11.0*	3.5*	16.7*	5.0*	1.6	1.3
Replicate	1	0.2	0.0	2.7	0.8	0.1	0.2	0.9
Panelist	8	46.5*	7.0*	30.8*	3.7*	32.6*	31.0*	31.8*

Table 2.5 Degrees of freedom and F -ratios from ANOVA of trained panel evaluations of pancakes for taste and flavor attributes. A ∗ represents a significant difference at $p \leq 0.05$

Source	df	Taste			Flavor				
		Sweet	Bitter	Astringency	Cooked pea flavor	Nutty flavor	Dough flavor	Cardboard	Sulfur flavor
Treatment	15	1.8*	3.1*	2.3*	35.6*	7.2*	0.7	4.2*	1.5
Replicate	1	0.0	3.4	1.8	0.4	0.0	0.1	0.1	0.7
Panelist	8	33.2*	47.1*	57.1*	8.7*	37.9*	66.0*	53.9*	5.7*

Table 2.6 Mean values with the standard error (shown below) for the samples for visual, odor and physical sensory attributes rated by 9 panelists. Different letters in the same column indicate significant differences between samples as analyzed by Tukey's HSD on a 15-cm unstructured line scale, with results presented on this scale between 0 and 15 ($p < 0.05$)

Treatment	**Visual**		**Odor**		**Physical**		
	Yellow color	**Golden brown color**	**Sweet odor**	**Pea odor**	**Toughness**	**Hardness**	**Cohesiveness of mass**
Control	5.08±0.66^{ab}	2.47±0.35^{e}	5.42 ±0.62^{a}	0.92 ±0.67^{e}	5.39 ±0.51^{a}	4.69 ±0.58^{a}	6.53 ±0.60^{a}
1% SMB	5.06±0.66^{ab}	2.17±0.35^{e}	5.61 ±0.62^{a}	1.17 ±0.67^{e}	5.22 ±0.51^{a}	4.75 ±0.58^{a}	6.42 ±0.60^{a}
2% SMB	4.94±0.66^{ab}	2.92±0.35^{cde}	5.92 ±0.62^{a}	1.94 ±0.67^{de}	5.89 ±0.51^{a}	5.42 ±0.58^{a}	6.36 ±0.60^{a}
5% SMB	5.31±0.66^{ab}	2.89±0.35^{cde}	5.61 ±0.62^{a}	3.00 ±0.67^{cde}	6.08 ±0.51^{a}	5.31 ±0.58^{a}	6.97 ±0.60^{a}
10% SMB	5.24±0.66^{ab}	2.89±0.35^{cde}	5.72 ±0.62^{a}	1.11 ±0.67^{e}	5.56 ±0.51^{a}	5.17 ±0.58^{a}	6.92 ±0.60^{a}
20% SMB	5.71±0.66^{ab}	2.92±0.35^{cde}	4.75 ±0.62^{a}	1.69 ±0.67^{de}	6.25 ±0.51^{a}	5.56 ±0.58^{a}	7.31 ±0.60^{a}
1% Pea +SMB	5.28±0.66^{ab}	2.61±0.35^{e}	5.69 ±0.62^{a}	1.31 ±0.67^{e}	5.67 ±0.51^{a}	4.92 ±0.58^{a}	6.44 ±0.60^{a}
2% Pea +SMB	4.92±0.66^{ab}	2.72±0.35^{de}	5.67 ±0.62^{a}	1.86 ±0.67^{de}	5.69 ±0.51^{a}	4.83 ±0.58^{a}	6.53 ±0.60^{a}
5% Pea +SMB	5.86±0.66^{ab}	4.33±0.35^{abcd}	4.72 ±0.62^{a}	2.94 ±0.67^{cde}	6.22 ±0.51^{a}	5.86 ±0.58^{a}	7.11 ±0.60^{a}
10% Pea +SMB	6.14±0.66^{ab}	4.44±0.35^{abc}	4.42 ±0.62^{a}	5.78 ±0.67^{abc}	6.64 ±0.51^{a}	5.75 ±0.58^{a}	5.97 ±0.60^{a}
20% Pea + SMB	7.22±0.66^{ab}	5.56±0.35^{a}	4.28 ±0.62^{a}	8.11 ±0.67^{ab}	7.42 ±0.51^{a}	5.78 ±0.58^{a}	5.75 ±0.60^{a}
1% pea	4.75±0.66^{b}	3.33±0.35^{cde}	5.47 ±0.62^{a}	2.03 ±0.67^{de}	5.17 ±0.51^{a}	4.86 ±0.58^{a}	6.39 ±0.60^{a}
2% pea	5.72±0.66^{ab}	2.92±0.35^{cde}	5.33 ±0.62^{a}	3.06 ±0.67^{cde}	5.42 ±0.51^{a}	5.33 ±0.58^{a}	6.72 ±0.60^{a}
5% Pea	5.47±0.66^{ab}	3.39±0.35^{cde}	5.50 ±0.62^{a}	4.81 ±0.67^{bcd}	6.56 ±0.51^{a}	5.06 ±0.58^{a}	6.14 ±0.60^{a}
10% pea	6.36±0.66^{ab}	3.69±0.35^{bcde}	4.25 ±0.62^{a}	5.97 ±0.67^{abc}	5.89 ±0.51^{a}	5.11 ±0.58^{a}	6.89 ±0.60^{a}
20% pea	8.06±0.66^{a}	5.28±0.35^{ab}	3.61 ±0.62^{a}	8.17 ±0.67^{a}	7.19 ±0.51^{a}	6.00 ±0.58^{a}	6.75 ±0.60^{a}

Table 2.7 Mean values with the standard error (shown below) for the samples for taste and flavor attributes rated by 9 panelists. Different letters in the same column indicate significant differences between samples as analyzed by Tukey's HSD on a 15-cm unstructured line scale, with results presented on this scale between 0 and 15 ($p < 0.05$)

Treatment	**Taste**			**Flavor**				
	Sweet	**Bitter**	**Astringency**	**Cooked pea flavor**	**Nutty flavor**	**Doughy flavor**	**Cardboard flavor**	**Sulfur flavor**
Control	4.36 ±0.58^{a}	2.00 ±0.90^{a}	4.50 ±0.84^{a}	1.36 ±0.54^{ef}	1.72 ±0.54^{a}	5.28 ±0.86^{a}	3.64 ±0.84^{a}	1.78 ±0.52^{a}
1% SMB	4.72 ±0.58^{a}	2.81 ±0.90^{a}	3.17 ±0.84^{a}	1.14 ±0.54^{f}	1.86 ±0.54^{a}	5.50 ±0.86^{a}	2.14 ±0.84^{a}	2.58 ±0.52^{a}
2% SMB	5.03 ±0.58^{a}	2.72 ±0.90^{a}	3.61 ±0.84^{a}	1.67 ±0.54^{def}	1.83 ±0.54^{a}	5.53 ±0.86^{a}	3.19 ±0.84^{a}	1.50 ±0.52^{a}
5% SMB	4.75 ±0.58^{a}	3.00 ±0.90^{a}	3.75 ±0.84^{a}	1.47 ±0.54^{ef}	3.00 ±0.54^{a}	6.06 ±0.86^{a}	2.67 ±0.84^{a}	3.36 ±0.52^{a}
10% SMB	5.50 ±0.58^{a}	1.81 ±0.90^{a}	4.39 ±0.84^{a}	1.17 ±0.54^{ef}	2.36 ±0.54^{a}	6.06 ±0.86^{a}	3.47 ±0.84^{a}	2.42 ±0.52^{a}
20% SMB	5.17 ±0.58^{a}	2.97 ±0.90^{a}	4.06 ±0.84^{a}	1.44 ±0.54^{ef}	2.28 ±0.54^{a}	6.06 ±0.86^{a}	3.53 ±0.84^{a}	3.22 ±0.52^{a}
1% Pea +SMB	5.56 ±0.58^{a}	1.92 ±0.90^{a}	3.97 ±0.84^{a}	1.28 ±0.54^{ef}	2.17 ±0.54^{a}	5.56 ±0.86^{a}	2.53 ±0.84^{a}	2.06 ±0.52^{a}
2% Pea +SMB	5.06 ±0.58^{a}	1.56 ±0.90^{a}	3.78 ±0.84^{a}	1.86 ±0.54^{def}	1.69 ±0.54^{a}	5.72 ±0.86^{a}	3.17 ±0.84^{a}	2.14 ±0.52^{a}
5% Pea +SMB	4.50 ±0.58^{a}	2.75 ±0.90^{a}	4.42 ±0.84^{a}	3.25±0.54^{cdef}	2.75 ±0.54^{a}	5.19 ±0.86^{a}	3.42 ±0.84^{a}	2.19 ±0.52^{a}
10% Pea +SMB	4.61 ±0.58^{a}	3.69 ±0.90^{a}	4.86 ±0.84^{a}	5.86 ±0.54^{bc}	3.33 ±0.54^{a}	5.83 ±0.86^{a}	4.56 ±0.84^{a}	2.92 ±0.52^{a}
20% Pea + SMB	4.17 ±0.58^{a}	4.11 ±0.90^{a}	4.97 ±0.84^{a}	8.72 ±0.54^{a}	4.06 ±0.54^{a}	5.19 ±0.86^{a}	4.64 ±0.84^{a}	2.31 ±0.52^{a}
1% pea	5.08 ±0.58^{a}	1.94 ±0.90^{a}	3.83 ±0.84^{a}	1.72 ±0.54^{def}	2.31 ±0.54^{a}	5.97 ±0.86^{a}	3.47 ±0.84^{a}	1.67 ±0.52^{a}
2% pea	4.39 ±0.58^{a}	3.64 ±0.90^{a}	4.69 ±0.84^{a}	2.94 ±0.54^{def}	2.67 ±0.54^{a}	5.50 ±0.86^{a}	3.39 ±0.84^{a}	3.25 ±0.52^{a}
5% Pea	5.08 ±0.58^{a}	2.94 ±0.90^{a}	4.50 ±0.84^{a}	3.83 ±0.54^{cde}	3.06 ±0.54^{a}	5.50 ±0.86^{a}	3.61 ±0.84^{a}	1.94 ±0.52^{a}
10% pea	4.08 ±0.58^{a}	2.94 ±0.90^{a}	4.81 ±0.84^{a}	4.31 ±0.54^{cd}	3.61 ±0.54^{a}	5.22 ±0.86^{a}	4.19 ±0.84^{a}	2.44 ±0.52^{a}
20% pea	4.44 ±0.58^{a}	4.08 ±0.90^{a}	5.53 ±0.84^{a}	8.47 ±0.54^{ab}	4.06 ±0.54^{a}	5.69 ±0.86^{a}	5.36 ±0.84^{a}	1.89 ±0.52^{a}

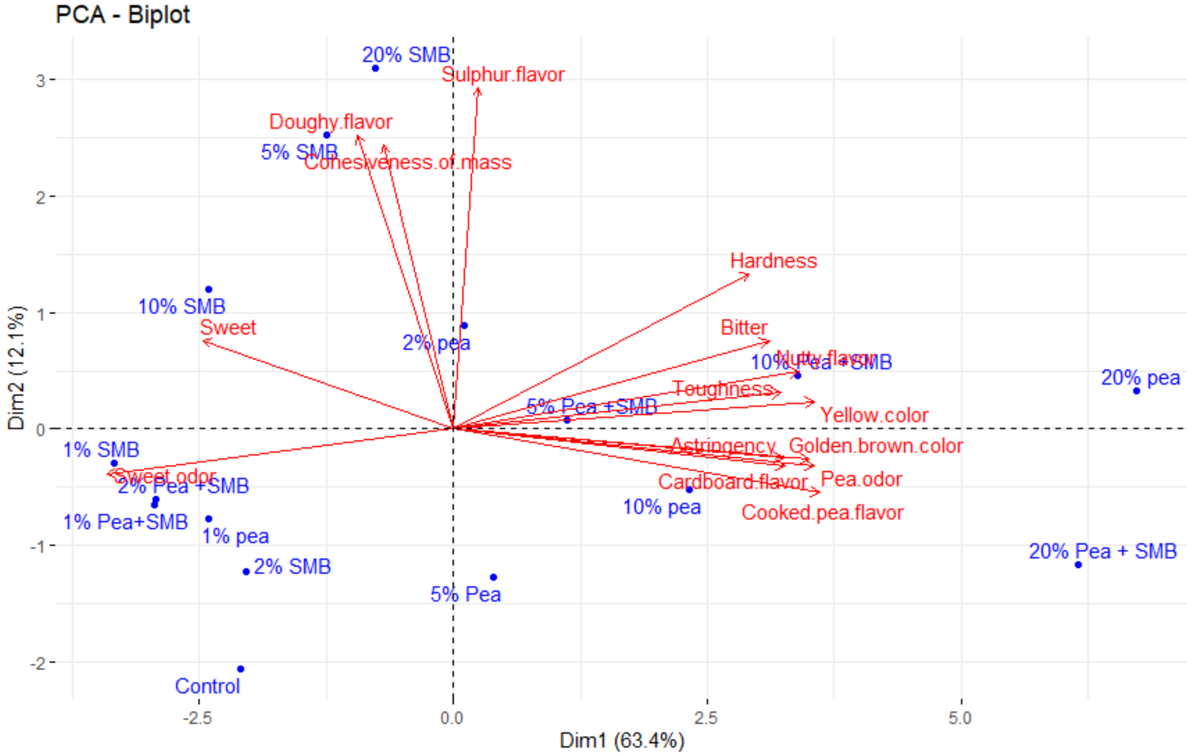

Figure 2.6 Principle component analysis (PCA) biplot of pancakes made with pea flour (1, 2, 5, 10, 20%), pea flour along with SMB at 500 ppm to pea flour and with only SBM (1, 2, 5, 10, 20 mg/200g of wheat flour) represented as blue points. The attributes evaluated are visual terms (yellow color, golden brown color), odor term (sweet odor, pea odor), in-hand term(toughness), mouth terms (hardness, cohesiveness of mass), taste term (sweet, bitter, astringent), and flavor terms (Cooked Pea, cardboard, nutty, doughy, sulfur) represented as red vectors. Vector are scaled to overlap treatment graph.

The principal component analysis allows for the identification of directionality and the importance of the pancake sensory attributes (Figure 2.6). With PCA, dimension 1 and dimension 2 were able to explain 78.6% of the variability. Dimension 1 (67.3%) was directly correlated to cooked pea flavor, pea odor, yellow color, golden brown color, nutty flavor, toughness, cardboard flavor, bitter, astringency, and hardness and negatively correlated to doughy flavor, sweet, and sweet odor. Dimension 2 (11.3%) was positively correlated to sulfur flavors and cohesiveness of mass.

All pancake treatments containing pea flour, both with and without SMB, were positively related to dimension 1 attributes (Figure 2.6). Samples with a higher amount of pea flour were perceived with more yellow color, golden brown color, nutty flavors, cardboard flavor, hardness, toughness, astringency, and bitterness. These results were expected based on previous literature (Fahmi et al., 2019; Zhao et al., 2005), but this study allowed for quantification of the degree or intensity of these attributes resulting from the different treatments.

Among the 16 pancake samples, all the SMB only pancakes remain to be perceived with a sweet taste, sweet odor, and doughy flavor irrespective of the SMB level (Figure 2.6). As the amount of SMB increased, the panelists assessed them with more sulfur flavor and more "cohesiveness of mass" feel in the mouth compared to the control pancake. The cohesiveness of mass is a desired attribute for baked products and is the opposite of crumbly textures. All the pancakes with lower incorporation of pea flour and SMB addition were close to the control. The increase in sulfur flavors is in line with the chemical modifications caused by SMB. SMB is a chemical reducing agent. When applied to the pancake system, it cleaves disulfide bonds, resulting in free sulfhydryl (S-H) groups.

2.5 Conclusion

If pea flour is prepared as described in this study, it can be incorporated into batter-based bake systems at a rate of 20% with little effect on sensory quality. To this end, only at 20% pea flour incorporation did pancakes begin to have noticeable changes in color and texture when measured through instrumental analyzes. While the application of SMB had profound effects on bitterness in preliminary experimentation, it had little effect later in the actual study.

Instead, the pea flour had already lost much of its bitter flavors. For this reason, more extensive storage and flour aging studies need to be completed in future work.

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Chapter 3: Incorporation of yellow pea flour into white pan bread

3.1 Abstract

Pea flour, like other pulse flours, is being widely investigated for plausible incorporation into regular baked products. Among many factors, the kind of milling has a drastic effect in determining the fitness of resulting pea into a different product application. The objective of this study is to understand the effect of pea flour incorporation into white pan bread milled in Miag Multomat. Bread loaf volume reduced as a higher level of pea flour was incorporated. Texture, specific volume, height was not significantly different till 10% w/w pea flour addition. The color of the bread crust was not affected by pea flour incorporation. The color of bread crumb was affected by an increasing amount of pea flour. Gas cell structure in crumb showed coalescence at a higher level of pea flour. Consumer perceived difference between control and bread with pea flour. But an increase in pea flour did not affect the sensory score drastically. Pea flour milled in roller mill makes sensorially acceptable bread even with 20% pea flour addition. The study reports bread baking, quality, and sensory appeal of pea flour incorporated bread made with dry split pea flour milled using roller mill and identifies the max level of pea flour incorporation of into bread.

Keywords

milling, dry split yellow pea flour, particle size, sensory, bread quality, pulse flour

3.2 Introduction

Once at the foundation of the food pyramid, cereal products like white pan bread are no longer considered healthy. Instead, whole grain, high fiber, and high protein foods are considered more desirable from a nutritional standpoint. Healthier bread options like those made with partial addition or completely of rye, barley, whole grains, and legumes are increasingly sought after (Aider et al., 2012; Council & NPD Group, 2009; Sullivan et al., 2013).

To this end, major wheat proteins (gliadin and glutenin) are deficient in the essential amino acids, lysine, tryptophan, and methionine (Žilić et al., 2011), whereas legumes being rich in lysine makes legumes and cereals complementary to each other. Consumptions of pulses are an effective dietary approach to reduce the risk of diabetes and cardiovascular diseases and increase satiety levels (Curran, 2012; Rebello et al., 2014). From an environmental viewpoint, legumes, when harvested in rotation with wheat or other cereal, improves the quality of soil and harvest (Saad et al., 2018; Uzoh et al., 2019).

Yellow pea has gained interest and momentum as an inexpensive option among legumes. Pea flour is significantly higher in fiber than cereals, has nearly twice the amount of protein, and incorporation into baked goods has the potential to improve overall nutritional quality. However, incorporation of pea flour into baked goods is thought to be hindered by its flavor, high level of hydrophilic proteins, and high fiber content, which decrease the quality and consumer acceptability of the resulting products (Adebiyi & Aluko, 2011; Jeffers et al., 1978; Lu et al., 2000; Marinangeli, 2009).

There have been numerous studies on pulse flour incorporation into baked and other cereal-based snacks. Pea flour has been investigated in baked goods like Cookies (Kamaljit et al., 2010; Zucco et al., 2011), baked crackers (Kohajdová et al., 2013; Millar et al., 2017), cake (Gómez et al., 2012; Hillen, 2016) and bread. In an article, bread with a maximum of 10% yellow pea flour addition showed a decrease in sensory appeal (Repetsky and Klein, 1982). Jeffers et al. (1978) reported that though the loaf volume decreased as the raw and cooked yellow pea flour was increased from 0 to 15 % w/w. The bread was acceptable by the panelist without the requirement of adding dough improvers. At the same time, the addition of dough improvers like ascorbic acid and potassium borate was effective in retaining the loaf volume. Researchers have also tried fermented or germinated pea flours, which, though seemed to improve the sensory character of bread, turned out to lose bread volume and quality. (Bourré et al., 2019b; Frohlich et al., 2019).

Keeping this in mind, the objective of this study was to determine how the incorporation of yellow split pea flour (YSPF) milled in Miag mill affects the quality of yeast-leavened bread and to identify the acceptable level of incorporation of pea flour. For this, bread volume, texture, and color were assessed objectively. The sensory quality of the experimental bread was assessed through a consumer acceptance study.

3.3 Material and Methods

3.3.1 Milling

Dehulled yellow split pea was provided by Spokane Seed Company from Spokane, Idaho, USA, and was milled using a Miag Multomat mill. The feed rate was 900 g/min. Pea flour was made by blending 1st, 2nd, 3rd break flour (BK), grading sizing roller flour (GR), middling reduction/sizing roller (MRd), and 1st 2nd, and 3rd reduction/millings (M) except the 4th middling. 4M was excluded due to high fiber content and starch damage. The resulting flour was 21.3% protein, 10.4% fiber. Nearly 92% of the flour had a particle size smaller than 125 µm followed by ~11% of flour particles between 125-150 µm. Prepared pea flour was tightly sealed into polyethylene bags and stored in ambient storage temperatures (23-25℃).

3.3.2 Baking Process

Hard red spring wheat flour used for this study was Pillsbury's Best Bread, enriched flour (Pillsbury Milling, Minneapolis, MN) 14.3% protein along with the Miag milled yellow pea flour as mentioned above. For this study, blends of wheat and pea flour were prepared with yellow pea flour at incorporation rates of 0, 1, 2, 5, 10, and 20% on a flour weight basis. All incorporation rates are w/w basis unless mentioned. Loaves of bread were made according to modified AACCI straight dough method 10-10.03, using 100 g of wheat flour-pea flour blends (14% moisture). Mixographs were run on the flour blends to determine optimal mixing time and water addition levels for each flour blend (AACCI Method 54-40.02 & 10-10.03). The proof height of all loaves was measured just before baking. After baking bread loaves were cooled for 2 h on a cooling rack at room temperature (23-25 °C).

3.3.3 Specific Volume

After cooling for 2 h, loaf weights and heights were recorded, and volume was measured by the rapeseed displacement. Specific volume was calculated by dividing a loaf's volume by its weight (AACCI Method 10-05.01).

3.3.4 Bread Color Analysis

Color measurements (L*, a*, b*) were completed using a Minolta colorimeter (CR 310, Japan). For each bread, three-color measurements were taken for crust and crumb color. For color measurement of crumb and texture analysis, three slices of 2.5 cm were cut out from the middle portion of bread.

3.3.5 Bread Crumb Structure

The bread slices were scanned using Ricoh Aficio MP C3002 copier (Ricoh, Tokyo, Japan) for pictures used in bread crumb structure analysis.

3.3.6 Texture Analysis

Texture analysis was done as described by Smith et al. (2012) with modification. TA-XT2i texture analyzer (Stable MicroSystems, Scarsdale, NY) equipped with a 5-kg load cell was used. Each bread slice was subjected to 40% compression at a test speed of 1.7mm/s. A 2.5cm diameter acrylic plastic probe was used with the trigger force of 5-Kg. Texture exponent 32 (Stable Microsystems) was the software used to analyze the data. Firmness values were noted down as the force equivalent to 25% of compression.

3.3.7 Consumer Sensory Panel

A consumer panel consisting of 60 individuals was used in this study. Panelists signed a consent form approved by the University of Idaho Institutional Review Board before participation. The panel consisted of 47 individuals between 18-25 years of age, 6 between 26-30 years, and the remainder falling between 30-60 years of age. 60% of the panelists had some form of a college education. Almost all of them (57) stated that they consumed at least one or more baked goods per week. Nearly half of all panelists (32) claimed to consume split pea in one form or another at least once a year.

Three of the bread formulations were given to panelists. These were the control, 5% pea, and 20% pea flour bread incorporation levels. The reduction in sample size for the consumer panel was made to reduce panelist fatigue (Bize et al., 2017). For presentation to the panelists, bread was sliced into ~12.5 mm x 20 mm x 20 mm cubes with crust removed. Cubes of bread were served to panelists on a disposable plate accompanied with water, crackers, and tissue. The consumer study was performed in the sensory lab facility at the University of Idaho under white light in sensory booths. Bread samples were assigned random three-digit numbers to discourage bias. Panelists were given a ballot with questions on liking and were asked to score the bread sample on the hedonic scale provided in the ballot. Appearance, texture, flavor, overall acceptability, and willingness to buy were scored with 0 as "dislike extremely", 5 as "neither like or dislike" and 9 as "like extremely". For after taste, 0 represented "no aftertaste" and 9 represented a "strong aftertaste".

3.3.8 Statistical Analysis

Three replicates of each bread with 6 different levels of pea flour, including the control, were evaluated unless otherwise stated. Every replicate of bread was baked on different days. For sensory data, each panelist was treated as one experimental unit. Analysis of variance (ANOVA) followed by Tukey-Kramer groupings was used to determine differences in treatment means using a level of significance of $P<0.05$.

3.4 Results and Discussion

3.4.1 Physical quality attributes

The proof height of the dough just prior to baking was not significantly different ($P>0.05$) across all treatments (Figure 3.1). Yet, a slight decrease in proof height was observed, corresponding to the increasing percentage of pea flour. Weight, height, and specific volume of all loaves (Table 3.1) were not significantly different ($P>0.05$) with one exception. The exception being a significant ($P<0.05$) reduction in bread height and specific volume with 20% pea flour incorporation. Here, bread height for 20% pea flour incorporation was (9.57±0.09 cm) when compared to the control (11.77±0.37 cm). The specific volume was 4.68±0.23 cm^3/g for 20% pea flour and 6.58±0.68 cm^3/g for the control. A significant drop in loaf volume at

20% pea flour was also observed by Jeffers et al. (1978). A specific volume of 6.0 cm^3/g is stated to be acceptable for bread (Rooney et al.,1972). At 10% pea flour incorporation, bread with a specific volume of 5.87±0.21 cm^3/g was found to be acceptable. Given the fact that all the bread doughs were proofed for the same amount of time and had no significant differences (P>0.05) in proof height or final weight suggests that bread with 20% pea flour did not have as much oven spring as the other treatments. Meaning, the 20% pea flour treatment expanded less in the oven than the other treatments. Furthermore, bread proofing was standardized based on time, and since all treatments had similar proof heights, further optimization of proofing was not needed. Jeffers et al. (1978) reported that proof time increased with the increasing addition of pea flour. Contrary to this, Bourre et al. (2019a) found that dough with 20% pulse flours (pea, navy bean, and red lentil) addition had lower proof time than the control wheat flour bread when standardized based on height. The discrepancy in the observation can be due to a number of factors. Jeffers et al. (1978) did not report the particle size of the pea flour used, and Bourre et al. (2019a) reported a particle size between 128-420 µm but added 2% gluten in the bread formulation which would likely lead to better gas retention and decreased proof time.

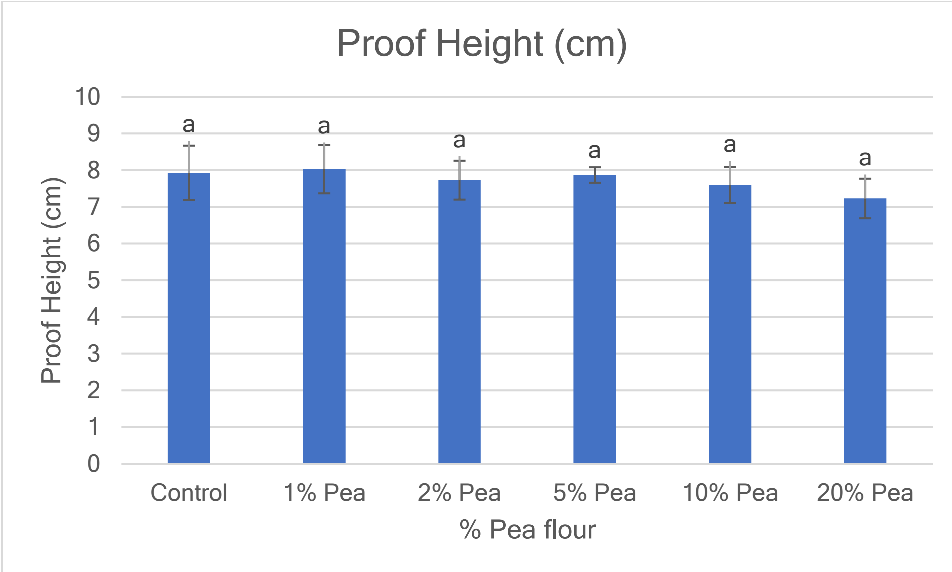

Figure 3.1 A graphical representation of height (y axis) of bread baked at five different levels of Pea flour treatments (x axis). None of the treatment means show a significant difference from one another (P<0.05).

Table 3.1 Weight of bread loaves made with different incorporation levels of Pea flour.

Treatment	Weight (g)	Height (cm)	Specific volume (cm^3/g)
Control	147.98±1.04[a]	11.77±0.37[a]	6.58±0.68[a]
1% Pea	149.32±1.61[a]	11.60±0.08[a]	6.34±0.32[a]
2% Pea	152.31±0.68[a]	11.47±0.17[a]	6.19±0.26[a]
5% Pea	148.56±0.31[a]	11.27±0.25[a]	6.25±0.09[a]
10% Pea	149.27±1.33[a]	11.30±0.14[a]	5.87±0.21[a]
20% Pea	149.47±0.80[a]	9.57±0.09[b]	4.68±0.23[b]

Means are replicates of 3 loaves. Means followed by different superscript letters in a column are significantly different (P<0.05). None of the treatment means show difference from each other.

3.4.2 Bread Color Analysis

Significant changes were observed in the color values of crumb (Table 3.2). The L* value, which is a measure of lightness, decreased from 80.13 in control to 77.32 in 20% pea flour bread. The a* values represent a hue ranging from reddish (+a* value) to greenish (-a* value). Increasing the amount of pea flour increased the redness of the crumb. The b* values which represent yellowness (+b* value) to blueness (-b* value) of a sample, increased with an increasing amount of pea flour. When color values of crust were assessed, significant differences could not be found between treatments (Table 3.3). Though it was expected that bread with a higher amount of pea flour would show more browning due to increased levels of reducing sugars (El-Adawy et al., 2003; Eheart & Mason, 1970), this was not the case. A possible explanation for this could be relatively long exposure time to high temperatures resulted in a high amount of Maillard browning (Jusoh et al., 2009) across all treatments, causing saturation in color values.

Table 3.2 Color measurements (L*, a*, b*) of bread crumb made with different treatment levels of Pea flour.

Treatment	**L* value**	**a* value**	**b* value**
Control	80.13±1.14^{a}	0.80±0.59^{ab}	16.82±0.37^{bc}
1% Pea	78.90±0.47^{ab}	0.17±0.09^{b}	16.01±0.50^{c}
2% Pea	78.81±0.52^{ab}	0.18±0.13^{b}	15.78±0.42^{c}
5% Pea	79.25±0.07^{ab}	0.37±0.13^{ab}	16.12±0.27^{bc}
10% Pea	79.08±0.56^{ab}	0.48±0.05^{ab}	17.16±0.14^{b}
20% Pea	77.32±0.20^{b}	1.08±0.18^{a}	19.06±0.06^{a}

Means are replicates from 3 batches. Means followed by different superscript letters in a column are significantly different (P<0.05).

Table 3.3 Color measurements (L*, a*, b*) of bread crust made with different levels of Pea flour.

Treatment	**L Value**	**a* Value**	**b* value**
Control	32.55±1.86a	9.52±1.48a	11.53±2.31a
1% Pea	32.47±2.50a	9.23±0.91a	10.86±2.38a
2% Pea	32.47±0.89a	9.72±0.42a	10.93±0.90a
5% Pea	31.06±0.33a	8.55±0.65a	9.36±0.57a
10% Pea	29.88±.36a	7.64±1.38a	7.99±1.46a
20% Pea	30.27±0.58a	8.41±0.25a	8.48±0.48a

Means are replicates from 3 batches. Means followed by different superscript letters in a column are significantly different (P<0.05).

3.4.3 Bread Crumb Structure

Assessing the bread images, bread with 20% pea flour addition has larger and fewer gas cells (Figure 3.2). Reduction in gluten, and an increase in other constituents from pea flour, like fiber, resulted in poor gluten structure. This makes it more difficult to trap gas, and thus many smaller gas cells coalesced into a few larger gas cells (Wang et al., 2002). As the level of pea flour increased, the swirling orientation of gas cells that result from molding was lost. In control, gas cells were characterized by elongated gas cells with thinner cell walls. Whereas in 20% pea flour, gas cells close to crust were densely packed slightly elongated and had thick cell walls resulting in a denser bread. Similar results were reported by Dabija et al. (2017), which was attributed to decreasing gluten content with increasing incorporation of pea flour.

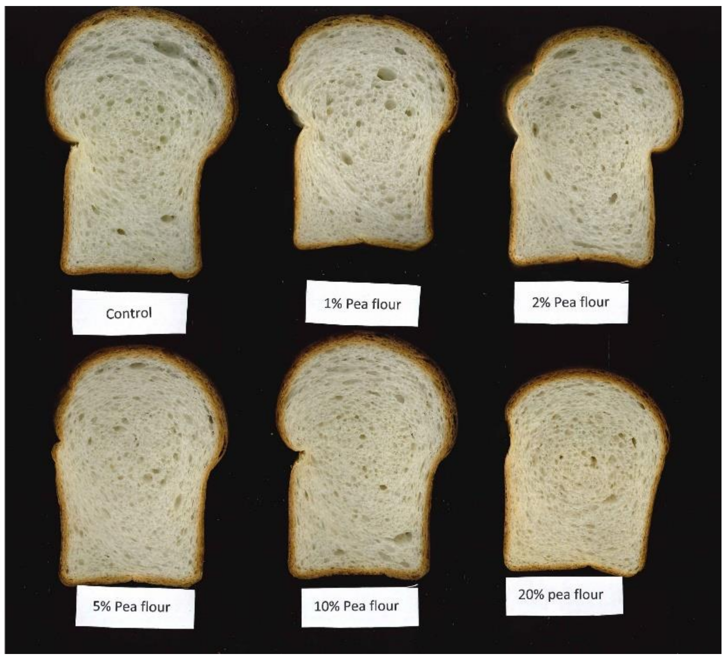

Figure 3.2 Image of bread with 6 different levels of pea flour addition. Top row left to right: Control, 1% Pea flour, 2% Pea flour. Bottom row left to right: 5% Pea flour, 10% Pea flour, 20% Pea flour.

3.4.4 Texture Analysis

Firmness increased as the percentage of pea color flour increased (Figure 3.3). This may be due to the decrease in specific volume as pea flour increased. Previous studies have indicated that there is an inverse correlation between bread hardness and specific volume (Smith et al., 2012). As cells collapse and gas cells with thicker cell walls are formed, the bread crumb becomes tightly packed and denser, increasing the hardness values for bread. Bourre et al. (2019a) also observed this in bread made with finely milled split pulse flour. A key finding in this is that up to 10% pea flour incorporation could be accomplished with no significant effect on bread firmness (Figure 3.3) or specific volume (Table 3.1)

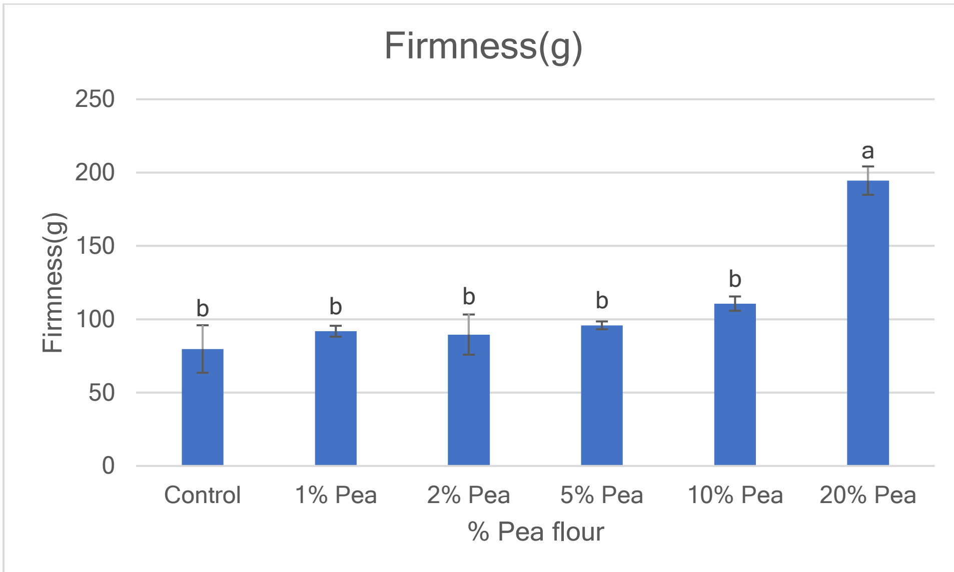

Figure 3.3 A graphical representation of Firmness (y axis) of bread baked at five different levels of Pea flour treatments (x axis). Treatment means with different letters (a, b) show a significant difference from one another ($P<0.05$).

3.4.5 Consumer Sensory Panel

The consumer study showed that hedonic scoring by the panelists resulted in different acceptances (Table 3.4, Figure 3.4). Consumers were able to perceive an aftertaste with bread containing pea flour at ≥5% incorporation. Differences in appearance could not be perceived by the consumers for any treatment. The texture of the control and 20% pea flour bread was perceived to be different, but 5% pea flour addition could not be differentiated between the two. An earlier researcher showed significant loss of sensory properties at 10 and 20% incorporation rate (Daija et al., 2017; Repetsky and Klein, 1982). Aftertaste scoring was low among all three samples. Though high standard deviations in this data point out that perception of aftertaste and feelings attached to that are highly subjective to individuals and their food habits. For flavor, overall acceptability, and willingness to buy, significant differences could not be seen between 5% and 20% pea flour addition, and the control bread did score significantly higher. This indicates that if a consumer is willing to buy a healthier alternative bread, then incorporation from 5% to 20% pea flour will not affect their overall acceptance. This gives researchers and manufacturers a range within which they can modulate pea flour addition. We hypothesize that the dominance of the lower age group (18-25 years) demographic is the plausible reason for low scoring in willingness to buy for all treatments and the control.

Table 3.4 Consumer panel scoring (Appearance, after taste, flavor, texture, overall acceptability, willingness to buy) of bread crust made with different levels of Pea flour.

Treatment	**After taste**	**Appearance**	**Flavor**	**Texture**	**Overall acceptability**	**Willing-ness to buy**
Control	2.73 ± 1.57^{b}	6.52 ± 1.47^{a}	7.07 ± 1.21^{a}	7.20 ± 1.24^{a}	7.42 ± 1.12^{a}	6.85 ± 1.60^{a}
5% Pea	3.68 ± 2.19^{a}	6.30 ± 1.50^{a}	6.17 ± 1.45^{b}	6.60 ± 1.58^{ab}	6.45 ± 1.50^{b}	5.92 ± 1.68^{b}
20% Pea	4.48 ± 2.19^{a}	6.43 ± 1.61^{a}	5.63 ± 1.91^{b}	6.30 ± 1.35^{b}	5.85 ± 1.98^{b}	5.15 ± 2.06^{b}

Means are score from 60 panelists. Means followed by different superscript letters in a column are significantly different ($P<0.05$).

3.5 Conclusions

A quality bread can be made containing yellow pea flour. In this study, it was demonstrated that only at incorporation levels up to 20% were quality attributes hindered. While consumers were able to pick up on pea flavors and aftertastes, the overall acceptability of bread made with 20% pea flour incorporation was not drastically different from the control. To this end, it is critical to point out that the objective physical quality of the bread decreased before sensory quality decreased. This means that if pea flour is prepared as mentioned in this study, a high-quality bread with only slightly decreased sensory attributes can be made with 20% yellow split pea flour incorporation.

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Chapter 4: Conclusion and future work

The work encompassed by this thesis identified the thresholds of pea flour incorporation into pancakes and bread with respect to the physical quality parameter and sensorial attributes. From the sensory evaluation by a descriptive and consumer panel, it can be said that 20% of pea flour addition in bread can make an acceptable product though with a slightly decreased bread quality. For pancakes, getting a desirable batter viscosity and the final product can be easily achieved with adjustment to water even at 20% incorporation of Pea flour.

Adjusting the batter viscosity was critical in facilitating the addition of pea flour into pancakes while maintaining quality. Yet, it could be seen that any further increase in pea flour even with optimized batter viscosity might have caused a drastic effect on the hardness and gas cell structure of pancake. The addition of emulsifiers and stabilizers have been proven to be effective in making gluten-free cakes. A future study could be conducted to incorporate even higher levels of pea flour in pancakes or other soft wheat products with the aid of emulsifiers and stabilizers.

Trained sensory panel studies on soft wheat flour products are limited, and even rarer are descriptive sensory studies on products containing pea flour and its derivatives. Further studies on developing descriptive terms and sensory references that can be associated with pea flour and its derivatives are needed for better sensorial evaluation of pea flour and resulting products as well as in evaluating the efficacy of future pea flour masking and deodorization studies.

Further studies are required to understand the effect of aging on components of pea flour. During the entire period of the experiments, it was observed that pea flour stored at ambient temperatures and frequently opened for use had a darker and more intense yellow color compared to pea flour in unopened bags, which had a lighter shade of yellow. This is indicative of some interaction between flour components and oxygen. Effect of oxidation on pigments, odor, and flavor needs to be further evaluated both in pea flour itself and food products made from it.

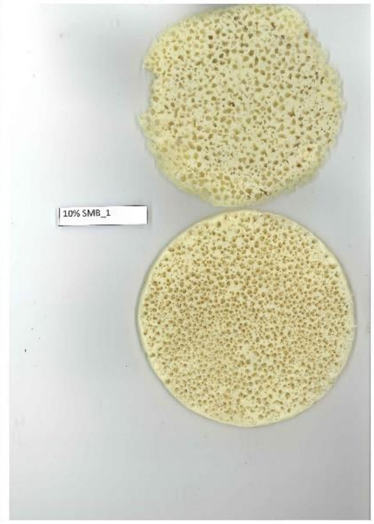
Appendix A:Photographs of pancake crumb

Figure A.1 Photographs of pancake crumb of 16 Pancake treatments.

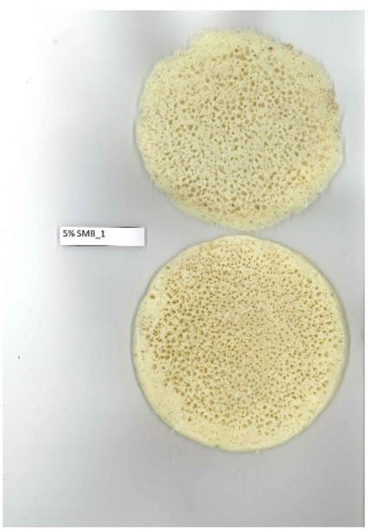
Control

20mg SMB

10mg SMB



5mg SMB



2mg SMB

1mg SMB

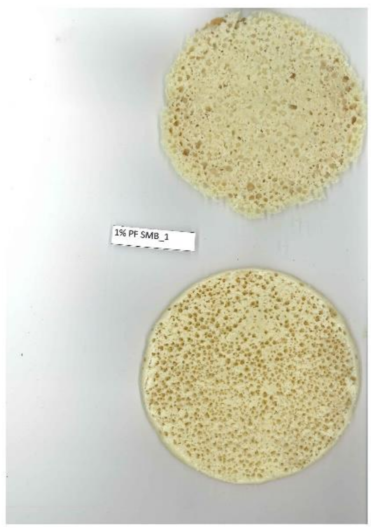
20% PF + 20mg SMB

10% PF + 10mg SMB

5% PF + 5mg SMB

2% PF + 2mg SMB

1% PF + 1mg SMB



20% PF

10% PF

5% PF

2% PF

1% PF