Milling of chickpea, lentil, and yellow pea and flowability, rheology, and bread-making properties of the flours

by

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Abstract

Pulses have excellent environmental adaptability, sustainability, nutritional, and agronomical advantages which have led to increasing consumer interests and global demand recently. The rising need of gluten-free products also contributes to this trend. Since then, the milling and baking industry started to assess the feasibility of integrating pulses into baked foods. So far, there are limited research studies on the application of current grain processing technologies for pulse grains and their baking potentials. This study aimed to develop milling techniques for pulse grains and understand their flowability and bread-making properties when incorporated into refined wheat flour.

The first objective was to develop milling processes to produce refined chickpea, lentil, and yellow pea flours with small, medium, and large particle sizes, and assess the bulk and flow properties of the flours. The grains were tempered and then milled using a laboratory roller mill. Three flours of different particle size with similar proximate composition were produced for each pulse grain. Hosokawa powder tester and FT4 powder rheometer equipment were used to determine the flow properties of the pulse flours. Among the pulses, chickpea flours had the lowest bulk and tapped density and the highest aeration ratio. Chickpea flours were found to be very cohesive and more compressible compared to the other pulse flours. For each pulse type, the small-sized flours were more cohesive than the medium and large-sized flours. The medium and large-sized lentil flours showed similar flow properties as the commercial wheat flour used.

The second objective was to investigate the effect of pulse flour substitution in refined wheat flour on bread making properties. The lentil, yellow pea, and chickpea flours of different particle size were incorporated into the refined wheat flour at levels of 5, 12.5, and 20% (w/w).

Mixograph test was done to determine the optimum water absorption and mixing time. The blends were then baked, and the bread physical properties were tested after baking. It was found that increased of incorporation reduced the bread's specific volume while increasing the bread hardness. The particle size difference did not significantly affect the qualities of the breads across different incorporation levels. At the same level of pulse incorporation, chickpea-wheat blends produced larger and softer loaves of bread. It was found that at 12.5% pulse incorporation level or lower, the bread qualities are acceptable.

Because of the better potential of chickpea for bread-making compared to lentil and yellow pea, we conducted a third study focusing on the dough rheological properties and processibility when incorporating chickpea flour into refined wheat flour. 20 different refined wheat flours of varying protein content and mixing properties were evaluated with chickpea incorporation, and chickpea flours with varying application ratios (0 – 30%), particle sizes (small, medium, large), types (kabuli vs. desi), and fractions were further tested. Mixograph and dough extensibility tests were performed. Sensory study was also conducted for the chickpea-wheat blend breads. Mixograph results showed that chickpea flour consistently increased the dough mixing tolerance of wheat flour when incorporated at 7.5%. For a few flours which were categorized as strong, there was no significant difference between the composite and control flour. Dough extensibility test showed that dough strength was increased significantly when chickpea flour was incorporated at 7.5% or lower. Further fractionation of the chickpea flour indicated that the insoluble protein fraction was more responsible for the observed dough strengthening and mixing tolerance improvement. The responses from consumer sensory study indicated no differences when bread was infused with chickpea flour at 7.5% or below compared to the regular wheat bread.

Concluding, roller mill can successfully produce refined pulse flours from whole grains. Compared with other pulse flours, the medium and large-sized lentil flours have better flowing properties comparable to wheat flour. Other pulse flours especially chickpea flours, would need special care to adapt to current grain processing facilities for proper handling and transportation. Comparing the bread-making properties of the pulses, chickpea flours are more suitable for incorporation in refined wheat flour as they produce better bread qualities than lentil and yellow pea flours. The incorporation of chickpea flour in wheat flour showed plainly improved mixing properties and dough strength for the composite flour. The sensory evaluation demonstrated that bread infused with chickpea appropriately is not different from wheat bread alone.

Keywords: chickpea, lentil, yellow pea, roller milling, flowability, baking, mixograph, extensibility, sensory

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Chapter 1 - Potential of chickpea, lentil, and pea in baking application

Abstract

Pulse has gained increasing attention recently. However, pulses are still underutilized, and yet they have great nutritional and health benefits. They can complement cereal's amino acid profile to form more nutritious products. This review aims to depict the current milling process and the potential of using pulses in the baking industry. Pulses are an excellent source of protein, and they contain several bioactive compounds compared to wheat. There is no standardized milling method optimized for pulses milling. Currently, the most used milling technique involves using the dehulled pulse grains or dehull before general milling to produce fine flour. This review shows how pulses are being incorporated into wheat products. Acceptable breads were produced when pulses were incorporated at low levels. The improvement of protein content and protein quality when pulses are incorporated into wheat were reported. The current progress shows that pulses have great potential to be applied in the baking industry to produce healthier foods.

1.1. Introduction

Pulses are legumes when harvested for their dry grains. The common pulses in America are peas, beans, lentils, and chickpeas. They are a good source of protein, dietary fibers, vitamins, and other bioactive compounds that are known to provide health benefits (Fujiwara et al., 2017). Being legumes, they easily adapt to different regions and are drought tolerant. Pulses can improve the soil health since they live in a symbiosis relationship with Rhizobia that nutrify the soil by fixing Nitrogen from the atmosphere in the soil (Herridge et al., 2008). Due to pulse's potential, the Food and Agriculture Organization of the United Nations (FAO) declared 2016 as the international year of pulses to raise public attention to pulse benefits (FAO FSN Forum, 2016). In the US, the average consumption of pulse products is around 4kg/person/year which is very low compared to the global average which is 7.2kg/person/year (Mitchell et al., 2009). The increased demand for nutritious healthy food has sparked the increased market for pulses (P. K. Joshi & Rao, 2017). Agronomically, it was found in Europe that rotating pulses with cereal resulted in reduced nitrogen application that is beneficial both to the environment and to the farmer not investing a lot of money in fertilizer application. It was also found that the biomass harvested increased when pulses were added to the rotation (Nemecek et al., 2008).

According to FAO (2022), India is the biggest pulse producer in the world (Figure 1.1); India produces the majority of chickpeas globally while Canada produces the most lentils and peas.

Looking at the characteristics of the pulses, peas (*Pisum sativum*) are smooth spherical grains usually green or yellow. They are grown all over the world; Canada is the biggest producer followed by Russia and China (Dahl et al., 2012). They are as well rich in protein, minerals, and bioactive compounds such as phenols and antioxidants (Han & Baik, 2008).

Lentils (*Lens Culinaris*) are an ancient crop that originated in Asia. Canada is the current leading producer of Lentils globally (FAO, 2022). They are rich in protein, minerals, and bioactive compounds. Globally, red and green lentils are the most produced. They are a staple in India, Turkey, and Egypt and they are also highly consumed in Europe (Erskine, 2019). Like most of the pulses, Lentils are also used in rotation cropping in Canada (MacWilliam et al., 2018).

Chickpeas (*Cicer arietinum* L), also known as Bengal gram or garbanzo beans, are ancient grains the second largest produced pulse grain in the world currently according to FAO (2022) as demonstrated in Figure 1.2. According to Nleya et al. (2002), The most common varieties produced are Kabuli (large cream grains) and Desi (small dark grains). Chickpea is grown in tropical, subtropical, and temperate regions. Asia is the biggest producer of chickpeas in the world; they produce more than 85% of the world's production (Rawal & Navarro, 2019). In the US, where chickpea is usually rotated with winter wheat; their yield in rotation can reach 2200 pounds per acre (Baltensperger et al., 2004). Chickpea rotation constantly improved the yield of the following crop (CIMMYT, 2000).

1.2. Nutritional attributes

Pulses are regarded as nutritious food globally. They are an excellent source of protein, vitamins, and minerals; they also contain carbohydrates all of which are crucial in providing needed nutrients and functional attributes to crucial body functions (Jukanti et al., 2012). Below is the discussion of each of the components listed above.

1.2.1. Protein

The protein content is crucial when considering the selection of food since proteins are functional and rare to find in ample quantity among common consumed food. As detailed in Table 1.1, pulses are an excellent source of protein, their protein content varies from 20% and goes a little above 25% which is significantly high compared to common cereal grains such as wheat (13%) (USDA, 2019). Pulses contain a plentiful amount of essential amino acids including lysine, threonine, and tryptophan that are limiting in common cereal grains. However, methionine amino acid is limiting. Because of the forementioned amino acid profile, pulses can complement cereal in amino acid composition (Singh, 2017). While the protein content in pulses is high, the presence of anti-nutritional factors such as tannins and trypsin inhibitors make the protein less available for digestion; processing techniques such as soaking and heating coupled with new breeds reduce the effects of the anti-nutritional factors (Sharma et al., 2013). Pulses protein isolates are extremely functional. They possess gel-forming abilities, which means, they can effectively retain sugar, water, and other food ingredients better than most other plant proteins. They also have foaming and emulsifying properties. Due to their functional properties, they are widely used in industry to make plant-based food materials such as plant based and tofu (M. Joshi et al., 2011; Lam et al., 2018; T. Zhang et al., 2007). The protein functional properties of pulses make them suitable for the baking application.

1.2.2. Carbohydrates

Carbohydrates are the major source of energy in grains. The total carbohydrate content in pulse grains varies around 50 to 65%; most stored carbohydrates are starch, other types include oligosaccharides (Hawkins and Johnson, 2005). The oligosaccharides are not digested by our digestive system; however, they are digested by gut microorganisms which make pulses to be beneficial to maintain the human gut environment healthy. Pulses can be claimed to be 'prebiotic' food. Pulse starch is considered a slowly digested starch compared to other staple food such as wheat and rice that is why they have a low glycemic index (GI) (Singh et al., 2021). Literature evidence shows that low GI foods play an important role in maintaining and controlling body weight; thus making low GI food "healthy" (Willet et al 2002; Fernando et al., 2010). The application of pulses into baking will make the product to be healthier.

1.2.3. Lipids

Although pulses are not considered an oilseed, among them, Chickpea has a high lipid content averaging 6%; this is significantly higher compared to wheat and corn. Lentils and peas have a lipid content that is around 1.7% which is very comparable to most cereal grains (Table 1.1). Pulses grains contain several types of lipids namely palmitic, stearic, oleic, linoleic, and linolenic fatty acids. Most of the fatty acid present in those pulses are unsaturated oleic and linoleic acid that makes up to 70% of the total fatty acids (Fouad & Rehab, 2015; Yoshida et al., 2007; Zia-Ul-Haq et al., 2007). The presence of unsaturated fatty acid could lead to the deterioration of flour due to lipid oxidation, but, the oxidation is hindered by the presence of bioactive compounds present in pulses (Zia-Ul-Haq et al., 2007).

1.2.4. Minerals and vitamins

Pulses are rich in B vitamins. With the US mandate to fortify cereal products with folate (a type of vitamin B), the use of pulses in baking can be a decent option for fortifying the cereal products. Pulses also contain a good amount of thiamin, riboflavin, and some vitamin C (CDC, 2021; Hall et al., 2017). Pulses contain bioactive compounds such as tocopherol, tocotrienols, and sterols all which have nutritional benefits and medicinal attributes; they have antioxidant properties as well as inhibition of cholesterol synthesis (Qureshi et al., 1986; Yamaoka et al., 1991).

Pulses contain ample amount of minerals including calcium, iron, magnesium, potassium, phosphorous, and zinc which are crucial for proper body functionality (Dahl et al., 2012; Ray et al., 2014). Pulses contains also other trace elements including aluminum, chromium, nickel, lead, and cadmium in safe amounts (Cabrera et al., 2003; Rawal & Navarro, 2019).

The nutritional and functional information above clearly shows the potential for pulse application in the baked product. Pulses can complement cereal grains proteins and can fortify them by providing necessary folate. Pulses can also enrich the cereal product with their bioactive compounds, hence producing a healthy product.

1.3. Pulse grain milling

For better incorporation of pulses into the baking industry, the pulses must mix well to easily be processed and transported throughout the existing channels. To do that, an appropriate size reduction (milling) method should be adopted (Scanlon et al., 2018). In industries, pulses are dehulled and split followed by hammer milling to produce fine flour. Other industries use the hammer mill to produce whole pulse flour (Wood and Malcolmson, 2021). Below here are several studies performed to reduce the size of pulses.

Ravi and Harte (2009) suggested that the first step in pulse milling should be dehulling the grain and obtaining a split grain. This is followed by dry or wet milling. In the dry milling, 10% (w/w) water is added to the grains before milling in a dhal mill. Regarding wet milling, the grains are soaked in water, then added to the dhal mill. The grains are then milled using a vertical chakki grinder which is an attrition-type grinder. It was found that the wet milling process had a higher flour yield compared to dry milling.

Price et al. (2021), developed a method of milling split peas using a pilot scale roller mill known as Buhler-Miag Multomat. This type of roller is mostly used for pilot-scale cereal grain milling. The findings showed that the milling yield was 99%. This high yield was due to the use of split (dehulled) peas for milling. The study showed that peas could be milled using currently available equipment.

Pulivarthi et al. (2021) used a laboratory-scale roller mill to grind whole lentils and yellow peas. They used different roll settings and sieves configurations to obtain refined yellow pea and lentil flours. They were also capable of obtaining flours of different particle sizes with the same proximate composition. Their flour yield ranged from 82 to 86% while the geometric mean diameter of flour obtained ranged from 50 to 96 µm.

Guldiken et al. (2022) milled whole green lentils and yellow peas. They used a combination of the hammer mill with roller mill or knife mill where they started with the hammer mill and the milled flour was then milled with either roller mill or knife mill. The flours produced in different streams for the roller mill were analyzed independently and the knife mill analyzed as one. There were no significant differences in proximate composition across different milling methods.

Wang et al. (2009) indicated that the pulse seed coat (hull) is indigestible and tastes bitter, they said that dehulled pulses contained less antinutritional compounds compared to whole grains. They added that the removal of the hull resulted in more palatability and taste of pulses. The application of any of the above milling methods will be suitable for pulses grinding since they used dehulled grains or they separate the hull to produce fine flour. Since roller mills can be easily manipulated in regard to flour particle size production (Scanlon et al., 1988), it is suggested that the use of roller mill would be preferred for pulse grains. The summarized milling progress is shown in Table 1.2.

1.4. Current baking application of lentil, pea, and chickpea flours

Pulses are naturally gluten-free, which makes them hard to use for conventional baking since gluten proteins are responsible for quality baking properties. Gluten protein provides the structure that support the baked product. With the increased demand for the healthy product in the baking industry, pulses are regarded as a good alternative because of their global availability and nutritional properties. Below are some studies performed to integrate pulses into the baking industry.

In the study done by Mohammed et al.(2012), chickpea was incorporated from 1 to 30% (w/w) levels in wheat flour and baked. Incorporation levels from 1 to 10% (w/w) produced loaves of bread that were very similar to the control in regard to bread specific volume and physical appearance. Higher levels of incorporation lowered the bread specific volume and darkened the bread's crust significantly. The sensory study performed showed that the incorporation levels of 20% or less produced acceptable bread.

Man et al.(2015) incorporated whole chickpea flour at levels 10, 20 and, 30%. It was observed that the increase of incorporation level reduced the specific volume of the bread, at the same time, the crude protein content of the bread increased. The sensory test conducted showed the overall acceptability of all bread produced.

Young et al. (2020) roasted whole yellow peas, milled them using a knife. They incorporated different roasted flour in wheat flour at 20% (w/w), followed by the baking test. The baking test showed that roasted pea flour produced better bread in regard to aroma compared to untreated pea flour. untreated yellow pea flour had a higher specific volume compared to roasted flours.

Paladugula et al. (2021) milled split yellow peas using a Miag Multomal mill (roller mill) and incorporated the yellow pea flour into the white wheat flour in levels of 1 to 20% (w/w). The baking test performed showed that the specific volume of the blended flour at level 10% and below were not significantly different from the control white pan bread. It was found that the crust color darkened as the incorporation increased. The sensory test demonstrated that at all levels of incorporation the bread loaves produced were of acceptable.

Hernandez-Aguilar et al. (2020) sprouted lentil seeds, dried them, and milled those seeds using a T-Fal blender to obtain sprouted flour. They blend the sprouted flour in wheat flour at 5 and 10% (w/w) and baked them. Germinated lentil flour at 5% produced bread with a similar specific volume compared to the control while the hardness of the bread increased significantly when a blend of 10% inclusion was used.

Zhang et al. (2021) milled yellow peas, green peas, red lentils, and chickpeas using a Wiley laboratory mill. The flours were incorporated at levels 5 to 25% (w/w) in whole wheat flour. They then performed the baking test. The specific volume did not change significantly within different pulse flours at the same level of incorporation. At 5% incorporation level for all pulse flour, the bread specific volume was very comparable to the control whole wheat flour. The crust of the bread became darker as the incorporation increased. The summarized application of pulses in baked product is show in Table 1.3. The major limitation of the baking studies performed was the non-consideration of the particle size. Another improvement that would better compare the pulses is to bake them head to head to better identify the most suitable pulse for baking application.

1.5. Conclusion

The above studies show that there is a potential application of pulses in the baking industry. Pulses are currently used as a blend to produce leavened baked products. Using pulses in baking can increase the protein content and provide a better amino acid profile than using common cereal grains. The incorporating pulses in baked product can produce healthier products. Further research is needed to optimize and standardize the milling method and find the optimum blending level for pulses and wheat. The pulse flour physical and flow properties need to be understood for the pulses to integrate the baking industry. Further research is needed to understand the rheological changes that occur in wheat flour as pulses are incorporated.

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Tables

Table 1.1 Proximate composition comparison of pulses and wheat kernels

Sample	Water (%)	Protein (%)	Lipid (%)	Ash (%)	Carbohydrate (%)
Wheat	10.7	13.2	2.5	1.58	72
Chickpea	7.68	20.5	6.04	2.85	63
Lentil	8.26	24.6	1.06	2.71	63.4
Peas	10.6	21.7	1.49	3.45	62.8

(USDA, 2019)

Table 1.2 Summary of the current pulse milling

Milling equipment (mechanism)	Grains condition	Output	Remarks
Chakki grinder (attrition grinder)	lentils - Dehulled grains - dry or wet milling	Fine flour	Wet milling had a higher flour yield [a]
Pilot scale Miag-Multomat (roller mill)	Split yellow peas - Spit peas (no hull)	Fine flour	Compatibility to use pilot scale roller mill [b]
Laboratory Ross (Roller mill)	Red lentils and yellow peas - Whole grain	- Fine flour - Bran - Shorts	- Different particle size flours - Yield higher than 82%[c]
Hammer mill+ roller mill/knife mill (impact)	Green lentils and yellow peas - Whole grains	- Fine flour - Hulls - shorts	- No composition effect caused by a milling equipment [d]

a: Ravi and Harte,2009; b: Price et al., 2021; c: Pulivarthi et al.,2021; d: Guldiken et al.,2022

Table 1.3 Summary of the current pulse application in baked products

Pulse grain used	Inclusion level (w/w)	Observation	
Chickpea in refined wheat flour	1-30%	- 1-10% incorporation level does not reduce the volume of the bread - Higher incorporation, lower volume - 20% or less produce acceptable bread	a
Chickpea in refined wheat flour	10, 20, and 30%	- Increased incorporation, decreased bread volume - Crude protein increases with increase of incorporation level	b
Yellow peas in refined wheat flour	20%	- Roasted pea flour increases the aroma - Untreated pea flour produced bigger loaf of bread compared to roasted	c
yellow pea in refined wheat flour	1-20%	- 10% or below don't affect the bread volume - All the bread produced were acceptable during a sensory analysis	d
Lentil in refined wheat flour	5 and 10%	- 5% do not affect the bread volume - 10% increases the hardness and lower the volume of the bread	e
Yellow pea, green pea, red lentil, and chickpea in whole wheat flour	5-25%	- 5% do not affect the volume of the bread - Higher inclusion, lower volume - Higher inclusion, crust darkened	f

a: Mohammed et al.,2012; b: Man et al.,2015; Young et al.,2020; Paladugula et al.,2021; Hernandez-Aguilar et al.,2020; Zhang et al.,2021

Figures

Figure 1.1 Pulse production per country worldwide (FAO, 2022)

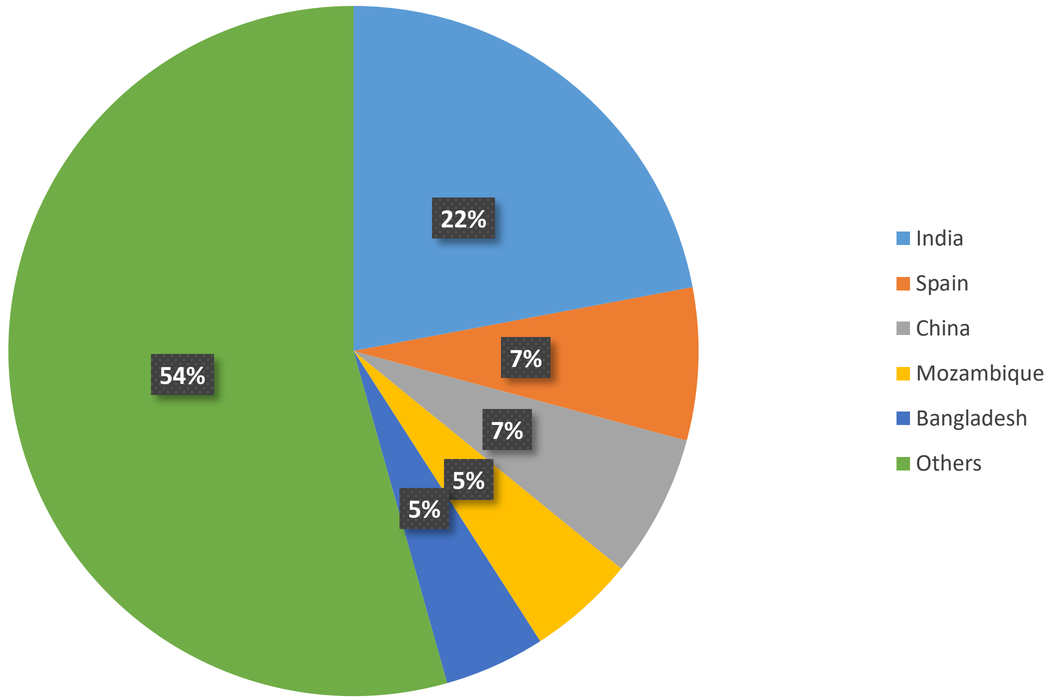
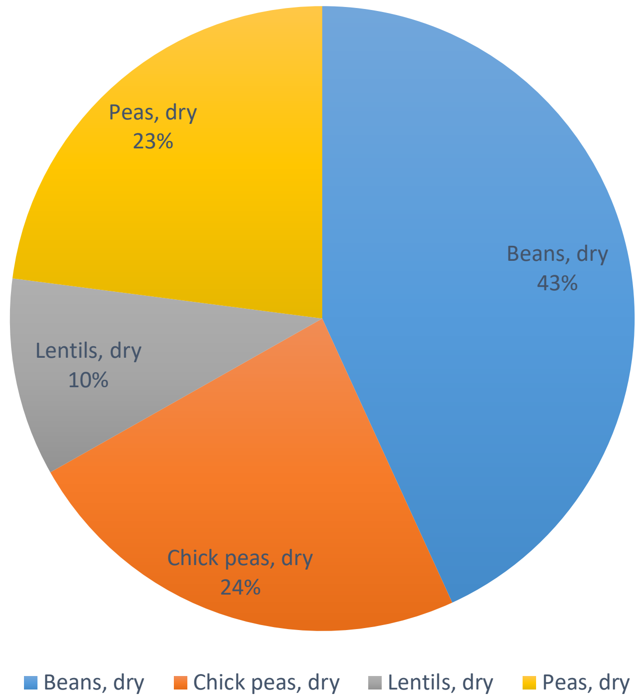


Figure 1.2 Graph showing the quantity of pulse production by type globally (FAO, 2022)



Chapter 2 - Bulk and flow properties of yellow pea, lentil, and chickpea flours of different particle size

Abstract

The demand for pulses is increasing due to their nutritional benefits, sustainability, and agronomical advantages. However, there are few studies reporting the bulk and dynamic flow properties of pulse flours that are critical for their proper handling and processing. This study was performed to investigate the flow properties of yellow pea, lentil, and chickpea flours compared to wheat flour. The pulse flours of different particle sizes were produced using a laboratory roller mill through optimizing the settings of the rolls gap opening and sieve arrangement and employing 75, 150, and 200 µm bottom sieves for small, medium, and large-sized flours, respectively. The flour flow properties were analyzed using a Hosokawa powder tester and FT4 powder rheometer. Chickpea flours had the lowest bulk density and the highest aeration ratio and were more compressible and cohesive among all the pulse flours and wheat flour. The small-sized flour for each pulse grain was more cohesive than the large-sized flours. For most tests, chickpea and small-sized yellow pea flours were characterized as non-flowing powder, while medium and large-sized lentil flours showed relatively good flow properties comparable to wheat flour. Generally, the pulses flours in this study have low bulk density and poor flowing flours compared to wheat flour. The production of small-sized pulse flours is not suggested based on the low bulk density, high compressibility, and overall bad-flowing properties. For the pulse flours to be incorporated into modern industrial platforms, there will need to be some adjustments made to equipment to allow the adequate flow of the pulse flours.

This study will help the milling and baking industries in preparing for pulse grain processing, and will also benefit transportation companies in evaluating pulse flours for proper handling.

Keywords: Lentil, chickpea, yellow pea, pulse flour, flow properties, compressibility

2.1. Introduction

Pulses are protein-rich grains that originate from the regions around the middle and the far East. In America, lentils, yellow peas, and chickpeas are the most produced pulse grains (USDA, 2017). Pulses are nutritious and contain more protein than common cereals such as wheat, rice, and maize. They are also rich in vitamins and minerals which are necessary for the body's core mechanisms. Having a higher amount of non-digestible carbohydrates and fibers, pulses are a low glycemic food source which means they can be good food for people with diabetes or people wanting low carbs food (Fujiwara et al., 2017). Because of all the above benefits, the demand for pulses has been increasing. People with celiac disease or with gluten sensitivity also contribute to the increasing demand for gluten-free food which pulses are part of (Asif et al., 2013; Bessada et al., 2019; Han et al., 2010). In 2016, the FAO (2016) suggested incorporating pulses into the commonly consumed food product. Since then, more scientists started to adopt pulses for the baking sector (Bourré et al., 2019; Paladugula et al., 2021). The incorporation of new grain in baking requires the production of flour. Pulivarthi et al. (2021) developed a milling method for yellow peas and lentils. They used the roller mill to produce pulse flours of different particle sizes but with approximately the same proximate composition.

When considering the flour and its utilization on an industrial level, the flow properties play a crucial role in determining the flour handling during transportation and processing in the plant facilities; flow properties are important to determine whether and what type of flow aids will be necessary for ease in handling (Fathollahi et al., 2020). It was found that moisture content, particle size, and chemical composition have a huge impact on the flow properties of flour, mainly due to interaction forces existing between different molecules and particles(Siliveru et al., 2017). The different flour compositions have varying influences on the flow of the flour.

Till the date, pulses flow properties are not extensively studied due to their minimal presence in modern industries. In most places where pulses are produced, they are processed in a pulse grain-specific facility. That is not suitable for the current economy that encourage for multipurpose equipment (Blanchard, 2016; Donke et al., 2017; Schneider, 2002). However, with research, the equipment can be adjusted to run pulses as well. In the study performed by Handu et al. (2022) on three varieties of chickpea flour one of which was commercial, it showed that the chickpea flour was in the hardened category on the powder flowability classification. This means that some adjustments should be made to chickpea flour to help with the flow.

Referring to the literature research performed, the studies on the flowability properties of pulses flours are very limited. Thus, this study was conducted to determine the flow functionality of lentil, yellow pea, and chickpea flours and to understand the effect of flour particle size on their flowability. The results from this study could serve the scientific community and related industry to adapt the pulse flours to current facilities or design processing and handling equipment to better handle the pulse flours.

2.2. Materials and methods

2.2.1. Pulse grain materials

Lentils and Kabuli chickpea grains were purchased from Food to live online store. Yellow pea grains were purchased from D’allesandro gourmet ingredients online store. All the grains were kept at room temperature until they were used. All-purpose wheat flour was purchased from the local store.

2.2.2. Milling pulse grains

Lentil, chickpea, and yellow pea were milled using a laboratory scale Ross roller mill. The milling was done by following the procedure developed by Pulivarthi et al. (2021). A few modifications were made to the procedure to accommodate chickpea milling. The grains were tempered to 13% moisture content overnight. The rolls gap opening and sieve arrangement were set to produce flours of different particle sizes. For all the grains, bottom sieve of 75, 150, and 200 µm was used to produce Small (S), Medium (M), and Large (L)-sized flours, respectively. Figure 2.1 shows details for the small-sized chickpea milling flow sheet. For other flours, the same milling flowsheet was followed with some minor adjustment as listed in Table 2.1.

2.2.3. Flour characterization

Alpine Jet sieve (Hosokawa Micron, E200 LS) was used to determine the geometric mean diameter (GMD) of the flours produced. Flours were passed through six sieves starting with the sieve of 25 µm up to the sieve of 220 µm; the following equation was used to calculate the GMD:

$$\boldsymbol{d_{gw} = log^{-1}\left[\frac{\sum_{i=1}^{n}(W_i\, log\bar{d}_i)}{\sum_{i=1}^{n} W_i}\right]} \text{--(1)}$$

d_{gw}: geometric mean diameter (µm)
W_i: amount of flour retained on the i^{th} sieve (g)

d_i: aperture size on the i^{th} sieve (µm)

n: total number of sieves

Ash, protein, moisture and lipid content were determined following the AACC method 08-01.01, 46-30.01, 44-17.01, and 30-10.01 (1961; 1961, 1999, 2003) Respectively. Total carbohydrate content was measured using the difference as shown in the equation below:

$$Carbohydrates\ (\%) = 100 - (Ash + Total\ lipids + Moisture + Protein) \text{-----(2)}$$

Flour starch damage was measured with a SDmatic TM equipment (Chopin Technologies, Villeneuve la Garenne, France) following the AACC 76-33.01 method (2007).

2.2.4. Bulk properties

A Hosokawa Powder tester PT-R (Hokosawa Micron B.V., Japan) was used to measure the aerated bulk density (ρ_b), tap density (ρ_t), and angle of repose (AoR) of the flours. 110 g of flour was placed into the equipment container and was vibrated at an amplitude of 1 mm for 30 s. The mass of the remaining flour was measured and used to calculate bulk density. The tap density was measured by tapping the extended container 180 times, and the mass of the flour remaining in the original container was used to measure tap density. Carr's compressibility index (CCI) and Hausner's ratio (HR) were measured using the following equation.

$$\text{Carr's compressibility index (CCI) (\%)} = \left(\frac{(\rho_t - \rho_b)}{\rho_t}\right) \times 100 \text{------------(3)}$$

$$Hausner's\ ratio\ (HR) = \frac{\rho_t}{\rho_b} \text{------------------------------(4)}$$

The angle of repose was measured by mounting a small glass funnel on a stainless-steel table. 110 g of the flour was placed in the sieve and vibrated at the amplitude of 1 mm for 30 s. The flour was allowed to flow on the stainless-steel table until it creates a dune. The built-in laser calculated the angle of repose (Berton et al., 2002).

2.2.5. True density

The true density of the flours was measured using ULTRAPYC 1200e (Quantachrome Instruments, Florida, USA) an automatic density analyzer equipment. The true density measurements were done in triplicates for each flour.

2.2.6. Dynamic flow test (stability, aeration, and variable flow rate)

The flow properties of the pulse flours were measured using a FT4 Powder Rheometer (Freeman Technologies, Tewkesbury, Gloucestershire, UK). Dynamic, shear, and bulk flow tests can be conducted with this equipment. The dynamic flow test measures the energy required to move the blade through the flour vertically from the top. The shear flow test analyzes the behavior of the flour when subjected to different handling and storing conditions. Whereas, the bulk flow test measures the changes in volume when a series of increasing stress is applied to the sample flour (Karde et al., 2015).

The parameters measured in the dynamic flow test were flow rate index (FRI), basic flow energy (BFE), and stability index (SI). The Stability index is the measure of stability of a powder and measures the changes due to the flow of flour. A 25 mm × 10 ml split cylinder was used with a 23.5 mm blade for the dynamic flow test on the FT4 Powder Rheometer. The sample was filled in the glass cylinder and conditioned using the blade followed by a test cycle at a blade tip speed of 100 mm/s. The resistance on the blade from the top to bottom represents the flow energy. The test was replicated 7 times to measure basic flow energy and stability index. The blade speed was then reduced gradually up to 10 mm/s, and four additional test runs were performed to measure the flow rate index. Tests 8, 9, 10, and 11 were measured at a speed of 100, 70, 40 and 10 mm/s respectively.

$$Stability\ index\ (SI) = \frac{Total\ energy\ consumed\ at\ test\ 7}{Total\ energy\ consumed\ at\ test\ 1} \text{-------------(5)}$$

$$Flow\ rate\ index\ (FRI) = \frac{Flow\ energy\ at\ test\ 11}{Flow\ energyat\ test\ 8} \text{-------------------(6)}$$

Aeration was measured by introducing airflow from the base of the vessel filled with flour. The flow energy was measured by varying air velocity. The following equation was used to calculate the aeration ratio (AeR) (Divya & Ganesh, 2019; Handu et al., 2022; Jan et al., 2016).

$$Aeration\ ratio\ (AeR) = \frac{E_r}{E_o} \times 100 \text{-------------------------(7)}$$

AeR- Aeration ratio

E_r- Residual flow energy during full aeration (air velocity 10 mm/s)

E_o- Flow energy during fixed bed conditions (air velocity 0mm/s)

2.2.7. Bulk flow tests (permeability and compressibility)

This test was performed using a vented piston and a 25 mm ×10 ml split cylindrical glass vessel attachment with the FT4 Powder Rheometer. The flour was placed in the glass vessel and compressed with pressure starting from 1 kPa to 15 kPa. Conditioned bulk density (CBD) was recorded by the powder rheometer before starting the test and the powder rheometer was also measure the density after compression; those two parameters were used to equate the compressibility index (CI). Poorly flowing flour had greater compressibility values. The CI was measured using the following equation.

$$Compressibility\ index\ (CI)\ (\%) = \frac{Density\ after\ compression}{CBD} \times 100 \text{----------(8)}$$

Permeability quantifies the flour's ability to allow fluids across. The airflow resistance was measured by the powder rheometer as air was blown into the powder at a speed of 2 mm/s for the permeability test (Barretto et al., 2021; Karde et al., 2015).

Flow tests were conducted at room temperature and pressure. Moisture content was monitored to reduce the effect of moisture on the flow tests.

2.2.8. Data analysis

All the measurements were conducted in triplicates. Experimental data was analyzed using the Statistical Analysis Software (SAS Studio). Mean difference was determined by analysis of variance and Tukey-Kramer grouping was used at a significance level of p <0.05.

2.3. Results and discussion

2.3.1. Pulse and wheat flours physical properties

The flour composition data are detailed in Table 2.2. The milling process produced pulse flours with yield ranging from 80.0 to 86.9%. The yield was lower for small-sized flours which was a result of the extended processes involved in making the small-sized flour. Lentil had a lower flour yield among the studied pulses, which was due to the smaller size nature of lentil grain compared to yellow pea and chickpea. Pulivarthi et al.(2021) observed an increased flour yield for bigger size grains compared to smaller size grains. The smaller grains have a higher surface area-to-volume ratio meaning higher percentage of hulls compared to grains will lower surface area-to-volume ratio. The average yield for all the pulse flours milled was overall acceptable.

As intended, using different milling settings produced flours with different particle sizes. The finest (44.82 µm) and coarsest (103.99 µm) flours were obtained by milling the lentil. For each grain, three flours of different particle sizes were obtained. The geometric mean diameter for the wheat flour was 62.59 µm which is comparable to medium-sized pulse flours used in this study. The moisture content of the pulse flours was around 10% which is suitable for this study as moisture content significantly affects the flowability properties of flour. The wheat flour moisture content was 13.56 % which is typical for commercial wheat flour. The ash content was higher in chickpea flour than yellow pea and lentils. Comparing the protein content among the flours, lentil's protein content was higher (~25 %) while other pulses protein content was around 20%. Chickpea had a very high lipid content (around 6.20 %) than wheat (1.47%), lentil (1.45 %) and yellow pea (1.70%) lipid content. Recent studies have shown that lipid content tends to affect the flow properties of powder significantly (Leturia et al., 2014).

The total carbohydrate showed some differences. The proximate composition obtained in this study was in accordance with those reported by the USDA database (2019) for pulses. The yellow pea flours had the highest total carbohydrate (64 %) in pulses content while the total carbohydrate content of the other pulse flours was around 60%. The total carbohydrate content of the wheat flour was around 74%. The milled lentil and yellow pea flours had higher ash and protein content than the commercial wheat flour used, while they had similar lipid content and lower carbohydrate content. The starch damage increased as smaller-sized pulse flours were created while is a result of extensive processing involved in producing the fine flour.

2.3.2. Bulk properties of pulse and wheat flours

For each grain type, the bulk density increased as the particle size increased (Table 2.3). Large-sized lentil flour had the highest bulk density (0.60 g/cm^3) while all the chickpea flours showed a very low bulk density (< 0.35g/cm^3). This was due to chickpea flour having more air gaps between the particles. Lentil bulk density varied around 0.46 to 0.60 g/cm^3 which was comparable to the wheat flour bulk density (0.56 g/cm^3). The current data suggests that more volume will be required to store or transport yellow pea and chickpea flour than wheat or lentil flours (Nawaz et al., 2015).

The density after tapping also showed higher densities for lentil and yellow pea flours (0.71 – 0.78 g/cm^3). Chickpea flour still showed much smaller tap density (0.58 – 0.60 g/cm^3), implying that its particles were cohesive enough to resist the release of air gaps between the particles during tapping. Chickpea flour showed a very high Carr's compressibility index (40.15 – 45.15%) than lentil and yellow pea flours (23.00 – 38.00%), indicating that chickpea flours are more compressible after tapping since they have more air pockets. These data are also supported by the aeration ratio values (Table 2.4); chickpea flours have more air pockets (higher aeration ratio) than other pulses implying the increased compressibility.

The true density data generally indicate the density of the particles excluding air space. Chickpea flours showed significantly lower true density among the flours tested. Large-sized flours true density were lower compared to small-sized flours. This is due to small-size flours having numerous particles compared to large-sized flours. The small-sized lentil and yellow pea flours were comparable to wheat in regard to true density.

Apart from the particle size that affect the compressibility, lipid content in chickpea flour is another factor leading to the increased compressibility. The study performed by Bian et al.(2015) reported the flow properties of soft and hard wheat flour, showing that soft wheat flour had more compressibility than hard wheat flour. Yet, soft wheat flour had a similar particle size as hard wheat flour, but with a significantly higher lipid content than the hard wheat flour. This study findings support the idea that lipid content was another factor for the compressibility changes observed. The medium and large-sized lentil flours showed similar bulk, tapped density, and Carr's compressibility index properties as wheat flour. Large-sized lentil flour was less compressible among the pulse flours since they showed a lower compressibility index (23 %).

Houssner's ratio (HR) is another important parameter to predict the flow of powder materials. Lower values of Houssner's ratio indicate excellent flowing powders; medium and large-size lentil flour showed lower HR values than other pulse flours indicating that they are better flowing powders compared to smaller-sized lentil flours, yellow pea, and chickpea flours. Chickpea flour had the highest HR values. The wheat flour used in this study had the lowest HR among the flours indicating that the wheat flour is the excellent flowing flour in this study. The combination of HR and Carr's compressibility index are often used to predict powder flowability.

According to Carr's (1965) classification of powders, wheat flour and medium and large-sized lentil flours are classified as passable, large-sized yellow pea flour is poor flowing, while small-sized lentil and medium-sized yellow pea are classified as very poor flowing. All the chickpea flour and the small yellow pea flow are non-flowing. The data from this study suggest that special practices should be considered if incorporating the pulse flours in modern industries.

Referring to the angle of repose to predict the flow, wheat flour and large-sized lentil and medium-sized chickpea flours were classified as very cohesive flours. All other pulse flours were classified as non-flowing flours. The wheat, large lentil, and medium chickpea flours had the angle of repose of 58.75°, 62.95°, and 63.15° respectively, indicating that they are very poor flowing powder per Carr's classification. Other pulse flours were classified as non-flowing powders. As observed earlier, wheat and large-sized lentil flours continue to exhibit better flowing properties than other flours used in this study. In the study conducted on three chickpea varieties by Handu et al (2022), the angle of repose for all was from 41 to 44° which would classify those chickpea flours as easily flowing powder. The observed angle of repose values indicate that the flours used in that study are better flowing than any flour used in this study regarding the angle repose. However, that could have been due to the physical nature of the flour used since they used the hammer mill to reduce the chickpea, and the hammer mill usually produces coarse flours than roller mill used in this research. Large particle-sized flours are often associated with better flowing properties (Jan et al., 2018).This would suggest that hulls can improve the flow properties of chickpea flour.

2.3.3. Dynamic flow properties

Bulk flow data are listed in Table 2.4. Basic flowability energy (BFE) represents the energy required to initiate the powder movement. Lower values indicate powders that require less energy to initial flow. In the current study, the smaller-sized flour for both lentils and yellow peas had significantly lower BFE compared to larger-sized flour, which means that smaller-sized lentil and yellow pea flours require less energy to initiate the movement (Figure A1-A3). Based on this parameter, they are more easily flowing than large-sized flours. The BFE values of chickpea flours were high and not significantly different across different particle sizes, which could have been resulted from the chickpea flour being cohesive. The flour particle size is responsible for the trend observed in yellow peas and lentils. For chickpea, it is believed that the lipid content made the flour to be more cohesive increasing the resistance to the flow hence requiring more energy to flow. The small-sized lentil flour shows a much better flowability (402.52 mJ) than any of the flour tested while the large-sized lentil flour had the worst flowability (953.01 mJ) properties according to the basic flowability energy. It is believed that the high surface area in small-sized flours is responsible for lower BFE observed as the blade would move more particles in a single move in small-sized flours than in large-sized flours. Barreto et al.(2021) also observed lower BFE for fine flour than large-sized teff flour. Comparing pulses to wheat flour, the wheat flow energy is relatable to medium-sized yellow pea and lentil flours (Figure 2.2).

After test 7, the tip speed is reduced, which increased the flow energy required for all the chickpea and yellow pea flour plus the small-sized lentil flour. The increase of flow energy after test 7 usually indicates cohesive flours (Freeman, 2007). This implies that wheat, medium, and large-sized lentil flours showed non-cohesive behavior compared to the chickpea flours.

The stability index (SI) indicates the stability of the flour while flowing. Wheat, medium, and large-sized lentil flours had a lower SI (<1), and that indicates lower stability. Yellow pea, chickpea, and large-sized lentil flours had a SI higher than 1 meaning better flow stability. For yellow pea flours, the differences in particle size did not affect the flour stability index. Lentils and chickpeas showed a decrease in stability index as their size increased. Chickpea flours showed a generally higher stability compared to other grains used in this study. This may arise from a higher lipid content which increased the cohesiveness making the flour more stable. Generally, all the flours in this study are very stable when flowing.

The flow rate index (FRI) is an important parameter to identify the flowability of the flour. FRI shows the flow energy as the tip of the blade speed is reduced. Cohesive flours are more responsive to change in speed, meaning non-cohesive flours have lower FRI values. Among the flour tested, wheat flour, medium and large-sized lentil flours had values below 1 which indicates they are good flowing flours compared to yellow pea and chickpea flour. Regarding FRI, the small-sized lentil flour was considered bad flowing powder.

The aeration ratio indicates how the flour allows fluids to pass through. Usually, cohesive flours have a high aeration ratio. Lentil flours showed non-cohesive behaviors (AeR < 9) while chickpea flour was more cohesive (AeR > 22). Different particle-sized flours of the same grain did not show a significant variation among them. Comparing the pulse flour to the wheat flour used in this study, only lentil flours showed similar properties in aeration to wheat flour, and they all (lentil and wheat flours) show non-cohesive properties which is desired for a production plant. The aeration ratio data was coherent with the amount of energy at maximum aeration (10 mm/s). Wheat flour required less energy (12.45 mJ) while cohesive flour like chickpea required 250 mJ at the same air velocity. This data shows clearly that chickpea is a cohesive flour and lentils are non-cohesive. As noticed for other parameters, this is due to higher lipid content in chickpea which increased the cohesiveness of the flour. Figure 2.3 showed a comparison of medium-sized lentil, yellow pea, and chickpea flour energy consumption with increasing air velocity. The chickpea flour required more flow energy at a higher speed indicating that chickpea flour is a cohesive flour compared to yellow pea and lentil flour which is further supporting evidence of previous data in this study. Generally, non-cohesive powders usually consume little flow energy when the air velocity is high (Freeman, 2007). Differences in particle size flour for each pulse did not show a drastic change in aeration tests (Figure A4-A6).

2.3.4. Bulk flow properties

During the permeability test, the air is passed through the flour at a constant speed and the change in pressure drop on the powder bed is measured. The bigger the change indicates a less permeable powder. In this study, chickpea flour showed more cohesive properties when compared the medium-sized pulse flours (Figure 2.4). Small-sized flours were significantly less permeable compared to medium and large-sized pulse flours; this trend was not observed in chickpea. All the chickpea flours showed no significant difference in permeability among different particle sizes. The permeability test also shows that the medium-sized lentil and yellow pea flours are practically as permeable as wheat flour used in this study. As consistently observed, the lipid content in chickpea flour makes the flour to be cohesive and less permeable.

The compressibility test indicates how the flour is resistant to compression. Compressibility is greatly influenced by the porosity of the flour where more compressible flours have more air gaps (Freeman, 2007). Chickpea flours have shown to be more compressible (Figure 2.5). This can be explained by chickpea flours having the highest aeration ratio (> 22) meaning there was more air space between the flour particles than in other flours used in this study. As explained above, the lipid content of chickpea flour contributed significantly to maintaining the air pockets in the flour which are responsible for high compressibility. Figure 2.5 clearly shows that the compressibility of medium-sized chickpea flour is greater than that of wheat, lentil, and yellow pea flours. Comparing different particle-sized flours of the same grain, small-sized flours of lentil and yellow pea are very compressible than medium and large-sized flour (Figure A7-A9). Wheat flour bulk density was 0.56 g/cm^3 which is comparable to medium-sized lentil and yellow pea flour. This also explains the similarity of compressibility as medium-sized lentil flour. As observed in the above parameters, chickpea flours were not significantly different in compressibility among different particle sizes, and medium-lentil flour is very comparable to the control wheat flour.

2.4. Conclusion

The data from this research shows that chickpea flour is very cohesive and classified as a non-flowing powder. The medium and large-sized lentil flours showed better flowing properties among the pulses, and their properties are very comparable to the wheat flour. The data also shows that chickpea flour is very compressible which is undesired for transportation and storage purposes. It is believed that the high lipid content in chickpea was responsible for the extensive bad flowability properties observed for chickpea flours. Since most industries uses air as flow aid, current data suggest that pulses flours would need more air to flow compared to wheat flour. This would mean that there will be more energy consumption to convey pulse flours in general. There is a need to further study flours flowability for easy comparison as the common source of comparison are industrial which behaves differently from grain flours. There is also a need to study these pulses flours flowability properties when they are aided by other compounds.

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Tables

Table 2.1 Roll gap settings and milling yield different pulse flours

	S Lentil (μm)	M Lentil (μm)	L Lentil (μm)
1st Break (15 Corr./in)	0.025	0.025	0.025
2nd Break (15 Corr./ in)	N/A	N/A	N/A
2nd Break (25 Corr./ in)	0.012	0.012	0.012
3rd Break (25 Corr./ in)	0.006	0.006	0.008
1st Reduction (no Corr.)	0.003	0.004	0.006
2nd Reduction (no Corr.)	0.001	0.003	0.004
Yield (%)	78.97±1.25[b]	81.79±0.56[a]	81.73±2.34[ab]
	S Yellow pea (μm)	M Yellow pea (μm)	L Yellow pea (μm)
1st Break (15 Corr./in)	0.11	0.11	0.11
2nd Break (15 Corr./in)	0.055	0.055	0.055
3rd Break (25 Corr./ in)	0.012	0.012	0.025
4th Break (25 Corr./ in)	0.006	0.008	0.012
1st Reduction (no Corr.)	0.003	0.006	0.008
2nd Reduction (no Corr.)	0.001	0.003	0.003
Yield (%)	82.55±3.12[ab]	84.07±0.98[ab]	86.86±0.74[a]
	S Chickpea (μm)	M Chickpea (μm)	L Chickpea (μm)
1st Break (15 Corr./in)	0.11	0.11	0.11
2nd Break (15 Corr./in)	0.055	0.055	0.055
3rd Break (25 Corr./ in)	0.012	0.012	0.025
4th Break (25 Corr./ in)	0.006	0.008	0.012
1st Reduction (no Corr.)	0.003	0.006	0.008
2nd Reduction (no Corr.)	0.001	0.003	0.003
Yield (%)	84.56±2.98[ab]	84.25±1.23[ab]	86.64±0.54[a]

Corr. – Corrugation, S- Small, M-Medium, L-Large

Table 2.2 Milling yield, particle size, and proximate composition of pulse flours

Sample ID	Moisture (%)	Ash (%)	Protein (%)	Lipid (%)	Total starch* (%)	Total carbohydrate (%)
Control	13.53±0.12 [a]	0.38±0.03 [f]	10.12±0.11[h]	1.47±0.03[b]	68.22±1.23[a]	74.50±0.08 [a]
SL	10.62±0.00[d]	2.16±0.07 [e]	25.66±0.03 [a]	1.45±0.04 [b]	45.71±0.11[b]	60.11±0.11 [e]
ML	10.81±0.02 [c]	2.13±0.03 [e]	25.50±0.03 [a]	1.42±0.07 [b]	45.00±1.18[bc]	60.14±0.08 [e]
LL	10.91±0.05 [c]	2.11±0.00 [e]	25.28±0.03 [b]	1.40±0.11 [b]	46.30±0.46[b]	60.30±0.09 [e]
SYP	10.67±0.02 [d]	2.24±0.01 [d]	21.06±0.00 [e]	1.72±0.15 [b]	39.26±0.18[e]	64.31±0.16 [b]
MYP	10.34±0.01 [e]	2.35±0.02 [c]	21.38±0.06 [d]	1.70±0.04 [b]	45.86±0.84[b]	64.24±0.12 [b]
LYP	11.08±0.00 [b]	2.37±0.02 [c]	21.66±0.03 [c]	1.65±0.01 [b]	44.27±0.95[bcd]	63.24±0.12 [c]
SCP	10.22 ± 0.02 [f]	2.56±0.02 [ab]	19.78±0.16 [g]	6.21±0.05 [a]	40.27±1.53[e]	61.00±0.39 [d]
MCP	9.25 ± 0.01 [g]	2.63±0.1 [a]	20.44±0.00 [f]	6.32±0.00 [a]	41.72±0.13[cde]	61.38±0.03 [d]
LCP	10.40 ± 0.02 [e]	2.53±0.01 [b]	19.63±0.06 [g]	6.45±0.31 [a]	41.57±0.20[de]	61.00±0.39 [d]

Means with different superscript letters within each column denote significant differences ($p<0.05$)
S- Small, M-Medium, L-Large

Table 2.3 Bulk and bulk flow properties of pulses and wheat flours

Sample	Bulk density (g/cm^3)	Tapped density (g/cm^3)	True density (g/cm^3)	Carr's compressibility index (%)	Houssner's ratio	Angle of repose (°)
Wheat	0.56 ± 0.04^{b}	0.72 ± 0.01^{c}	1.46 ± 0.00^{a}	22.17 ± 0.12^{g}	1.28 ± 0.01^{h}	58.75 ± 0.75^{d}
S Lentil	0.46 ± 0.00^{d}	0.71 ± 0.00^{c}	1.46 ± 0.00^{a}	35.05 ± 1.20^{cd}	1.56 ± 0.01^{d}	67.35 ± 0.92^{bc}
M Lentil	0.57 ± 0.00^{b}	0.77 ± 0.00^{a}	1.45 ± 0.00^{b}	24.10 ± 2.55^{f}	1.35 ± 0.01^{f}	71.10 ± 4.38^{ab}
L Lentil	0.60 ± 0.00^{a}	0.78 ± 0.00^{a}	1.45 ± 0.00^{b}	23.00 ± 0.28^{f}	1.30 ± 0.01^{g}	62.95 ± 1.48^{c}
S Yellow Pea	0.45 ± 0.00^{d}	0.72 ± 0.01^{c}	1.46 ± 0.00^{ab}	38.05 ± 0.07^{bc}	1.61 ± 0.01^{d}	77.50 ± 1.13^{a}
M Yellow Pea	0.50 ± 0.01^{c}	0.73 ± 0.00^{bc}	1.46 ± 0.00^{a}	31.30 ± 0.71^{de}	1.47 ± 0.00^{e}	71.25 ± 1.20^{ab}
L Yellow Pea	0.51 ± 0.00^{c}	0.74 ± 0.01^{b}	1.45 ± 0.00^{b}	30.50 ± 0.71^{e}	1.43 ± 0.01^{e}	76.80 ± 2.26^{a}
S Chickpea	0.32 ± 0.01^{g}	0.58 ± 0.00^{e}	1.43 ± 0.00^{d}	45.15 ± 0.35^{a}	1.85 ± 0.03^{a}	66.00 ± 0.99^{bc}
M Chickpea	0.37 ± 0.00^{e}	0.62 ± 0.00^{d}	1.44 ± 0.00^{c}	40.15 ± 0.07^{b}	1.67 ± 0.01^{c}	63.15 ± 1.48^{c}
L Chickpea	0.35 ± 0.00^{f}	0.60 ± 0.00^{e}	1.43 ± 0.00^{d}	41.50 ± 0.71^{ab}	1.72 ± 0.01^{b}	68.00 ± 1.56^{bc}

Means with different superscript letters within each column denote significant differences ($p<0.05$)
S- Small, M-Medium, L-Large
Houssner's ratio classification: Excellent (1.00-1.11); Good (1.12-1.18); Fair (1.19-1.25); Passable (1.26-1.34); Poor (1.35-1.45); Very poor (1.46-1.59); Non-flowing (>1.60)
Carr's index classification: Excellent (<10); Good (11-15); Fair (16-20); Passable (21-25); Poor (26-31); Very poor (32-37); Non-flowing (>38)

Table 2.4 Dynamic flow properties of pulses and wheat flours

Sample	Basic Flowing Energy (mJ)	Stability Index	Flow Rate Index	Aeration ratio	Aerated energy at 10 mm/s (mJ)
Wheat	711.31±5.91[b]	1.04±0.02[a]	0.99±0.04[bc]	2.74±0.14[c]	12.45±2.14[h]
S Lentil	402.52±3.90[c]	1.02±0.01[bc]	1.71±0.02[a]	8.39±0.79[bc]	34.97±1.50[ef]
M Lentil	730.22±28.57[b]	0.97±0.02[cd]	0.93±0.02[e]	3.98±0.17[c]	16.29±2.36[g]
L Lentil	953.01±31.98[a]	0.90±0.00[d]	0.97±0.01[e]	2.01±0.37[c]	36.66±1.82[e]
S Yellow Pea	531.52±27.36[c]	1.02±0.03[bc]	1.66±0.01[a]	11.06±0.14[b]	33.51±0.95[f]
M Yellow Pea	715.42±36.73[b]	1.01±0.01[bc]	1.20±0.01[c]	14.51±2.01[b]	63.14±14.54[d]
L Yellow Pea	790.92±43.36[b]	1.02±0.02[bc]	1.05±0.01[d]	12.13±1.53[b]	99.48±2.54[c]
S Chickpea	802.97±29.82[ab]	1.16±0.01[a]	1.30±0.00[b]	28.62±1.41[a]	254.32±20.25[a]
M Chickpea	790.24±10.01[b]	1.01±0.04[bc]	1.26±0.04[bc]	25.47±3.29[a]	170.18±25.08[b]
L Chickpea	763.93±90.39[b]	1.05±0.01[b]	1.28±0.01[b]	22.75±2.15[a]	250.53±41.83[a]

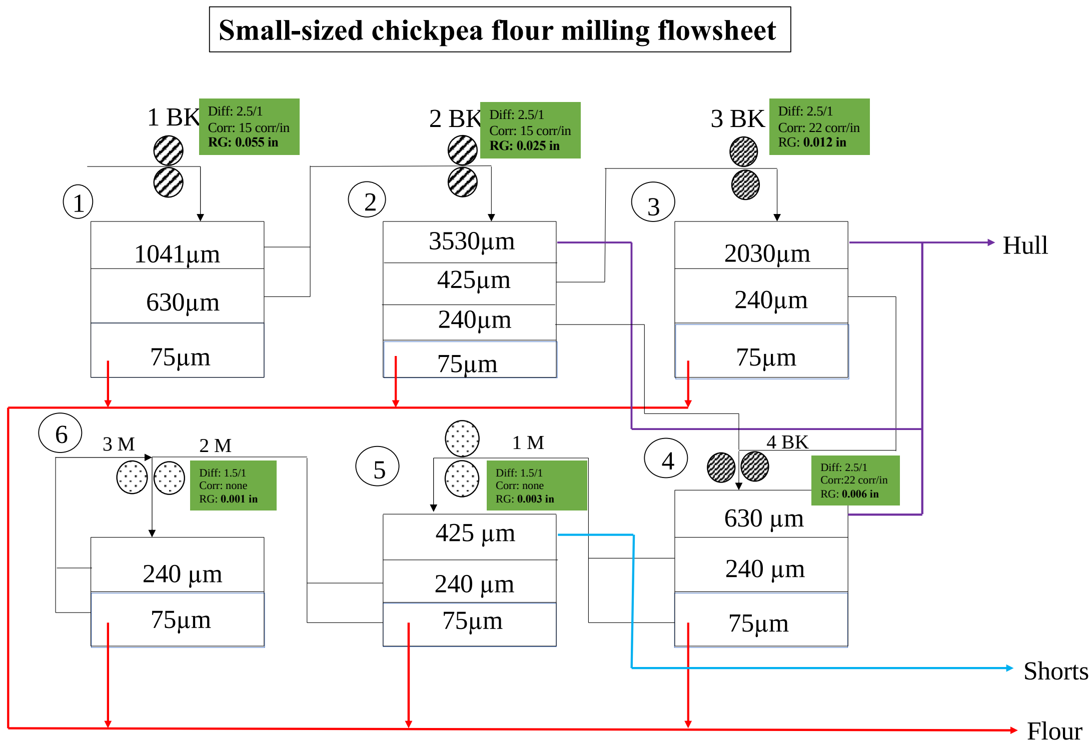
BFE- basic flowability energy; SI- stability index; FRI- Flow rate index

Means with different superscript letters within each column denote significant differences (*$p<0.05$*)

S- Small, M-Medium, L-Large

Figures

Figure 2.1 Milling flow sheet for producing small-sized chickpea flour



Bk- Break rolls; M-Reduction rolls; Corr: Corrugation; RG: Roll gap; Diff: Differential speed

Figure 2.2 Flow energy of medium-sized pulse and wheat flours

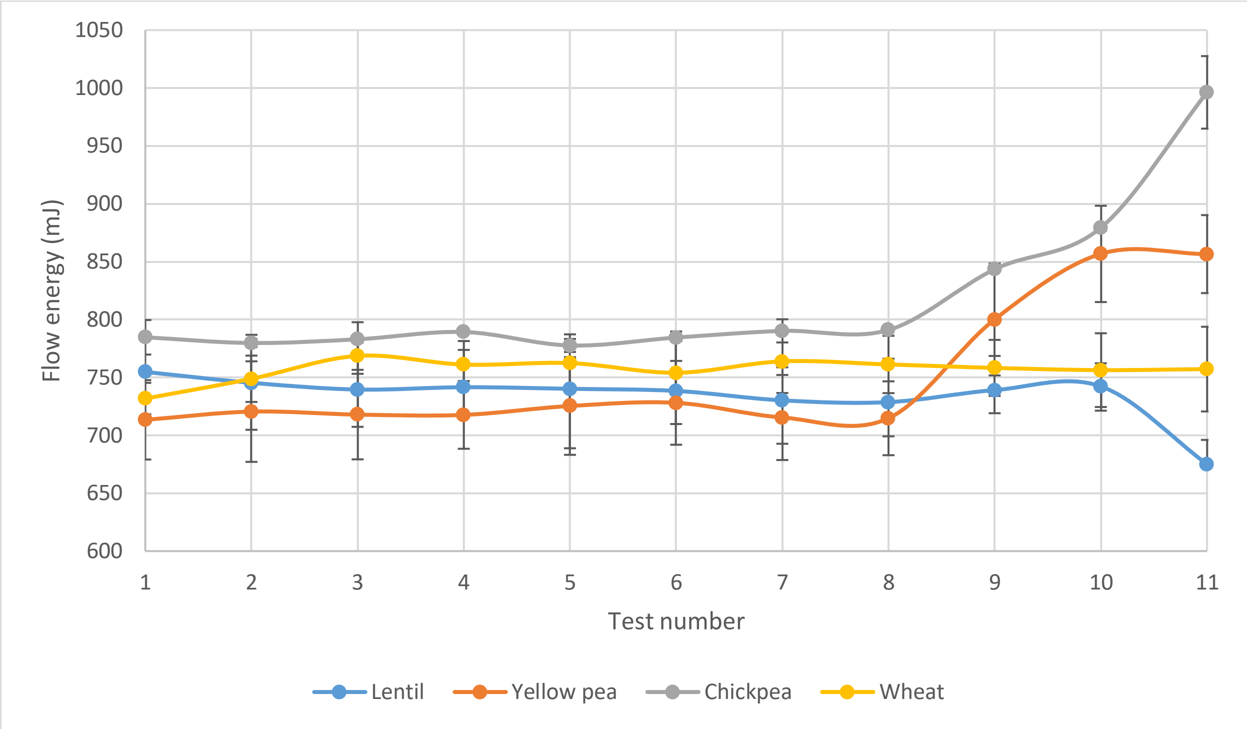


Figure 2.3 Aeration energy at different air speed for medium-sized pulse flours and wheat flour

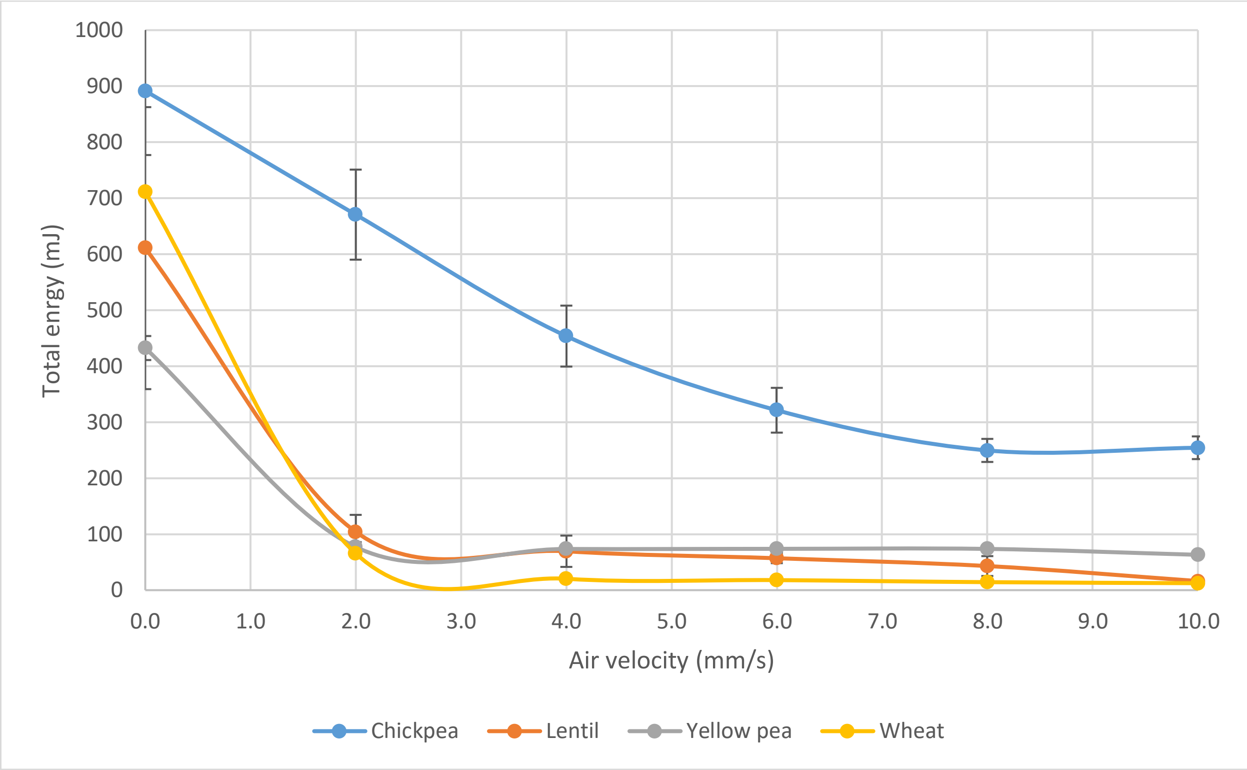


Figure 2.4 Pressure drop across the powder bed as the pressure increases for medium-sized pulse flours and wheat flour

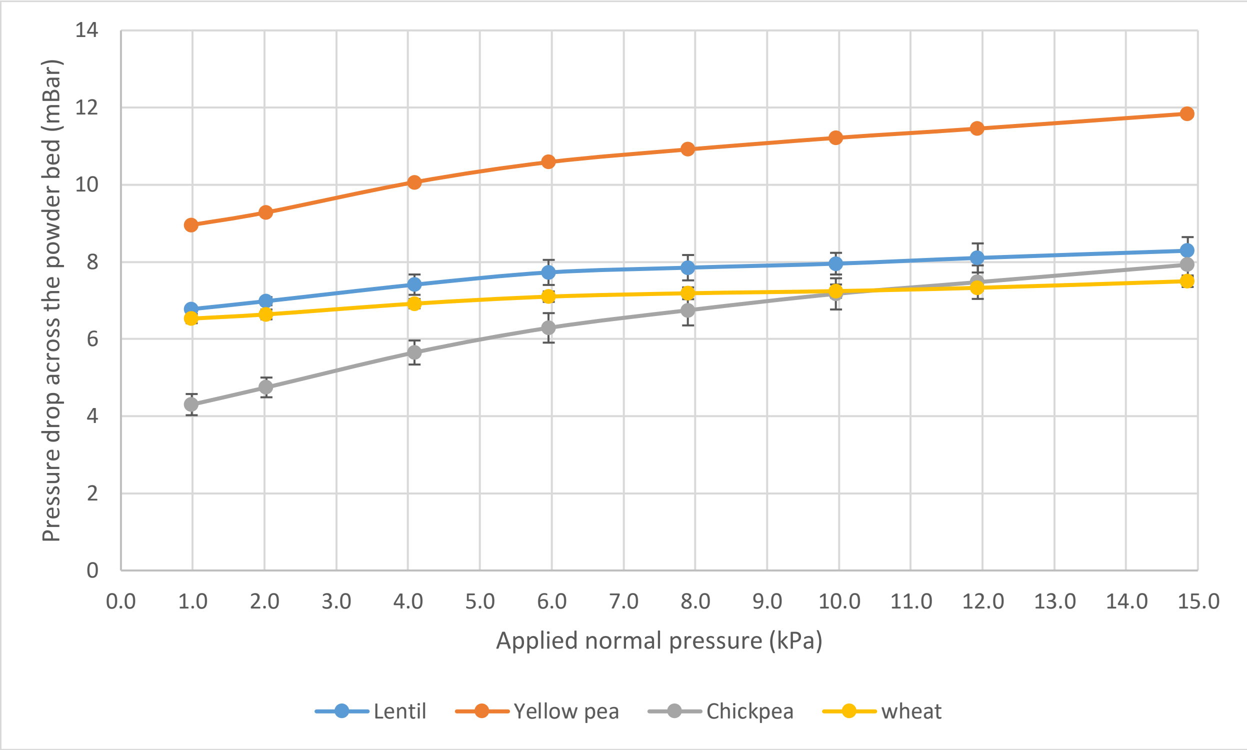
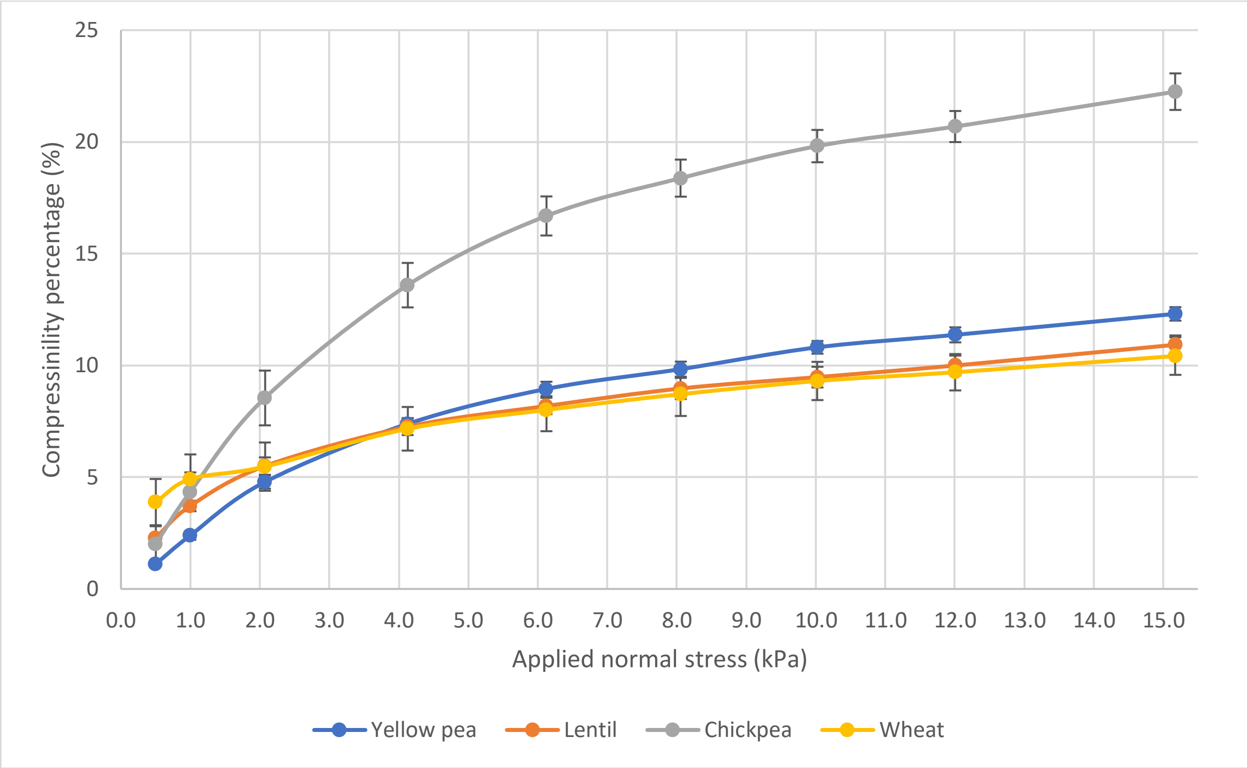


Figure 2.5 Compressibility of medium-sized pulse flours and wheat flour



Appendix A - Supplementary data

SL: Small lentil, ML: Medium lentil, LL: Large lentil, SYP: Small yellow pea, MYP: Medium yellow pea, LYP: Large yellow pea, SCP: Small chickpea, MCP: Medium chickpea, LCP: Large chickpea

Figure A1. Flow energy for yellow pea flours

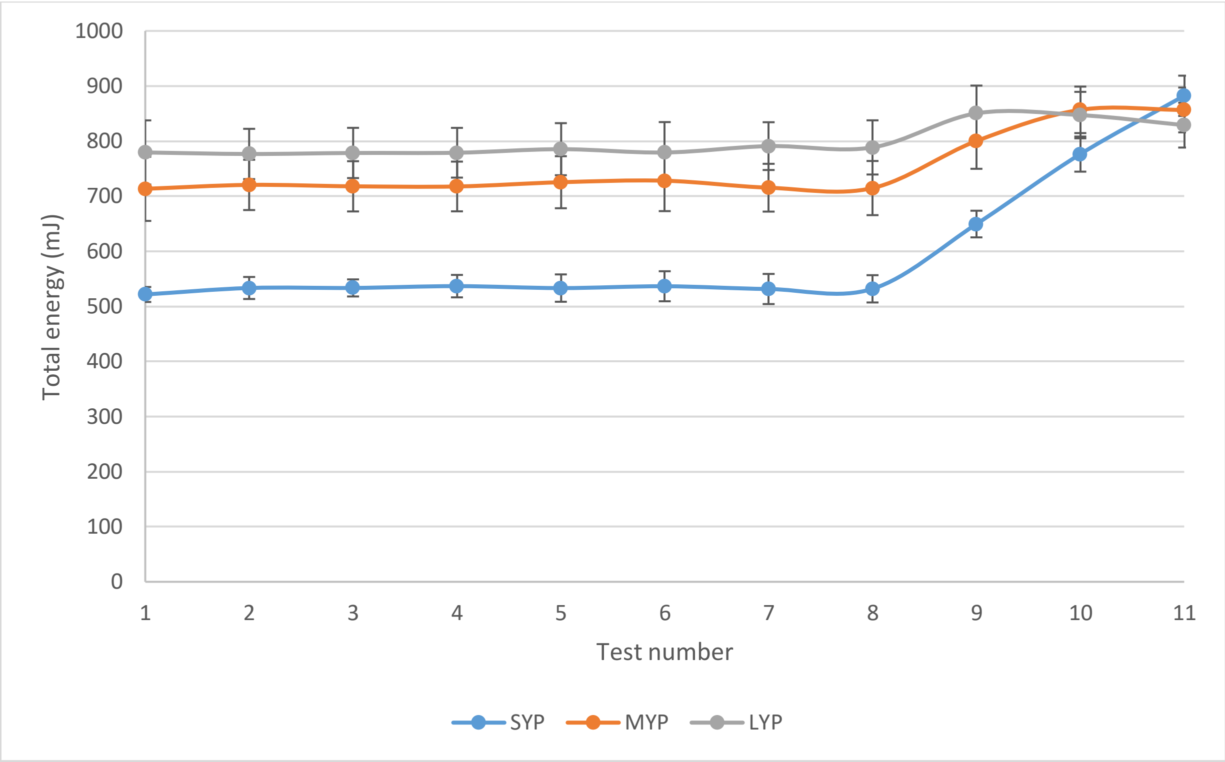


Figure A2. Flow energy of lentil flours

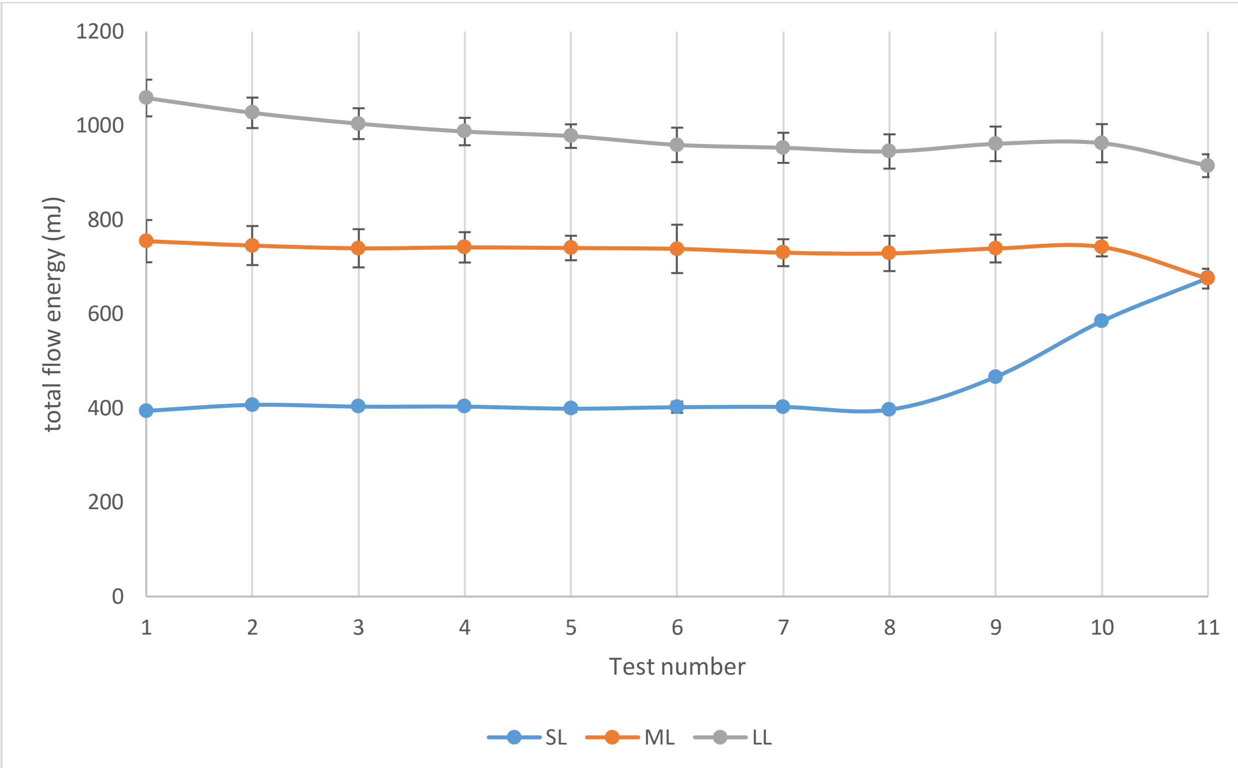


Figure A3. Flow energy for chickpea flours

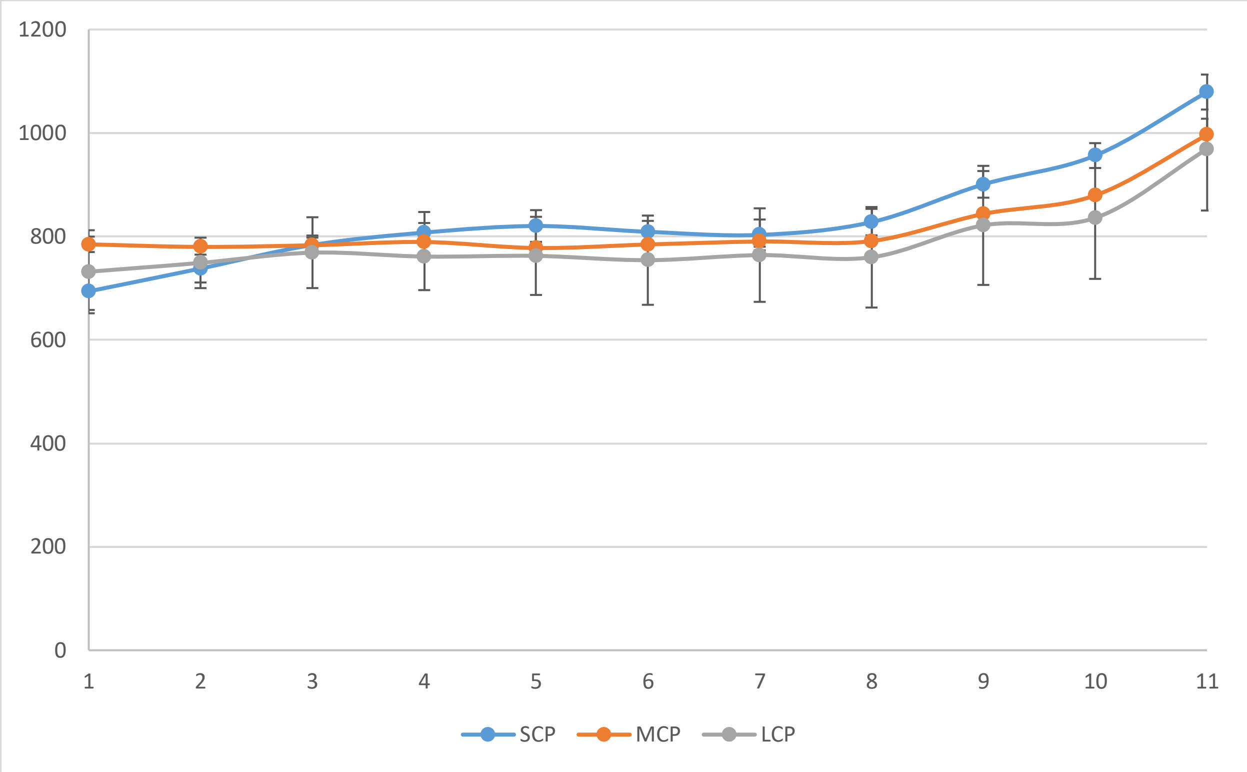


Figure A4. Aeration energy graph for yellow pea flours

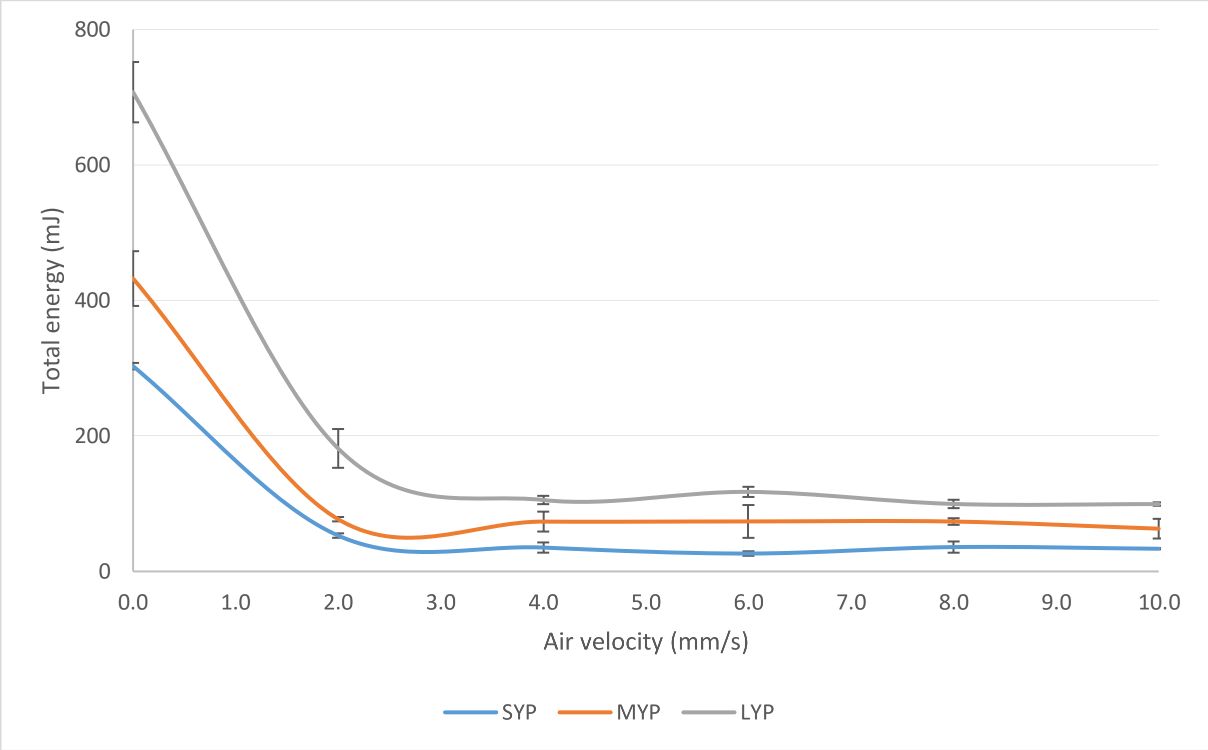


Figure A5. Aeration energy graph for lentil flours

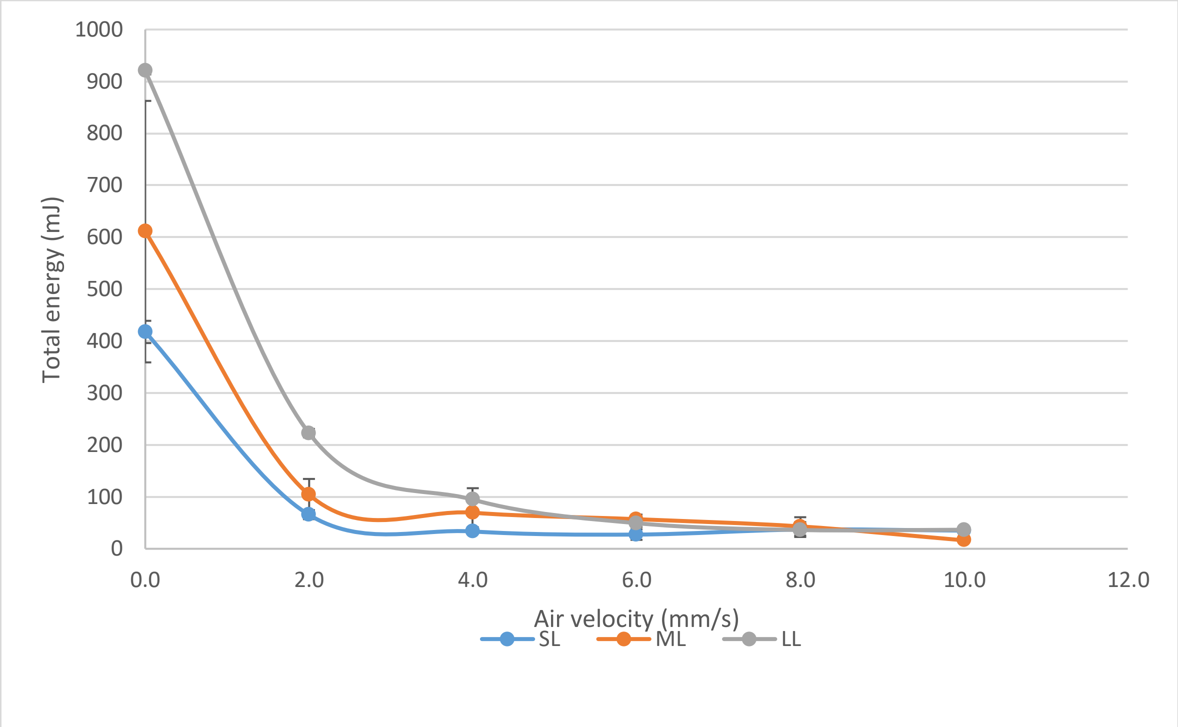


Figure A6. Aeration energy graph for chickpea flours

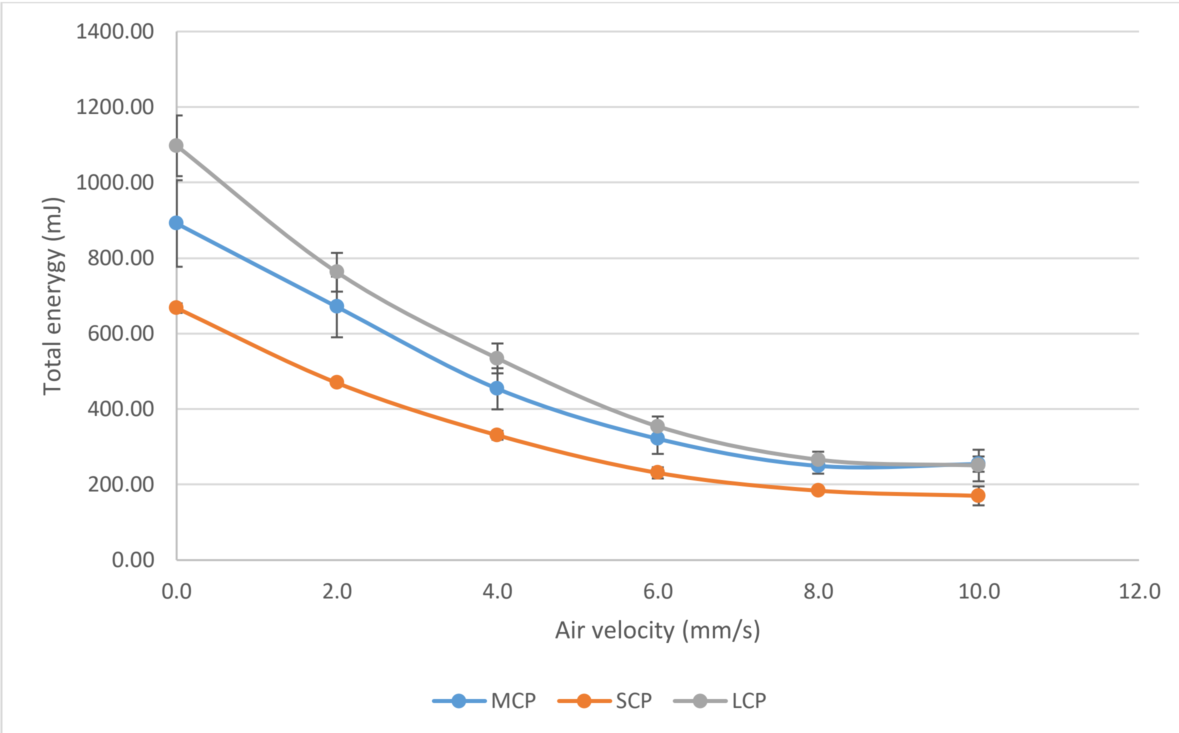


Figure A7. Compressibility of yellow pea flours

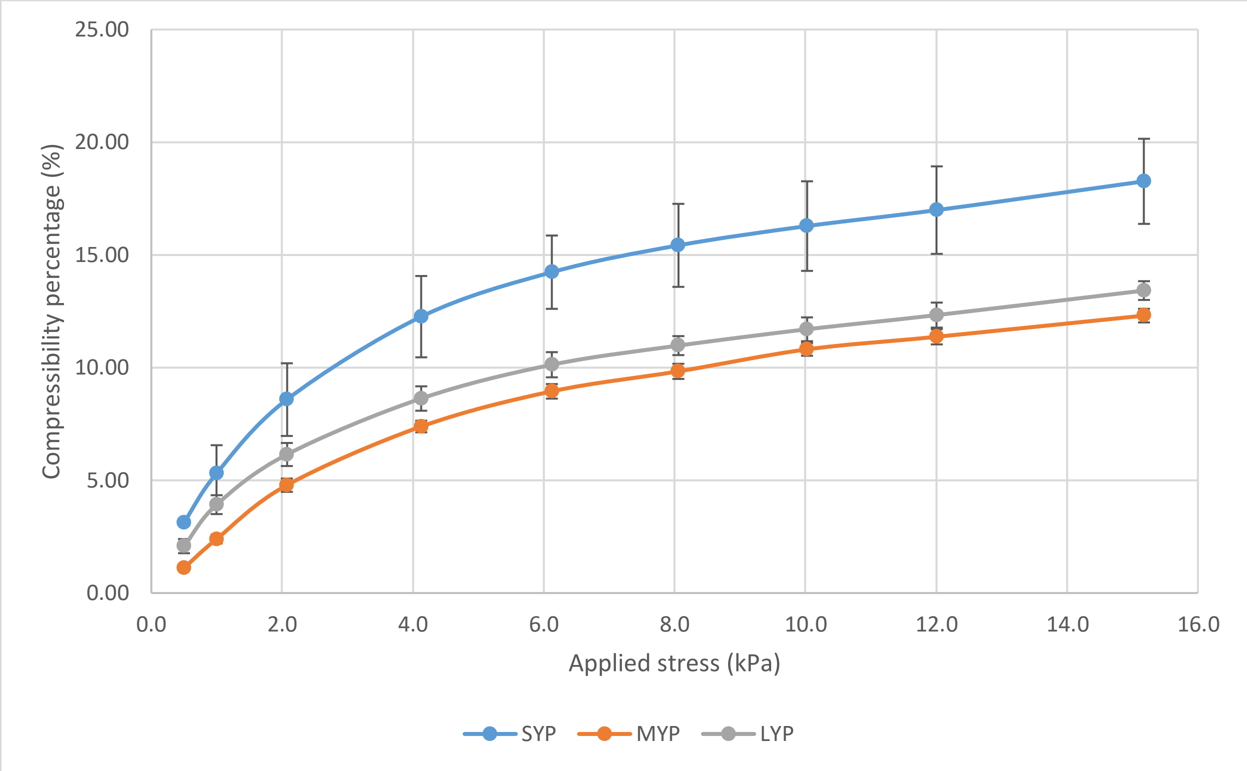


Figure A8. Compressibility of lentil flours

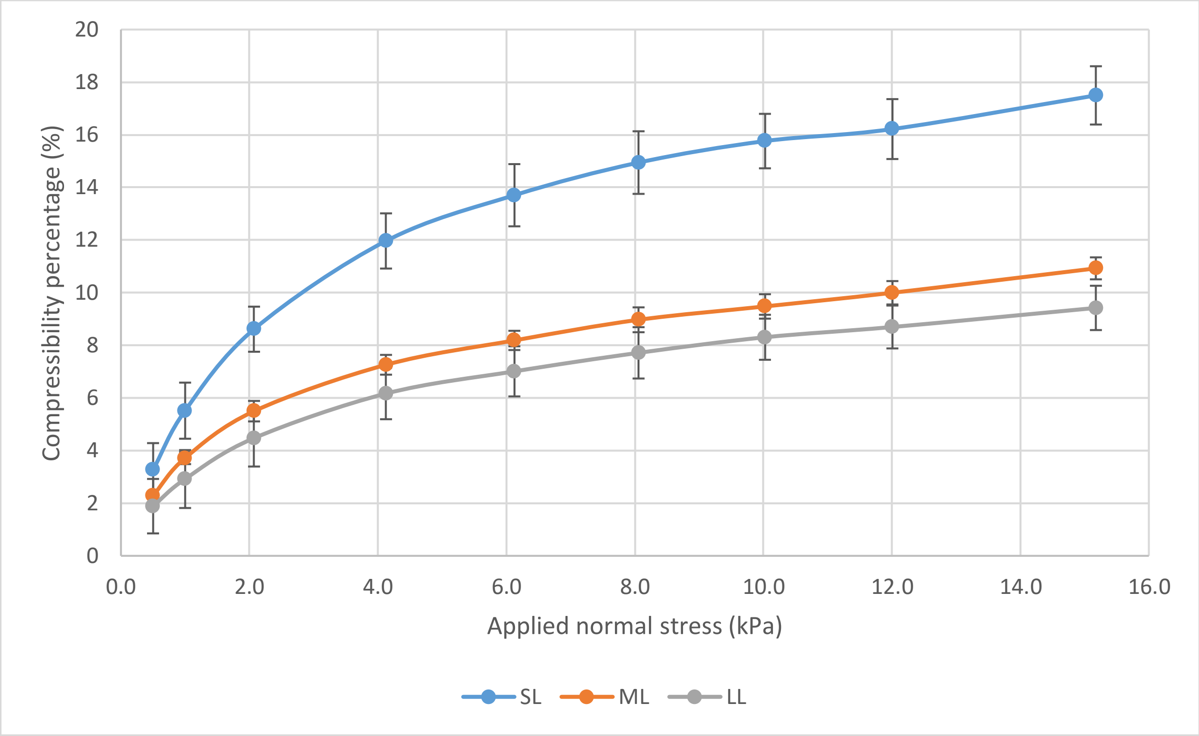
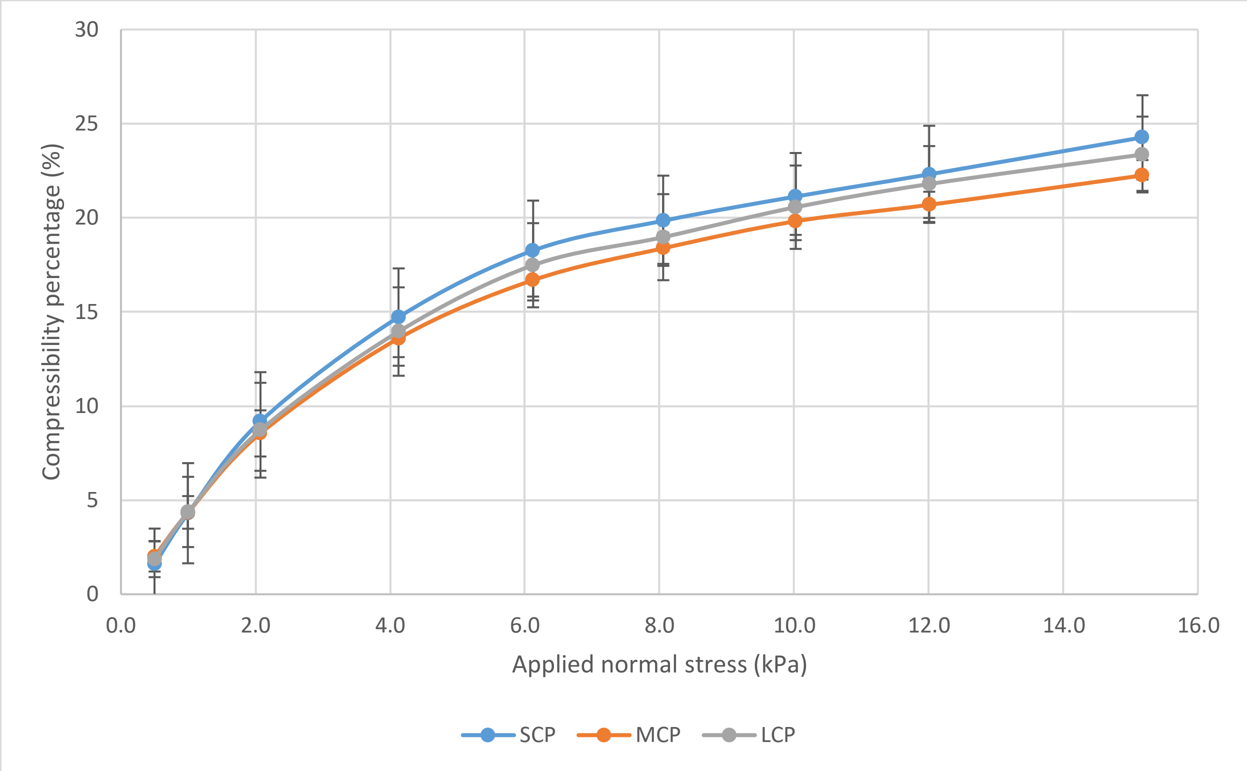


Figure A9. Compressibility of chickpea flours



Chapter 3 - Bread-making properties of varying size pulse flours at different ratios of application in composites with refined wheat flour

Abstract

There has been a growing demand for pulses due to the nutrition, health benefits, and agronomical advantages, along with the recommendation of international organizations to diversify the use of pulses. Lentil, yellow pea, and chickpea were studied for their effect on the quality of the bread when incorporated into refined wheat flour. Pulse grains were roller milled into different particle sizes (S, M, and L), and each refined pulse flour was incorporated in refined wheat flour at levels of 5, 12.5, and 20% (w/w). The flours were characterized for particle size distribution, starch damage, proximate composition, water retention, and dough mixing properties, followed by baking test and texture analysis. The particle size of the pulse flours did not significantly affect the bread volume or the texture, and increasing the pulse flour incorporation decreased the bread volume while the hardness of the bread increased. The crust color darkened as the pulse flour incorporation was increased, while the effect on crumb color was marginable. Among the three pulses, chickpea performed better compared to others, while yellow pea produced bread with lower volume at all levels of incorporation. The incorporation of pulses is optimal at or below 12.5%, and chickpea is more suitable for incorporation. Enriched bread can be produced by incorporating pulse flours at a level of 12.5% (w/w) or lower with a slight specific volume reduction. Chickpeas possess better baking properties than yellow pea or lentil when incorporated into refined wheat flour.

Keywords: Lentil, yellow pea, chickpea, pulses, bread baking, mixograph

3.1. Introduction

Pulses are legumes harvested for their dry grains, and they have been consumed worldwide for a long time (Roy et al., 2010). Pulses rose to worldwide attention when the Food and Agriculture Organization of the United Nations (FAO) declared the year 2016 as the "International Year of Pulses (IYP) (Calles, 2016). Pulses have proven to be sustainable for agriculture by their ability to improve the soil quality compared to common cereals (Uzoh et al., 2019). They are highly nutritious, especially that they are rich in protein, dietary fibers, vitamins and minerals, and other bioactive compounds beneficial to human health. They are also classified as low glycemic index food which makes them healthier than most other cereal grains such as rice and wheat (Jenkins et al., 2012; USDA, 2019). The FAO strongly recommends increased use or incorporation of pulses into the frequently consumed product (FAO FSN Forum, 2016).

Whilst pulses are limiting in amino acids such as methionine and tryptophan, they can complement cereals by providing lysine which is the main limiting amino acid in cereals, hence producing a healthier alternative (Erbersdobler et al., 2017). However, that can be a hard task since pulses lack gluten protein which is crucial for quality bread properties, and they have an off-flavor aftertaste that makes them unfavorable (Setia et al., 2020). Whole wheat bread are always associated with some undesirable bread qualities such as strong flavor, gritty textures, and firm bread and that is the main reason the consumers prefers refined flour for bread production (Tebben et al., 2018). Few studies were done incorporating refined pulse flour into refined wheat flour. A recent study incorporated split pea flour into white pan bread, and acceptable loaves of bread were produced at around 10% (w/w) of incorporation (Paladugula et al., 2021). In another study, different whole pulse flours were incorporated into whole wheat flour; similarly, acceptable whole bread were produced (Zhang et al., 2021). Yet, no study was performed to compare the baking performance of different refined pulses head-to-head in refined wheat flour.

Flour particle size is a crucial factor contributing to the quality of the bread. Previous research does not conclude which particle size is better, and some claimed that the finer particle flour produces better bread attributes, while others contradicted that (De La Hera et al., 2014; Marchini et al., 2021; Wang et al., 2017). There are different approaches to producing flours with different particle sizes, and depending on the method, the functionality of the flour can be affected. One approach is the utilization of different milling equipment or mill settings to produce flours of different particle sizes (Fang & Campbell, 2003; Yu et al., 2018); another approach is to sieve the flour to obtain different fractions with different particle size (Marchini et al., 2021), while the composition could vary. It is crucial to understand the effect of flour particle size when incorporating a novel flour to properly determine the optimum performance of such flour (Borsuk et al., 2012). For better comparison of different particle size, it is always more desirable to have flours of similar proximate composition.

This study aims to investigate the bread-making properties of refined pulse flour when incorporated in refined wheat flour. The specific objectives are to (1) identify the more suitable pulse flour to incorporate in the white pan bread, (2) to determine the optimum level of incorporation, and (3) to evaluate the effect of the pulse particle size on the white pan bread. White bread was chosen for this study because of its prominent consumption, and the pulses used for this study were chosen because they are the common pulses used in the United States and the world in general. This study will benefit scientists in understanding the pulse-wheat interaction during bread making and will contribute to developing healthy and nutritious baked products.

3.2. Materials and methods

3.2.1. Materials

Refined wheat flour (13.59% moisture content; 10.50% protein content) was kindly provided by Ardent Mills (Wichita, KS, USA). Commercial lentil (moisture content 9.25%; protein content 23.69%) and chickpea (moisture content 13.21%; protein content 19.5%) grains were purchased from Food to live online store. Commercial yellow pea grain (moisture content 12.5%; protein content 19.69%) was purchased from D'allesandro gourmet ingredients online store. All other ingredients were purchased from local grocery store.

3.2.2. Milling and characterization of pulse flours

Lentil, chickpea, and yellow pea grains were milled using Ross roller mill (Model 915, Ross Machine and Mill Supply, Oklahoma City, OK, USA) using the same protocol and facilities as described by Pulvarthi et al. (2021). Firstly, the grains were tempered to 13% moisture content. The settings on opening of the rolls and sieves arrangements were set up to produce three flour of different particle sizes, based on preliminary trials. According to roll configuration and sieves arrangement, flours produced from a sieve of 75, 150, and 200 µm on the bottom were named Small (S), Medium (M), and Large (L), respectively. Figures 3.1 shows detailed milling flow sheet of small-sized chickpea flour; the sieve arrangement is also shown. For all the other grains and other particle sizes, the setting details are described in Table 3.1, with the same milling flow. The milling yield was measured using the following equation (1):

$$Milling\ Yield\ (\%) = \frac{Weight\ of\ flour}{Weight\ of\ pulse\ grain}\ X\ 100 \text{ ---- (1)}$$

The milled flours were later analyzed for the particle size distribution using the Alpine Jet sieve (Hosokawa Micron, E200 LS), and Microsoft Excel software was used to plot the graph for particle size distribution; the geometric mean diameter was also calculated to estimate the average particle size of each flour using the following equation (2):

$$d_{gw} = log^{-1}\left[\frac{\sum_{i=1}^{n}(W_i\, log\bar{d}_i)}{\sum_{i=1}^{n} W_i}\right] \text{-------------------------------(2)}$$

d_{gw}: geometric mean diameter

W_i: amount of flour retained on the i^{th} sieve

d_i: aperture size on the i^{th} sieve

n: total number of sieves

Starch damage was measured for all the flours using the SDmatic TM (Chopin Technologies, Villeneuve la Garenne, France) following the AACC76-33.01 method. Ash, protein, and moisture were measured according to the AACC approved method 08-01.01, 46-30.01, and 44-17.01 (Cereals & Grains Association, 1961, 1999, 2003). The lipid content was measured using a modified AACC method 30-10.01. Briefly, the flour samples were mixed in ethyl ether at a ratio of 1:20. The mixture was shaken for 30 minutes and then centrifuged at 3000× g for 10 minutes. The supernatant was collected in tared aluminum pan. The extraction was repeated twice. The pan with the collected liquid were kept in a fume hood over night to evaporate the solvent. The weight of the extracted lipids was measured, and the lipid percentage was calculated. Total starch content was measured following the AACC Approved Method 76-

13.01 (Megazyme Amyloglucosidase/alpha-Amylase Method) (AACC 2000). Total carbohydrates were measured using the difference according to the formula (3) below:

$Total\ carbohydrates\ (\%) = 100 - (Ash + Total\ lipids + Moisture + Protein)$---(3)

3.2.3. Water holding capacity of pulse flours

Water holding capacity of the flours was measured using the modified AACC Method 57-13.01. 1.000±0.01g of flour was measured and transferred in a centrifuge tube, then 5 ml of water was added. The flour was allowed to hydrate for 30 minutes while shaking the tubes at 15 and 25 minutes. The samples were then centrifuged at 1000 × g for 15 minutes. After centrifugation, the tubes were tilted at 45^{o} and allowed to drain for 10 minutes. Water holding capacity (WHC) was then measured using this formula (4):

$$WHC = \frac{(W_3 - W_2) + (W_1 \times m_c)}{(1 - m_c)W_1} \text{ -- (4)}$$

WHC= Water holding Capacity

W_1= weight in grams of the sample before water addition

W_2= weight in grams of the centrifuge test tube

W_3= weight in grams of the test tube and sample after centrifugation and draining

m_c = moisture content of the flour

3.2.4. Mixograph test of composite flours

A 10 g pin mixograph (National Manufacturing Div., TMCO, Inc., Lincoln, NE) was used to conduct the mixograph test of the composite flours. The mixograph was connected to a computer, and MixSmart software was used to analyze the midline of the mixograms. Peak mixing time and torque value were recorded. Mixing tolerance and breakdown tolerance were calculated using the following equations, (5) & (6):

$$Mixing\ tolerance\ (\%) = Ptv\ (\%) - \ xv\ (\%) \quad \text{-------------------------}\ (5)$$

Where:

Ptv - mixograph value at peak time value (%)

xv - mixograph value at “8 minute” (%)

$$breakdown\ tolerance\ (\%) = |(1\ min.bpt - 1min.apt)| \text{-------------}\ (6)$$

1min. bpt - mixograph value 1 minute before peak time (%)

1min. apt - mixograph value 1 minute after peak time (%)

3.2.5. Baking

Pulse flour incorporation was performed at 0 (control), 5, 12.5, and 20% on a total flour weight basis for each particle size (S, M &L) and for each pulse flour, which created a total of 10 different blends for each pulse. Incorporation levels applied were made based on preliminary analysis performed. All the blended flours were baked in triplicate according to 90-minutes fermentation AACC Method 10-10.3. The formulation was comprised of 100 g of flour (14% moisture basis), 2 g of instant dry yeast (SAF instant yeast), 3 g shortening, 6 g sucrose, 1.5 g salt, 0.2 g of malt flour, and an optimized amount of water. Mixograph tests were performed for each incorporation level to determine the water absorption and mixing time. After baking, all loaves of bread were allowed to cool for 2 hours on the cooling racks at room temperature before testing.

3.2.6. Bread specific volume, color, and texture analysis

After cooling, the weight of the bread was recorded, and the bread volume was measured using the rapeseed displacement AACC method 10-05.01; specific volume was measured by dividing the bread volume by the bread weight. The crust color of each bread was measured using the Minolta calorimeter (CR 310, Konica Minolta, Inc., Tokyo, Japan) by measuring three points on the crust. Each bread was sliced into 25 mm thick slices, the crumb color was measured by pointing the colorimeter to three different points on the crumb. The middle slice was used for bread crumb structure analysis using C-Cell Bread Imaging System (Calibre Control International Ltd., Warrington, U.K.); number of cells, cell wall thickness, and cell diameter were recorded.

For texture profile analysis (TPA), the central slices were measured using a TA-XT2i texture analyzer (Stable Micro Systems, Surrey, U.K.) equipped with a 30 kg load cell. Each slice was subjected to a 50% compression at a speed of 1.0 mm/s and trigger speed of 20 g. Texture exponent software was then used to analyze the data.

3.2.7. Statistical analysis

Three replicates of each composite bread including the control were analyzed. Differences in treatment means were determined by analysis of variance (ANOVA) and Tukey-Kramer grouping was used at a significance level of $p < 0.05$ using SAS Online studio (SAS Institute, Cary, North Carolina, USA).

3.3. Results and discussion

3.3.1. Flours proximate compositions

The flour yield values for medium and large particle-sized flours were higher than that of small particle-sized flours (Table 3.2). This could be a result of the utilization of finer sieves and more passed in between the rolls which resulted in more milling losses.

After milling, all flours (S, M, and L) from the same pulse grain showed a similar proximate composition as detailed in Table 3.2. There were some slight differences in moisture content for each flour from the same pulse grain; however, the differences observed were substantially low to alter the properties of the flour. Overall, the refined wheat flour had a significantly higher moisture content (13.53%) compared to all the pulse flour where the moisture content ranged from 9.25 to 11.08%. This difference is due to the tempering process performed on wheat prior to milling. In this study, the targeted tempering moisture content was 13% for pulse grains while it is typically around 15% for bread wheat.

Most of the ash content for flours from the same pulses was not significantly different. Exceptions were seen in small yellow pea flour which had a significantly lower ash content than medium and large-sized flours; another significant difference in ash content was seen between medium and large chickpea. The differences in ash content can be related to milling loss. When the flours passed continuously to produce smaller sized flours, the minerals from the bran fraction were accumulated. Overall, chickpea flours had higher ash content compared to others, and refined wheat flour had the lowest ash content. The difference in ash content between different grains is driven by the different mineral compositions of the sample. The USDA database (2019) shows a similar ash content range as the one obtained in this study.

Lentil flours showed a significantly higher protein content (~25%), followed by yellow peas (~21%), then by chickpea (~20%). Wheat flour had the lowest protein content (10.5%). We observed an increase of protein content in the flour compared to the grain when pulses were milled. This was caused by the removal of seed coat and embryo which have lower protein content than the endosperm when pulse was milled to refined pulse flour. All the pulses had a much higher protein content compared to the wheat flour and in some instances, the pulse protein content doubled the wheat flour content. The availability of more proteins when incorporate into wheat flour increases the nutritional value and economical value of the foods (Teferra, 2021). For lipid content, chickpea flours had significantly higher lipid content (6%) compared to the other flours. However, all the other flours were not significantly different in lipid content. The chickpea lipid content is similar with the that reported in the USDA database (2019). When considering flours for air fractionation into starch and protein fractions, lipid greatly affects the fractionation process by making it almost impossible to separate starch from protein. It was shown that lipid removal can solve that problem of lipid rich flour during fractionation (Sibakov et al., 2011).

The total starch content shows that the refined pulse flours had significantly lower starch content (39 - 45%) when compared to the refined wheat flour (> 68%). Among the pulses, chickpea flour had lower total starch content (~41%) than yellow pea (~44%) and lentil (~45%) flours. The total starch results obtained in this study for yellow pea are consistent with the data reported by Ren et al. (2020). Flours with different particle size showed similar starch content as observed in other proximate composition measured. However, there was an exception for the small-sized yellow pea flour which had significantly lower starch (39%) content than medium and large-sized (45%) flours; it is believed that milling process was responsible diminished starch as observed from the starch damage analysis. The small-sized flour had the highest starch damage.

Total carbohydrate content was determined by the compositional difference, wheat flour had the highest carbohydrate content among all the flours due to the lowest protein content. The total carbohydrate content in yellow pea flours was significantly higher compared to that of chickpea and lentil flours. This carbohydrate content is endorsed by the fact that wheat is considered a high glycemic index food while pulses are lower compared to wheat as reported in the literature (Mirrahimi et al., 2013). The pulse carbohydrates typically have higher amount of amylose compared to normal cereal starches (Singh, 2021), and they are slowly digestible and resistant, making them more desirable to increase dietary fibers in the diet. The consumption of resistant starch can be more beneficial to people with diabetes (Singh, 2017). Particularly, the consumption of pulses is beneficial to people wanting low carbohydrate food as both starch and total carbohydrate content are drastically lower than wheat.

3.3.2. Flour physical properties

All the flour physical properties are reported in Table 3.3. The milling process was able to produce flours with different geometric mean diameters (GMD) from the pulse grains. The average GMD for small, medium, and large lentil flour was 44.8, 85.2, and 104.0 µm, respectively, and 59.2, 70.4, and 96.2 µm for yellow pea flours, and for chickpea flour, the average GMD was 59.7, 74.7, and 95.6 µm, respectively. As intended, small, medium, and large-sized flours were successfully produced for each pulse grain.

Referring to Figure 3.2, the particle size distribution for all the pulses flours shows a bimodal distribution except for the small-sized-lentil flour. The bimodal distribution can be attributed to the quick release of fine protein-starch aggregates that that contributed to the first peak, and the second peak was a result of gradual reduction of the remaining bigger starch-protein aggregates. Pulvarthi et al.(2021) reported the same distribution when pulses were ground. The unimodal distribution observed in small-sized lentil flour is believed to be the result of longer processing that caused most of the particles to be very fine.

Starch damage in the flours differed among different pulse grain types and particle sizes as detailed in Table 3.3. The yellow pea flours showed significantly higher starch damage (9.05%) followed by lentil (6.32%) and then chickpea (3.28%). The control refined wheat flour used in this study had a starch damage of 6.93%. The flours of the same grain with different particle sizes showed variation in starch damage. The smaller particle-sized flours for each pulse always had significantly high starch damage compared to the medium and large-sized flour. To produce fine flour, the passes through rolls were increased significantly compared to producing medium and large-sized flours. The increase of passes between rolls extensively damaged the starch granules, resulting in high starch damages among small-sized flour than other flours.

As shown in Table 3.3, The water holding capacity (WHC) of pulse flours across different particle sizes was not significantly different, except that the small-sized lentil flour had a significantly higher water holding capacity than the medium and large-sized lentil flours. According to Barak et al (2014), as the particle size reduces, the water absorption increase. This phenomenon is due to increased surface area when particles are smaller. It is also affected by the starch damage where high starch damage increases WHC. This trend was not observed in yellow pea and chickpea flours due to a small difference in small and medium or large-sized flour. In lentils, the difference was around 41 µm while it was 11 µm in yellow and chickpea. It is believed that that small difference in particle size resulted in not observing a significant difference in water holding capacity.

The milling process affected the color of the flours as well. The L* (0 black, 100 white) value which represents the lightness, decreased significantly with the increase of the particle size for lentil and yellow pea flour, but was not different for the chickpea flours. The a* value which represents the hue (+a* is for a reddish while -a* value shows the greenish), differences were only observed in lentil flour only. The small-sized flours a* values were significantly lower compared to medium and large-sized flours. The b* value that represent the yellowness when positive (+) and blueness when negative (-) showed differences in the lentil flours only. The small sized flour had a lower yellowness value compared to medium and large. The above color changes indicate that small and medium-sized lentil and yellow pea flour were much lighter compared to the large-sized flour. The changes were only observed in lentils since the grain pigmentation (red) is very different from other grains (yellow and cream). The increased lightness in small-sized flour is related to more breakdown of starches that increased the lightness of the flour. These observations were similarly noticed in the study done by Pulivarthi et al. (2021).

3.3.3. Mixograph properties of the composite flours.

As shown in Table 3.4, during the mixograph test, absorption was reduced gradually as the pulse incorporation level increased. This was caused by the gluten dilution which made the system to be very sticky and produced unreliable data before absorption reduction. There was no effect of pulse flour addition to the peak generally. However, the exception was observed when medium-sized lentil flour was added at a 5% level which reduced the mixing significantly. Another exception was when chickpea flour at 20% level was incorporated in the refined wheat flour, the peak time increased significantly. This might be caused by the chickpea flour absorbing water hence delaying the hydration of the whole system, finally causing the delay in reaching the peak. That delay was also shown at the peak value where the peak value was also significantly reduced. For other flours, the peak value was not affected by pulse flour incorporation. The peak width value decreased when the incorporation level was around 20% for all the pulses. The excessive substitution was the reason behind the peak width value reduction because pulses are gluten-free flour, and they don't contribute to dough's viscoelasticity like wheat does. The 8-minute value represents the curve tail. The curve tail value was only affected when 20% of all yellow pea flour (S, M, and L) were incorporated. They significantly reduced the curve tail. The curve tail width was not affected by any pulse flour incorporation. The integral which represents the general strength of the dough was only affected by the incorporation of large-sized yellow pea flour. The mixing tolerance depicts how stable the flour stays with continued mixing, and it is the change between the peak and the curve tail. Lower values indicate better dough stability. There was a slight mixing tolerance reduction when chickpea flour was incorporated at 5 and 12.5 %, and this could be beneficial since the dough will tolerate excessive mixing. On the other hand, 20% of yellow pea flour incorporation increased the mixing tolerance value significantly which also means that they weakened the dough. Breakdown resistance measures how the dough strength changes before and after reaching the peak mixing time. This was not affected by any pulse flour incorporation.

3.3.4. Bread physical properties

The control refined wheat flour used in this study produced bread of a specific volume of around 5 cm^3/g. That specific volume is lower compared to the bread (6 cm^3/g) reported by Paladugula et al. (2021), where they used a higher protein content wheat flour (14%); however, the specific volume of the control flour used in this study is still acceptable regarding the use of a low protein content flour (10%). Typically, low protein flour produces bread with smaller volume (Thanhaeuser et al., 2014).

The particle size of the pulse flours had no significant effect on the specific volume of the pulse/wheat blend bread (Figure B1), except for yellow pea flour at incorporation of 20% (w/w) where small-sized yellow pea flour produced bread with significantly smaller specific volume (3.22 cm^3/g) compared to the medium and large particle sized yellow pea (3.51cm^3/g). Bourré et al. observed no effect of the particle size on the final bread specific volume when refined pulse flour are blended with refined wheat flour (2019). Flours of different particle size producing the bread of a similar volume can be attributed to the flours having similar WHC since WHC have a significant effect on the bread volume (Kotoki & Deka, 2010). Li et al. (2012) observed that medium flour (97 µm) produced better quality bread compared to small (50 µm) and large (235 µm) whole wheat flours. They could have observed the effect due to extent in particle size differences (185 µm) and greater effect from the bran particles; in this current study the difference was much lower (41 µm).

Increased incorporation of pulse flours significantly reduced the bread-specific volume. The decreased volume can be linked to the substitution of wheat flour with gluten-free flours which reduced the gluten content of the system and further reduced the loaf's specific volume. Multiple studies have got a similar observation of the specific volume decrease with increased pulse incorporation (Dhingra & Jood, 2002; Turfani et al., 2017; Zhang et al., 2021).

At every level of incorporation, chickpea blends bread had higher specific volume compared to lentil and yellow pea blends bread. At 5% (w/w) of incorporation, chickpea blend bread's specific volume was very comparable to the control bread (Figure B2). No other literature was done to compare chickpea, lentil, and yellow pea blended in refined wheat flour. However, the study conducted by Zhang et al. (2021) found no significant difference in specific volume when whole pulse flours were incorporate in whole wheat flour. It is believed that the effect of the pulses was not observed because of the presence of hull, bran, and fibers that cause the bread not to expand very much.

Table 3.5 shows the detailed C-cell analysis while Figure 3.3 shows the slice C-cell images. The number of bread cells reduced as the pulse flour incorporation level increased. This is due to the reduced bread volume observed as well. The area of the cell also followed the same trend where a gradual decrease was observed as the bread's specific volume decreased; however, the wall thickness of the bread cell did not significantly change. The cell diameter was not significantly different from the control except when the pulse flours were incorporated at 20% (w/w).

The texture of the bread produced with the pulse-wheat blend was affected as well. An increase in hardness was observed as the incorporation level increased; however, there was no significant influence of pulse particle size on the hardness of the bread at the same level of incorporation. Interestingly, at a higher incorporation level (20%), Chickpea produced softer bread compared to lentil and yellow pea (Figure B3). The increase in hardness pattern is due mainly to the shrinking of the bread cells which in effect condense the bread structure making the bread firmer. Paladugula et al. (2021) observed a comparable trend.

The texture profile analysis results are detailed in Table 3.6. There were no major differences in adhesiveness, resilience, cohesion, springiness, and gumminess; but the chewiness increased significantly as the incorporation level of pulse flours increased. This is related to the hardness profile of the bread.

Furthermore, the incorporation influenced the crust and crumb color. Table 3.7 shows the crust and crumb color observed as pulse flours are added in refined wheat flour. The crust became darker (L* value) as the incorporation increased while the hue (a* value), yellowness and blueness (b* value) was not significantly different. Among the pulses used in this study, the chickpea darkening effect on the bread crust's color was minimal compared to lentil and yellow pea. Chickpea incorporated at 20% crust color was similar to lentil and yellow pea incorporation at 12.5% portraying that the chickpea darkening effect was minimal. The general darkening effect of pulse addition is believed to result from an increased rate of Maillard reactions as the pulses have a higher protein content which will impact the rate of Maillard reaction. Zhang et al. (2021) similarly observed the crust darkening effect when pulse flour was added to whole wheat flour

For the crumb color, there was no significant difference in crumb lightness except when lentil or yellow pea flour were incorporated at levels of 20% (Figure 3.3). At all incorporation levels, chickpea incorporated bread showed a lighter crumb than other pulse incorporated bread crumb. There was a meaningful difference between the control and pulse incorporation where the control had a more reddish (negative values) color while all pulse incorporated bread showed a more greenish crumb color (positive values) in general.

3.4. Conclusion

The substitution of refined wheat flour with refined pulse flour reduced the specific volume of the bread. Among all the pulses utilized in this study, chickpea led to better baking properties compared to yellow pea and lentil at all levels of incorporation. The addition of pulse flour darkened the crust of the bread. There was no effect of pulse flour particles on the quality of the bread except for the small-sized yellow pea flour that produced significantly smaller bread compared to medium and large-sized yellow pea flour when incorporated at 20% (w/w). The incorporation of pulse flours at 12.5% produced bread with comparable properties to the control. The results of this study suggest a future study to understand the properties of chickpea that influenced the baking properties since chickpea flour produced better bread compared to lentil and yellow pea flour. The sensory study is also recommended to assess the consumer acceptability of the pulse-wheat composite bread.

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Tables

Table 3.1 Roll gap setting for different pulse flours

	S Lentil (μm)	M Lentil (μm)	L Lentil (μm)
1st Break (15 Corr./in)	0.025	0.025	0.025
2nd Break (15 Corr./ in)	N/A	N/A	N/A
2nd Break (25 Corr./ in)	0.012	0.012	0.012
3rd Break (25 Corr./ in)	0.006	0.006	0.008
1st Reduction (no Corr.)	0.003	0.004	0.006
2nd Reduction (no Corr.)	0.001	0.003	0.004
Yield (%)	78.97±1.25^{b}	81.79±0.56^{a}	81.73±2.34^{ab}
	S Yellow pea (μm)	M Yellow pea (μm)	L Yellow pea (μm)
1st Break (15 Corr./in)	0.11	0.11	0.11
2nd Break (15 Corr./in)	0.055	0.055	0.055
3rd Break (25 Corr./ in)	0.012	0.012	0.025
4th Break (25 Corr./ in)	0.006	0.008	0.012
1st Reduction (no Corr.)	0.003	0.006	0.008
2nd Reduction (no Corr.)	0.001	0.003	0.003
Yield (%)	82.55±3.12^{ab}	84.07±0.98^{ab}	86.86±0.74^{a}
	S Chickpea (μm)	M Chickpea (μm)	L Chickpea (μm)
1st Break (15 Corr./in)	0.11	0.11	0.11
2nd Break (15 Corr./in)	0.055	0.055	0.055
3rd Break (25 Corr./ in)	0.012	0.012	0.025
4th Break (25 Corr./ in)	0.006	0.008	0.012
1st Reduction (no Corr.)	0.003	0.006	0.008
2nd Reduction (no Corr.)	0.001	0.003	0.003
Yield (%)	84.56±2.98^{ab}	84.25±1.23^{ab}	86.64±0.54^{a}

Corr. Corrugation

S- Small, M-Medium, L-Large

Table 3.2 Flours proximate composition

Sample ID	Moisture (%)	Ash (%)	Protein (%)	Lipid (%)	Total starch* (%)	Total carbohydrate (%)
Control	13.53±0.12 ^{a}	0.38±0.03 ^{f}	10.12±0.11^{h}	1.47±0.03^{b}	68.22±1.23^{a}	74.50±0.08 ^{a}
SL	10.62±0.00^{d}	2.16±0.07 ^{e}	25.66±0.03 ^{a}	1.45±0.04 ^{b}	45.71±0.11^{b}	60.11±0.11 ^{e}
ML	10.81±0.02 ^{c}	2.13±0.03 ^{e}	25.50±0.03 ^{a}	1.42±0.07 ^{b}	45.00±1.18^{bc}	60.14±0.08 ^{e}
LL	10.91±0.05 ^{c}	2.11±0.00 ^{e}	25.28±0.03 ^{b}	1.40±0.11 ^{b}	46.30±0.46^{b}	60.30±0.09 ^{e}
SYP	10.67±0.02 ^{d}	2.24±0.01 ^{d}	21.06±0.00 ^{e}	1.72±0.15 ^{b}	39.26±0.18^{e}	64.31±0.16 ^{b}
MYP	10.34±0.01 ^{e}	2.35±0.02 ^{c}	21.38±0.06 ^{d}	1.70±0.04 ^{b}	45.86±0.84^{b}	64.24±0.12 ^{b}
LYP	11.08±0.00 ^{b}	2.37±0.02 ^{c}	21.66±0.03 ^{c}	1.65±0.01 ^{b}	44.27±0.95^{bcd}	63.24±0.12 ^{c}
SCP	10.22 ± 0.02 ^{f}	2.56±0.02 ^{ab}	19.78±0.16 ^{g}	6.21±0.05 ^{a}	40.27±1.53^{e}	61.00±0.39 ^{d}
MCP	9.25 ± 0.01 ^{g}	2.63±0.1 ^{a}	20.44±0.00 ^{f}	6.32±0.00 ^{a}	41.72±0.13^{cde}	61.38±0.03 ^{d}
LCP	10.40 ± 0.02 ^{e}	2.53±0.01 ^{b}	19.63±0.06 ^{g}	6.45±0.31 ^{a}	41.57±0.20^{de}	61.00±0.39 ^{d}

Means with different superscript letter within each column denote significant differences ($p<0.05$)

Control: Commercial refined wheat flour, SL: Small lentil, ML: Medium lentil, LL: Large lentil, SYP: Small yellow pea, MYP: Medium yellow pea, LYP: Large yellow pea, SCP: Small chickpea, MCP: Medium chickpea, LCP: Large chickpea

Table 3.3 Flours physical properties

Sample ID	L*	a*	b*	WHC (%)	GMD(μm)	Starch damage (%)
CONTROL	104.82±1.66[a]	0.20±0.08[c]	14.69±0.13[f]	66.20±1.34 [c]	62.59±0.49[f]	6.93± 0.58 [b]
SL	89.30±0.75 [de]	10.36±0.11 [b]	31.37±0.15 [b]	85.80±1.36 [b]	44.82±0.06 [h]	6.32±0.21 [bc]
ML	86.96±0.78 [f]	13.44±0.20 [a]	36.39±0.33 [a]	68.23±2.10 [c]	85.17±0.62 [c]	3.81±0.44 [d]
LL	84.99±0.66 [f]	13.50±0.68 [a]	36.00±0.92 [a]	65.43±1.83 [c]	103.99±0.44 [a]	3.13±0.09 [f]
SYP	93.56±0.44 [b]	-0.29±0.22 [cd]	27.07±1.16 [e]	101.86±0.95 [ab]	59.21±0.08 [g]	9.05±0.28 [a]
MYP	92.84±0.60 [b]	-0.37±0.11 [cd]	28.07±0.25 [cde]	106.83±0.92 [a]	70.42±0.28 [e]	7.10±0.02 [b]
LYP	90.53±0.30 [de]	-0.56±0.04 [cd]	27.66±0.25 [de]	101.25±0.63[ab]	96.18±0.66 [b]	5.90±0.66 [c]
SCP	92.41±0.65 [bcd]	-0.57±0.27 [cd]	29.36±0.94 [cd]	88.57±6.82[b]	59.66±0.09 [g]	3.28±0.04 [e]
MCP	92.33±0.22 [bcd]	-0.74±0.22 [c]	29.10±0.23 [cd]	87.73±6.80[b]	74.69±0.83 [d]	3.06±0.03 [f]
LCP	90.98±0.26 [cde]	-0.48±0.04 [cd]	29.65±0.14 [bc]	86.01±11.78 [b]	95.58±0.20 [b]	2.83±0.13 [g]

Means with different superscript letters within each column denote significant differences ($p<0.05$)

WHC: Water holding capacity, GMD: Geometric mean diameter, Control: Commercial refined wheat flour, SL: Small lentil, ML: Medium lentil, LL: Large lentil, SYP: Small yellow pea, MYP: Medium yellow pea, LYP: Large yellow pea, SCP: Small chickpea, MCP: Medium chickpea, LCP: Large chickpea

Table 3.4 Midline analysis of the mixograms from different pulse/wheat blend flours.

Sample	Absorption (%)	Peak time (min.)	Peak value (%)	Peak width (%)	8 min. value (%)	8 min. width (%)	8 min. integral %*min	Mixing tolerance (%)	Breakdown resistance (%)
Control	61	3.92±0.28	34.53±1.03	15.73±0.09	30.71±2.34 ^{a}	12.83±0.97 ^{a}	232.12±3.02	3.82±1.31	1.40±1.00
5% SL	61	3.24±0.02	37.23±0.21^{a}	22.48±0.98	32.49±0.30 ^{a}	12.54±0.24 ^{a}	255.85±2.11	4.74±0.08	3.53±0.15
5% ML	61	3.13±0.04 ^{f}	35.44±0.03	24.05±0.43^{a}	31.64±0.14 ^{a}	11.48±0.06 ^{a}	251.49±1.58	3.80±0.11	2.67±0.62
5% LL	61	4.15±0.10	33.36±0.94	15.70±0.82	30.03±0.55 ^{a}	11.55±1.14 ^{a}	236.63±1.23	3.33±0.39	0.45±0.00
12.5% SL	60	3.61±0.08	35.78±0.54	20.31±0.08	30.80±0.03 ^{a}	13.61±0.18 ^{a}	250.93±2.36	4.98±0.57	0.67±0.26
12.5% ML	60	3.66±0.02	33.93±0.07	17.09±0.11	29.79±0.04 ^{a}	12.45±0.22 ^{a}	240.24±0.08	4.14±0.03	0.67±0.52
12.5% LL	60	3.72±0.25	35.53±0.26	19.58±0.91	30.37±0.18 ^{a}	12.59±0.17 ^{a}	242.65±0.37	5.16±0.08	1.23±1.15
20% SL	59	4.28±0.02	33.75±0.14	16.46±0.87	28.81±0.57^{ab}	12.20±0.16 ^{a}	232.03±1.51	4.94±0.71	0.46±0.24
20% ML	59	4.27±0.05	32.31±0.37	15.40±0.22^{h}	27.57±0.48^{ab}	11.24±0.67 ^{a}	217.74±3.12	4.73±0.11	0.93±0.20
20%LL	59	4.26±0.20	33.48±0.44	16.74±1.03	27.09±2.19^{ab}	10.09±1.36 ^{a}	226.61±4.60	6.39±2.63	0.94±0.12
5% SYP	61	3.43±0.19	36.82±0.78	22.88±0.48	32.58±0.48 ^{a}	13.84±1.20 ^{a}	257.07±8.97^{a}	4.24±1.26	2.65±0.47
5% MYP	61	4.11±0.35	33.36±1.37	16.41±1.09	31.14±1.25 ^{a}	12.26±1.09 ^{a}	236.69±11.46	2.22±0.34	0.39±0.50
5% LYP	61	4.32±0.12	33.49±0.27	16.31±0.49	31.50±0.00 ^{a}	13.53±0.00 ^{a}	239.08±0.59	1.99±0.28	0.21±0.31
12.5% SYP	60	3.93±0.05	32.25±0.59	17.11±1.19	29.62±0.52 ^{a}	13.15±0.57 ^{a}	228.66±2.88	2.63±0.10	0.17±0.09
12.5% MYP	60	3.95±0.09	33.40±0.24	16.57±0.21	30.22±0.61 ^{a}	12.30±0.38 ^{a}	235.58±1.22	3.18±0.38	0.40±0.40
12.5% LYP	60	3.87±0.42	34.08±0.77	18.94±1.56	28.41±0.99^{ab}	11.82±1.67 ^{a}	234.31±6.70	5.67±1.66	1.49±0.20
20% SYP	59	3.93±0.04	31.97±0.58	16.68±1.15	22.64±3.94^{bc}	11.38±1.58 ^{a}	217.66±3.64	9.33±4.33	0.40±0.30
20% MYP	59	4.35±0.41	33.44±0.96	17.15±1.54	19.44±1.55^{cd}	12.49±7.25 ^{a}	223.71±6.23	14.01±0.60^{a}	1.50±0.65
20% LYP	59	4.07±0.13	31.60±0.24	15.15±0.88^{h}	13.76±2.10^{d}	12.97±2.89 ^{a}	204.76±2.89^{j}	17.84±2.28^{a}	0.18±0.16
5% SCP	61	3.36±0.14	34.41±0.18	20.92±1.13	31.97±0.01 ^{a}	13.28±0.83 ^{a}	248.34±1.21	2.44±0.19	1.86±1.20
5% MCP	61	3.59±0.23	33.78±0.41	19.29±0.24	31.48±0.04 ^{a}	13.68±0.35 ^{a}	243.19±2.14	2.30±0.37	0.97±0.97
5% LCP	61	3.49±0.13	33.97±0.79	18.95±0.71	31.29±1.17 ^{a}	12.92±0.47 ^{a}	242.75±3.69	1.67±0.35	1.41±0.40

12.5% SCP	60	3.88±0.02	33.22±0.28	20.35±1.32	29.84±0.76 [a]	14.36±0.23 [a]	231.12±2.11	3.38±1.04	1.89±0.25
12.5% MCP	60	3.89±0.04	32.05±1.46	17.43±0.64	29.77±0.74 [a]	12.59±0.20 [a]	229.93±3.78	2.28±0.72	2.16±2.16
12.5% LCP	60	3.78±0.05	32.69±1.03	16.92±0.70	29.69±0.81 [a]	12.88±0.35 [a]	230.30±1.89	1.81±0.22	1.98±0.20
20% SCP	59	4.01±0.24	31.10±0.39	16.61±2.23	27.22±0.14[ab]	13.03±0.23 [a]	215.87±0.19	3.88±0.53	1.03±0.86
20% MCP	59	4.59±0.57 [a]	30.79±0.39[i]	16.17±1.17	28.03±0.31[ab]	11.78±0.41 [a]	209.90±4.41	2.76±0.09	0.98±0.80
20% LCP	59	3.97±0.06	31.00±1.21	18.05±0.85	27.52±1.32[ab]	13.13±1.40 [a]	212.41±2.76	3.16±0.72	1.69±0.64

*Means with different superscript letters within each column denote significant differences (*p<0.05*)

*Means without a superscript letter are not significantly different from the mean value of the sample with superscript letter a.

SCP: Small chickpea, MCP: Medium chickpea, LCP: Large chickpea, SL: Small lentil, ML: Medium lentil, LL: Large lentil, SYP: Small yellow pea, MYP: Medium yellow pea, LYP: Large yellow pea.

Table 3.5 Pulse-refined wheat flour blend bread physical properties averaged across different particle sizes for each pulse type.

Sample	Volume/cm^3	Specific volume (cm^3/g)	Number of cells	Area of cells/%	Wall thickness/mm	Cell diameter/mm
Control	700.59±8.64 [a]	5.03±0.06 [a]	3596.76±131.26 [a]	50.64±0.40 [ab]	0.42±0.00 [a]	1.78±0.07 [a]
5% Lentil	679.44±6.35 [b]	4.82±0.06 [bc]	3664.00±168.41 [a]	50.82±0.42 [a]	0.42±0.00 [a]	1.77±0.07 [a]
5% Chickpea	694.44±7.26 [ab]	4.93±0.05 [ab]	3569.33±91.10 [a]	50.71±0.43 [ab]	0.42±0.00 [a]	1.76±0.05 [ab]
5% Yellow pea	657.22±5.65 [c]	4.68±0.05 [cd]	3534.11±198.77 [ab]	50.50±0.53 [abc]	0.42±0.01 [a]	1.76±0.11 [ab]
12.5% Lentil	628.89±8.58 [d]	4.45±0.08 [e]	3344.44±137.80 [bc]	50.57±0.47 [abc]	0.42±0.00 [a]	1.71±0.07 [abc]
12.5% Chickpea	655.00±16.96 [c]	4.64±0.10 [d]	3509.78±99.86 [ab]	50.48±0.29 [abc]	0.42±0.01 [a]	1.68±0.06 [abc]
12.5% Yellow pea	592.78±10.03 [e]	4.23±0.10 [f]	3290.78±109.51 [c]	50.17±0.38 [bcd]	0.42±0.00 [a]	1.69±0.07 [abc]
20% Lentil	506.67±26.34 [g]	3.62±0.20 [h]	2860.56±217.08 [de]	49.98±0.35 [cd]	0.42±0.01 [a]	1.66±0.06 [bc]
20% Chickpea	527.22±18.22 [f]	3.79±0.13 [g]	3024.56±78.35 [d]	49.99±0.36 [cd]	0.42±0.01 [a]	1.63±0.04 [c]
20% Yellow pea	481.11±17.28 [h]	3.40±0.15 [i]	2806.89±135.45 [e]	49.68±0.34 [d]	0.42±0.01 [a]	1.63±0.06 [c]

Each represent the average of all particle size flour i.e. Small, Medium, and Large sized flour

Means with different superscript letters within each column denote significant differences ($p<0.05$)

N/A- not applicable

Table 3.6 Pulse/ refined wheat flour blend bread texture profile analysis averaged across different particle sizes for each pulse type

Sample	Hardness (g)	Adhesiveness (g*sec)	Resilience (%)	Cohesion	Springiness (%)	Gumminess	Chewiness
Control	397.76±42.08^{g}	0.05±0.11^{a}	38.96±1.47^{a}	0.75±0.02^{a}	102.69±6.72^{a}	302.45±35.64^{d}	309.23±29.03^{d}
5% Lentil	451.49±45.42 ^{efg}	0.15±0.09 ^{a}	38.03±1.80^{ab}	0.73±0.02^{ab}	99.18±1.39^{ab}	330.12±28.77 ^{d}	327.09±24.98 ^{d}
5% Chickpea	420.48±51.04 ^{fg}	-0.04±0.06^{ab}	38.67±1.76^{a}	0.75±0.02^{a}	99.85±2.32 ^{ab}	312.95±33.75 ^{d}	312.20±31.82 ^{d}
5% Yellow pea	479.51±63.20 ^{efg}	-0.27±0.40^{b}	36.79±1.77^{ab}	0.73±0.01^{ab}	98.33±1.71 ^{abc}	348.69±48.69 ^{cd}	342.23±43.74 ^{d}
12.5% Lentil	562.63±45.60 ^{cde}	0.14±0.11 ^{a}	32.96±4.42^{cd}	0.67±0.06^{cd}	97.04±1.12 ^{bc}	373.36±37.10^{cd}	362.62±93.02 ^{cd}
12.5% Chickpea	532.35±72.82 ^{def}	0.03±0.15 ^{a}	35.76±1.20^{abc}	0.71±0.01^{ab}	97.20±0.93 ^{bc}	378.24±47.68^{cd}	367.33±44.21^{cd}
12.5% Yellow pea	624.14±89.97 ^{cd}	-0.10±0.25^{ab}	34.81±1.71^{bc}	0.70±0.01^{bc}	96.69±1.69 ^{bc}	436.27±55.77^{bc}	421.00±47.37^{bc}
20% Lentil	807.69±63.37 ^{b}	0.14±0.06 ^{a}	29.20±2.43^{e}	0.63±0.04^{de}	95.32±0.64 ^{bc}	498.83±37.42^{b}	475.44±35.46^{b}
20% Chickpea	674.56±75.36 ^{c}	0.11±0.08 ^{a}	30.77±2.21^{de}	0.64±0.02^{de}	96.53±1.00 ^{bc}	386.91±138.29^{cd}	416.04±40.03^{cb}
20% Yellow pea	1011.96±155.60^{a}	0.05±0.22 ^{a}	28.55±0.97^{e}	0.61±0.01^{e}	93.91±0.85^{c}	623.08±103.94^{a}	584.73±95.00^{a}

Each represent the average of all particle size flour i.e.Small, Medium, and Large sized flour

Means with different superscript letters within each column denote significant differences ($p<0.05$)

N/A- not applicable

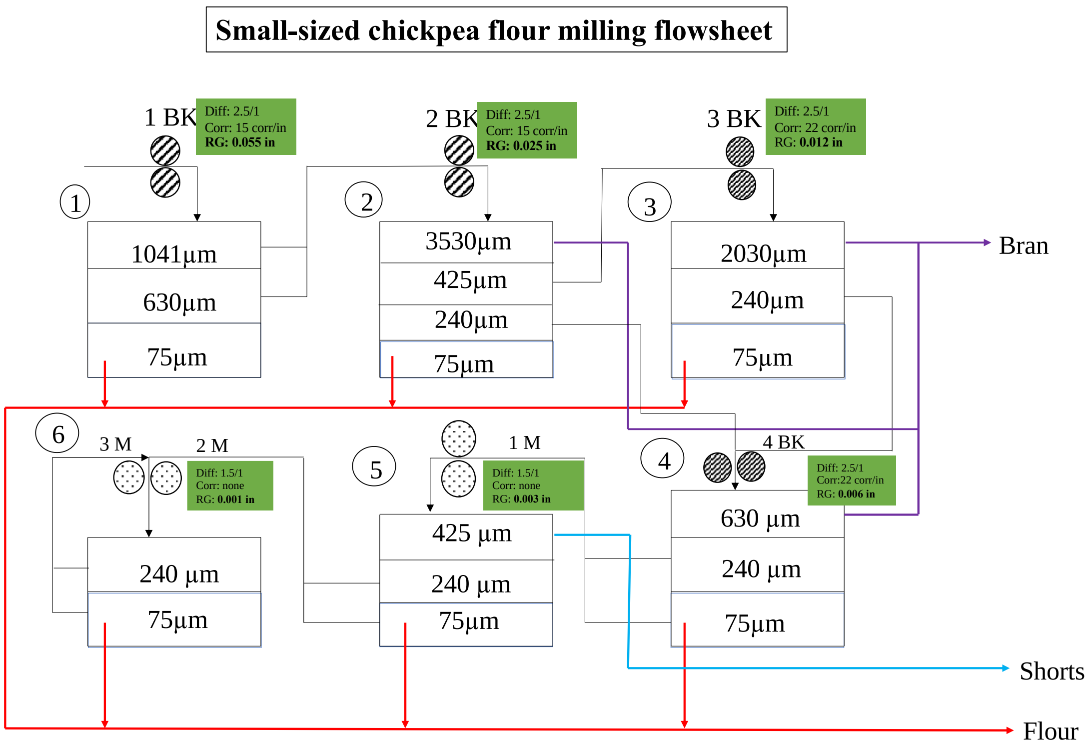
Table 3.7. Crust and crumb color of the pulse/wheat blends bread

	Crust color			Crumb color		
Sample	L*	a*	b*	L*	a*	b*
Control	50.11±1.52[a]	13.89±0.56[a]	26.61±1.94[a]	78.38±1.08[ab]	-0.43±0.09[g]	20.05±0.34[c]
5% Lentil	46.24±1.64[b]	14.52±0.59 [a]	23.52±2.61[bc]	78.41±0.61[ab]	0.64±0.08[def]	17.42±0.37[d]
12.5% Lentil	41.53±2.15[c]	14.61±0.93 [a]	19.86±2.84[de]	77.15±0.73[bc]	0.90±0.11[b]	19.57±0.54[c]
20% Lentil	40.26±2.07[c]	13.96±1.19 [a]	17.59±1.99[e]	73.44±0.83[e]	1.23±0.14[a]	24.09±1.11[a]
5% Yellow pea	46.40±1.26[b]	14.28±0.37 [a]	25.22±1.19[ab]	79.10±0.68[a]	0.71±0.06[cde]	17.18±0.42[d]
12.5% Yellow pea	42.12±1.52[c]	14.41±0.63 [a]	21.38±1.48[cd]	77.87±0.93[abc]	0.82±0.09[cb]	19.36±0.94[c]
20% Yellow pea	39.97±1.51[c]	14.49±0.66 [a]	19.25±1.36[de]	75.03±1.23[d]	1.17±0.11[a]	22.90±0.84[b]
5% Chickpea	46.29±0.86[b]	14.10±0.53 [a]	24.26±1.04[ab]	78.51±1.38[ab]	0.52±0.05[f]	17.26±0.35[d]
12.5% Chickpea	44.94±1.79[b]	14.37±0.50 [a]	23.30±0.88[bc]	78.47±0.83[ab]	0.63±0.05[ef]	19.36±0.34[c]
20% Chickpea	45.10±2.38[b]	14.43±0.63 [a]	22.85±2.07[bc]	76.51±0.94[c]	0.79±0.12[bcd]	23.29±0.61[ab]

*Means with different superscript letters within each column denote significant differences ($p<0.05$)

Figures

Figure 3.1 Milling flowsheet of the small-sized chickpea flour



(BK: Break system; M: Reduction system)

Figure 3.2 Particles distribution in (a) lentil, (b) yellow pea, (c) chickpea, and (d) refined wheat flour (S: small; M: medium; L: large).

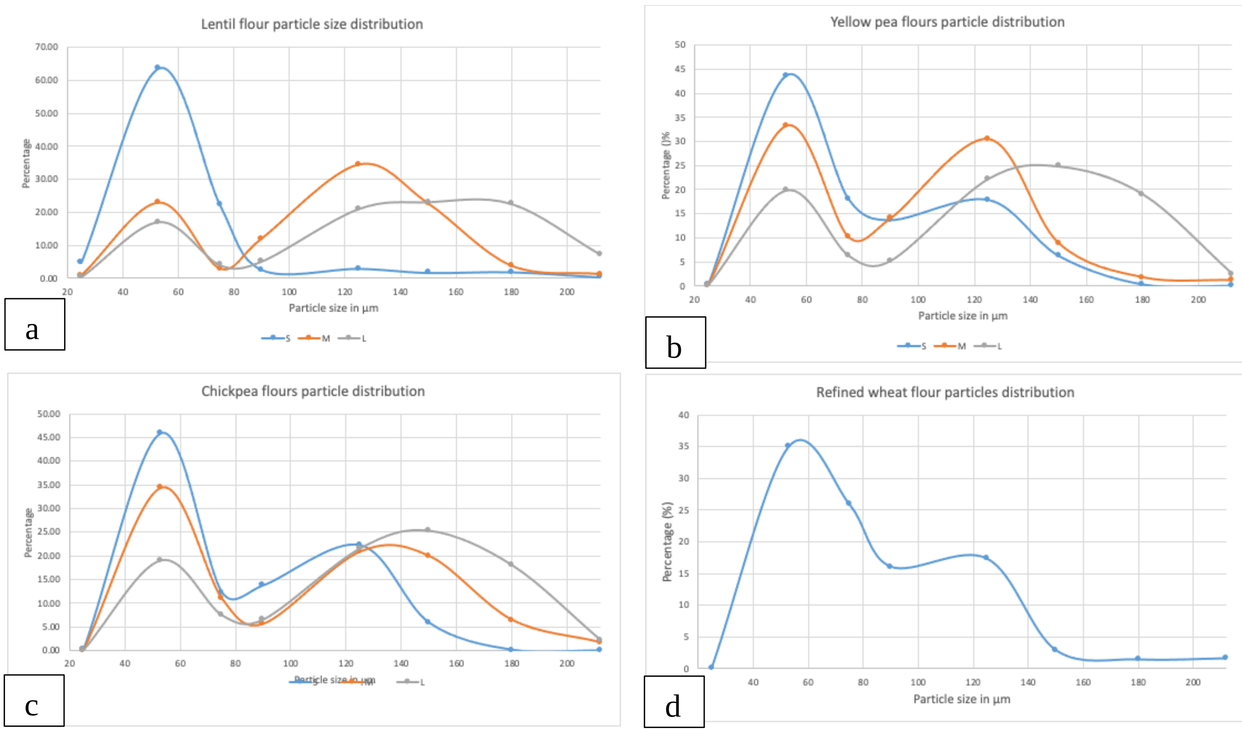
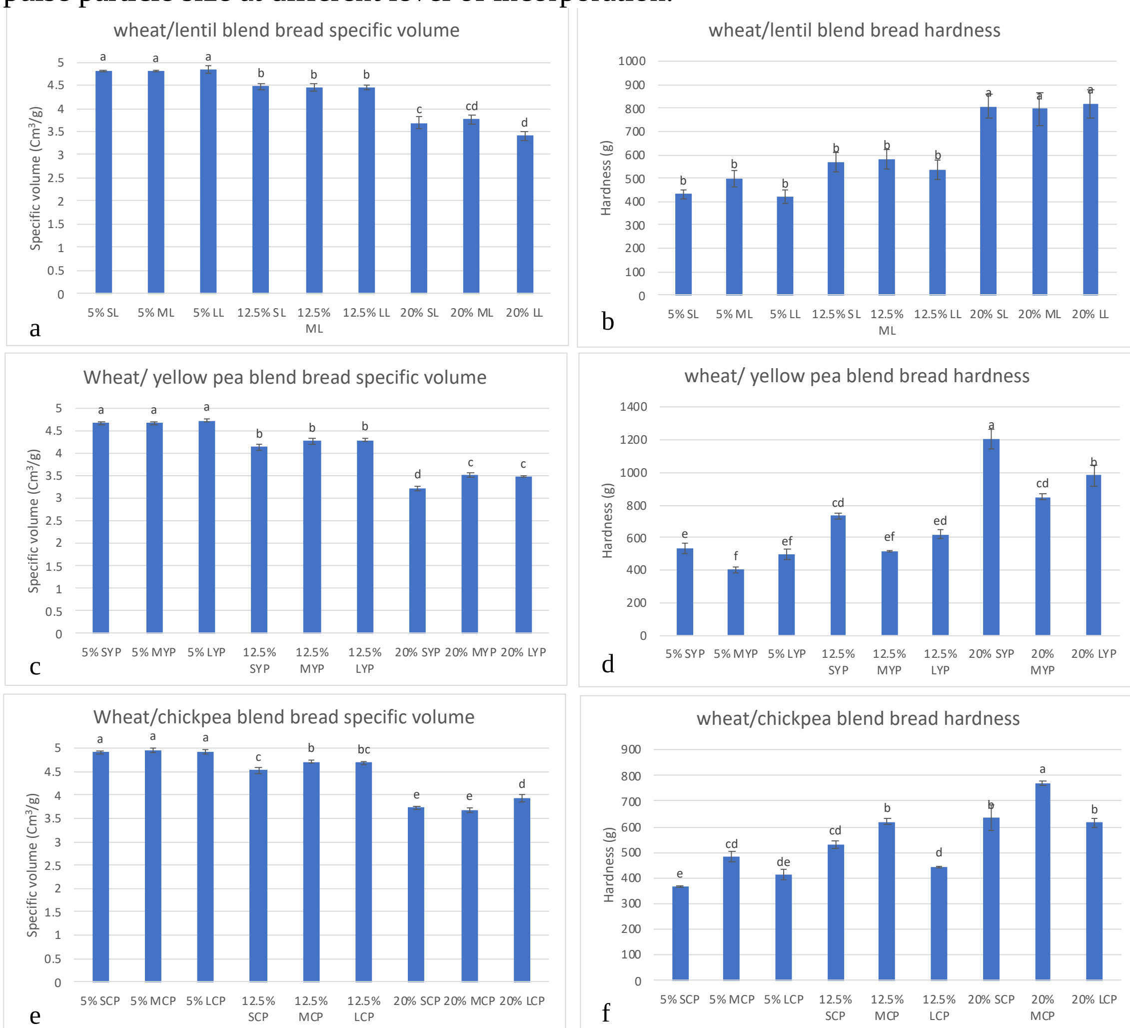


Figure 3.3 Slice pictures of pulse/refined wheat flour blend at different levels

Control 	5% Lentil 	12.5% Lentil 	20% Lentil 
	5% Yellow pea 	12.5% Yellow pea 	20% yellow pea 
	5% Chickpea 	12.5% Chickpea 	20% Chickpea 

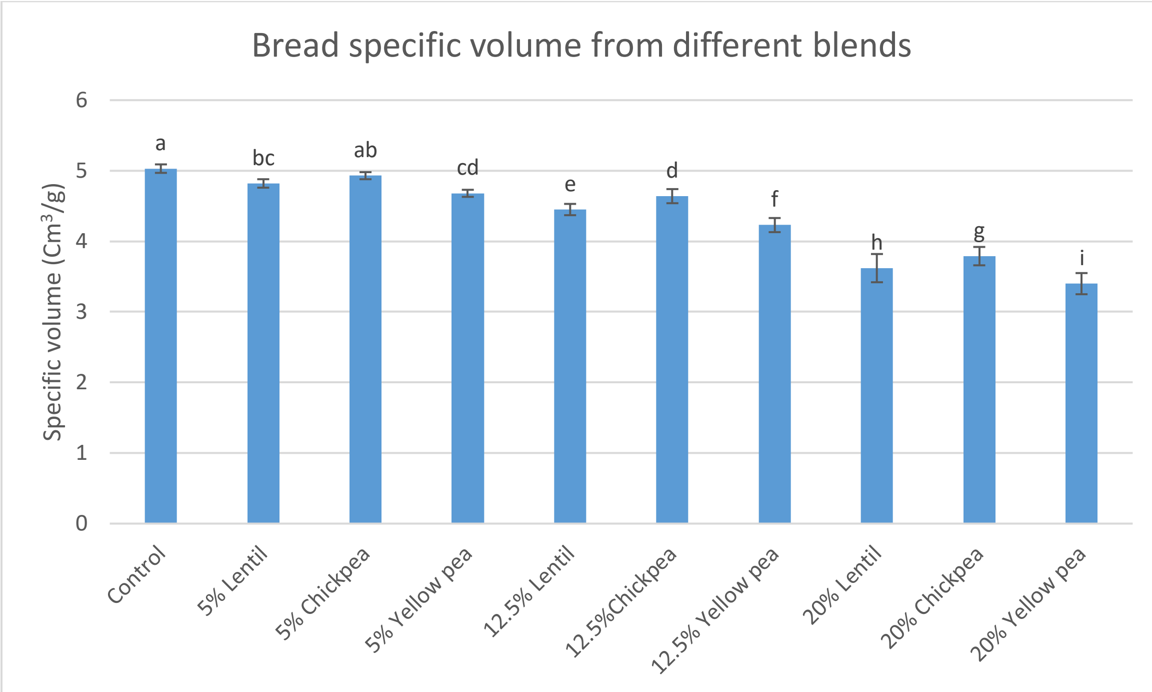
Appendix B - Supplementary data

Figure B1. Bread specific volume and hardness from different composite flour with different pulse particle size at different level of incorporation.



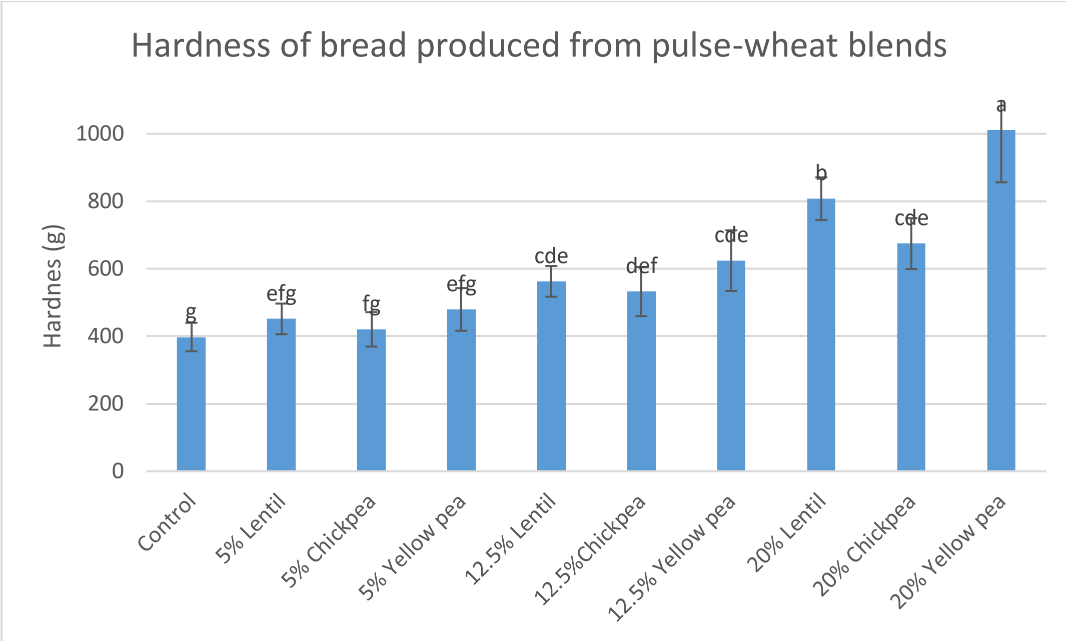
Bars with different superscript letters on their top represent values with significant (*p<0.05*) different means between them. SCP: Small chickpea, MCP: Medium chickpea, LCP: Large chickpea, SL: Small lentil, ML: Medium lentil, LL: Large lentil, SYP: Small yellow pea, MYP: Medium yellow pea, LYP: Large yellow pea.

Figure B2. Bread specific volume produced by different pulse/wheat blend.



Bars with different superscript letters on their top represent values with significantly (*p<0.05*) different means between them.

Figure B3. Hardness of the bread containing pulse flour at different levels.



Bars with different superscript letters on their top represent values with significantly (*p<0.05*) different means between them.

Chapter 4 - Incorporating chickpea flour can enhance mixing tolerance and dough strength of wheat flour

Abstract

Dough mixing properties are crucial to determine the usability of wheat flour. The resistance to mixing is an important property that bakers consider when selecting flour. Nowadays some additives have been used to improve the mixing stability of the dough and most of them are industrial sourced chemicals. Chickpea flour effect on the dough strength improvement based on 20 different wheat genotypes has been tested in this study. Different types of chickpea flour (e.g., Kabuli, Desi) and its fractions were also studied. Mixograph, dough strength and extensibility, and baking test were performed. At incorporation level of 7.5% (w/w) or lower, chickpea flour clearly improved the mixing stability and dough strength of wheat flour. Adding the insoluble fraction of the chickpea flour resulted in better stability and extended dough strength compared to other fractions used. Adding the soluble fraction of the chickpea flour weakened the dough. At optimum incorporation level (7.5%) or lower, chickpea flour inclusion did not alter the physical, texture, and taste attribute of the bread. This study shows that adding chickpea flour can improve the dough mixing properties without affecting the quality of the bread. The optimum for chickpea flour incorporation in refined wheat flour is 7.5%. Chickpea flour incorporation could also help bakers in case of overmixing the dough. This study portrays the use of natural ingredients to improve the dough mixing properties. It will benefit the bakers and scientific society in finding natural alternatives for improving the wheat flour mixing properties while raising the quality and nutrition of the flour since chickpea is a protein-rich grain. This study will also help product developers in developing chickpea enriched bread.

Keywords: Wheat, Chickpea, mixograph, mixing stability, dough strength, and extensibility, bread, sensory

4.1. Introduction

Dough properties are important to determine bread-making performances of wheat flour. There are three major classifications of the dough/flour based on mixing properties, namely: weak, normal, and strong dough/flour. A weak dough is very sticky while mixing, breakdowns very quickly, and produces bread with a smaller loaf volume compared to normal dough. A weak dough is undesirable by the majority for bread-baking purpose. Different additives are being used to improve the dough mixing properties mostly for weak dough (Jazaeri et al., 2015; Lang et al., 1992; Nash et al., 2006). To determine the dough properties, a mixograph is often utilized. The mixograph test has been consistently a crucial tool in evaluating the functionality of wheat flour. As published in literature, mixograph test was used to evaluate different additives in the flour such as water, vital gluten, oxidants, reductant, and surfactants as described by Lang et al. (1992). It was also used to determine the mechanism of lipoxygenase in increasing the mixing tolerance of wheat flour (Hoseney et al., 1972). In that study, the formation of lipid-free radical created by lipoxygenase was found to be the main contributor to the increased mixing tolerance of the dough. In another study performed by Weak et al. (1977), a mixograph test was used to assess mixing time reduction properties of ascorbic acid.

Dough extensibility test is another method to assess the functionality of wheat flour. For the dough extensibility test, the dough is stretched up until it ruptures; the force and distance to rupture are measured, characterizing the strength and elasticity of the dough, respectively (Nash et al., 2006). To better understand the relationship of extensibility and mixograph, additives such as hydrocolloids, resistant starch, potassium chloride and gluten protein effect on the extensibility of dough were analyzed by different scientists, and the results obtained were generally in accordance with the results of the mixograph tests (G. Chen et al., 2018; G. Chen & Li, 2019; Miller & Bianchi, 2017; Rosell et al., 2001).

Chickpea is a pulse grain which is nutritionally rich and agronomically adaptable. Kabuli (cream like) and desi (dark green) are the main type of chickpea globally available. The main difference between them is the color and kernel size, and desi chickpea usually has higher protein content than kabuli chickpea. Chickpea is a good source of proteins, fibers, and bioactive compounds (Grasso et al., 2022). Incorporation of chickpea flour into wheat flour makes bread healthier because of protein and fiber addition. Chickpea flour can also be regarded as a good “natural” ingredient making it a clean label when used as an ingredient in any food product. The use of legume flour to improve the dough mixing tolerance was previously reported. Hoseney et al. (1972) demonstrated how the enzyme-active soybean flour increased the mixing tolerance of the dough. In a study performed by Saad et al. (2015), the chickpea fermented liquor showed a potential to increase the dough stability. The study done by Nkurikiye et al (2022) where chickpea flour was incorporated into refined wheat flour, chickpea baking properties were much better compared to lentils and yellow peas when incorporated at the same level. Those studies show that chickpea may have potential to improve the properties of wheat dough.

To better understand the potential dough strengthening abilities of chickpea flour, this study was conducted to test the effect of chickpea flour in increasing the mixing tolerance and the extensibility of wheat flour using 20 different wheat genotypes, to test the baking quality effect of chickpea incorporation, and to understand the consumer accessibility of the wheat-chickpea composite bread. This study will benefits bakers to get an easy to use and fortified flour.

4.2. Materials and methods

4.2.1. Wheat grains and flours

20 different wheat genotypes from the 2021 Kansas wheat breeding program were used. The wheat samples were milled using a Brabender Quadrumat Junior mill following the AACC approved method 26-50.01 (1999). The bran and shorts were discarded, and the refined flour was collected. The 20 flours (M1-20) obtained had protein content ranging from 9 to 14%. They were selected representing different protein content and different mixograms properties. Chickpea grains were purchased from the Food to live online store and were milled using a laboratory roller mill as described below.

4.2.2. Milling of chickpea

The chickpea grains were milled using a Ross Roller mill according to the procedure developed by Pulivarthi et al. (2021) with minor modification. The grains were tempered to 13% moisture content overnight, and they were passed through a set of 3 different rolls and sieves with adjusted setting to control the particle size of the final flour. Three different flours were produced. Small (S), medium (M), and Large (L) flour were named based on the base sieve of 75, 150, 200 µm respectively. Figure C1 shows the detailed milling flow sheet.

4.2.3. Chickpea flour fractionation

The chickpea flour fractionation was based on a modified water washing fractionation method (Van Der Borght et al., 2005). Chickpea flour was first defatted. Briefly, 100 g of the flour was mixed with 500 ml of ethyl ether. The mixture was mixed for 30 minutes in a fume hood. The mixture was then centrifuged at 7000 ×g for 25 minutes. The supernatant containing the fat was discarded, and the process was repeated twice. The defatted flour was allowed to stay in the fume hood for 3 days for complete ethyl ether evaporation. Some of the flour was collected and named *defatted chickpea flour*. For the remaining defatted flour, deionized water was added at a ratio of 10:1 and mixed for 30 minutes, and the mixture was centrifuged at 7000 ×g for 15 minutes. The supernatant was collected and freeze dried, named as *soluble protein fraction*. For the precipitate, the top slimy colored layer was scrapped off and lyophilized, named as the *insoluble protein fraction*. The remaining part of the precipitate was also lyophilized and named as the *starch fraction*. The complete fractionation process is provided in Figure 4.1, and the yield and protein content of each fraction are also listed.

4.2.4. Wheat/chickpea composite flour preparation

Each wheat flour was tested as a control; and for the same flour, 7.5% (w/w) of kabuli medium (KM) sized chickpea flour was incorporated and tested. KM chickpea flour was later added at levels of 1.5, 3.75, 15, and 30% (w/w) into the two selected wheat flours W-11 (weak flour) and W-17 (strong flour), desi type chickpea flour was also tested with those selected flours (W 11 & 17). For those two selected wheat flours, 7.5% (w/w) of the fractionated KM chickpea flour (i.e., defat, starch, soluble proteins, and insoluble proteins) was added, and dough tests were performed.

4.2.5. Mixograph test

A 10-g mixograph (National Manufacturing Div., TMCO, Inc., Lincoln, NE) connected to a computer was used to perform the mixograph test. MixSmart software was utilized to analyze the mixograph data. Mixing tolerance and breakdown tolerance was calculated. Mixing tolerance was measured by calculating the percentage difference at peak time and at 8 minutes of mixing. Below is the formula used:

$$Mixing\ tolerance\ (\%) = Ptv\ (\%) - \ xv\ (\%)$$

Ptv - mixograph value at Peak time value (%)

xv - mixograph value at “8 minute” (%)

The breakdown tolerance was measured by getting the absolute value of the difference between 1 minute before and after reaching the peak time. The detailed formulate is shown below

$$breakdown\ tolerance\ (\%) = |(1\ min.bpt - 1min.apt)|$$

1 min. bpt - mixograph value 1 minute before peak time (%)

1 min. apt - mixograph value 1 minute after peak time (%)

The detailed definition for mixogram parameters is shown in Figure 4.3.

4.2.6. Dough strength and extensibility test

The dough extensibility test was performed at room temperature using a TA-TX2 Texture analyzer equipped with a SMS/Keiffer rig. A 10 g dough was prepared using the Mixograph pin mixer with the optimized time according to mixograph data. The dough was molded into a rectangular shape and placed on the grooved section of the Teflon former with the lametta strips placed on the bottom. A cover block was placed on the top, and both were compressed together. The excess dough on the side was then removed, and the whole assembly was allowed to rest for 30 minutes before further testing. After resting, the strips were carefully removed from the former. The dough on the strip was placed on the SMS/Keiffer rig where it was pulled up till rupture. The strength and the distance to rupture were measured by the Texture analyzer. The testing settings were: 5.0 mm/s pre-test speed, 3.3 mm/s test speed, 10.0 mm/s post-test speed, 5 g trigger force for dough strength measurement. The 10g trigger force for dough extensibility distance was used while the total distance was set to 75 mm. Five strips from each dough were tested for each treatment.

4.2.7. Bread baking test

Bread loaves were prepared by incorporating KM chickpea flour at levels 0, 1.5, 3.75, 7.5, 15, and 30% (w/w) in all-purpose flour (Organic Arrowhead all-purpose flour, lot#

219380810, 11.27% protein content, 13.56% moisture content). The baking test was done in triplicate for each treatment following the 90-minutes fermentation AACC method 10-10.03 (1999). Formulation included 100 g of control or composite flour (14% moisture basis), 2 g of instant dry yeast, 3 g of shortening, 6 g of sucrose, 1.5 g of salt, 0.2 g of malt flour, and water (referring to the mixograph data). All the ingredients were mixed to optimized time according to mixograph data. Overmixing of the control and the composite flour (7.5% KM chickpea incorporation level) for 8 minutes was also performed, respectively, to understand the overmixing effect on bread quality. The loaves of bread were baked at 205 ^{0}C for 24 minutes, allowed to cool for 2 hours on the racks at room temperature before testing.

4.2.8. Bread specific volume, color, and texture analysis

After cooling, the weight of the bread was recorded, and the bread volume was measured according to the rapeseed displacement AACC method 10-05.01; specific volume was measured by dividing the bread volume by the bread weight. The crust color of each bread was measured using the Minolta calorimeter (CR 310, Konica Minolta, Inc., Tokyo, Japan) by measuring three points on the crust. Each bread was sliced into 25 mm thick slices, and crumb color was measured by pointing the colorimeter to three different points on the crumb. The middle slice was used for bread crumb structure analysis using C-Cell Bread Imaging System (Calibre Control International Ltd., Warrington, U.K.); number of cells, cell wall thickness, and cell diameter were recorded.

To assess the texture profile analysis (TPA), the central slices were measured using a TA-XT2i texture analyzer (Stable Micro Systems, Surrey, U.K.) equipped with a 30 kg load cell and 25mm cylindrical probe. Each slice was subjected to a 50% compression at a speed of 1.0 mm/s and trigger speed of 20 g. Texture exponent software was then used to analyze the data. The tests were repeated for at least 6 times for each treatment.

4.2.9. Bread sensory evaluation

Bread sensory study was done according to a consumer hedonic test (Azami et al., 2018; Fellendorf et al., 2018). 30 random participants from Manhattan (Kansas) community voluntarily participated in this study. Those participants are considered as general bread consumers with no known allergies to bread ingredients. Each participant was provided with three bread slices. The slices were labelled with three random digits to reduce the bias. Water was given in between tests to reduce the previous influence. They scored the bread slice from 1 to 9 (1- highly dislike; 5 -neither like or dislike; 9 - highly preferred) on appearance, aroma, taste, and overall acceptability of the bread.

4.2.10. Statistical analysis

All tests performed in this study were at least duplicated unless specified previously in the methods. The mean differences were determined by analysis of variance (ANOVA) and Tukey grouping using the SAS Online studio (SAS Institute, Cary, North Carolina, USA) with a significance level of $p < 0.05$.

4.3. Results and Discussion

4.3.1. Mixograph

4.3.1.1. Mixograph of 20 control wheat samples and their blends containing 7.5% chickpea flour

Table S1 details the mixograph midline parameters for the 20 wheat flour samples before (control) and after chickpea flour substitution (treated), and the mixograms were provided in

Figure 4.2 and Figure C3. The midline peak time that indicates the optimum time for dough development was generally not affected by the addition of chickpea flour, except that W-15, W-17, W-19, and W-20 showed a significantly increased peak time as chickpea flour was added. Excluding W-19, the other three flours were considered as strong flours. Generally, strong flours have a longer dough development time since they are more resistant to gluten formation compared to normal flours (Barak et al., 2013; Safari-Ardi & Phan-Thien, 1998). The addition of the chickpea flour decreased the midline peak value. This could be to the substitution of wheat flour with gluten-free flour which diluted gluten hence lowering the peak value (Lazaridou & Biliaderis, 2009). For flours W-1, W-9, and W-10, the peak value was not significantly affected. The peak width for all the flours was not significantly affected. This demonstrates that despite the reduction of the peak value, the dough consistency was not significantly affected. The curve tail (8-minute mixing) mid-line value which indicates the dough strength after 8 minutes of mixing showed no significant difference in general between the control flours and the treated flour; however, the curve tail (8-minute mixing) width was increased considerably when chickpea was added. This phenomenon implies that the addition of the chickpea flour preserved better the consistency of the dough throughout the extended mixing. The curve tail integral which signifies the dough strength showed no significant difference between the control and the treated flour, which suggests that the dough strength was negatively affected by the chickpea addition.

The breakdown tolerance index which shows the strength of the dough with continued mixing decreased when chickpea flour was added. The higher values of the breakdown tolerance index indicate a high breakdown while low values indicate higher tolerance to dough breakdown (Hoseney et al., 1972). This finding shows that generally, the addition of refined chickpea flour to the refined wheat flour increases the dough stability by reducing the dough breakdown tolerance index value. This trend was observed in all the flour tested and the flour tested represent most of the flours found commercially.

On the other hand, the mixing stability was not affected by the addition of chickpea flour. The mixing stability measures how the dough strength change before and after reaching the peak. The higher values will indicate the dough which is not very stable and breakdown as soon as the peak is reached while low values show a dough that maintains the energy before and after reaching the optimum gluten development (Khatkar et al., 2002). Despite the chickpea flour enhancing the dough stability as discussed above, the addition of chickpea does not alter the dough strength before and after reaching the optimum mixing based on mixograph test.

4.3.1.2. Mixograph parameters of a weak wheat flour containing different ratios, particle-sizes, and types of chickpea flour

Table C2 shows the midline mixograph parameter of the weak wheat flour (W-11) when different ratios, particle-sized, and type of chickpea flour substituted the wheat flour, and the mixograms are shown in Figure C4.

The addition of different ratios or different types of chickpea flours did not affect the peak time. As observed before, the peak value was reduced with the addition of chickpea flour at levels 1 to 7.5%; when the ratio increased (15 to 30%), there was a further drastic peak value reduction. Desi or small-sized chickpea (SCP) flour showed no significant differences when added at a level of 7.5% (w/w). The peak width was not affected by the addition of chickpea flour at a different ratio or different type of chickpea flour. The curve tail value was higher when desi or SCP were added, followed by large-sized chickpea (LCP) then the control wheat flour. While the lowest curve tail values were observed when chickpea was incorporated at levels 15 and 30%. The curve tail width increased significantly as the chickpea flour was added at different ratios or types. The curve tail integral was higher when desi-type chickpea was added, and it was lowest when chickpea was added to a level of 30% (w/w). The substitution of wheat flour with chickpea flour decreased the breakdown tolerance value significantly and did not affect the mixing stability. This infers that the addition of chickpea flour at a different rate or different type of chickpea increase the dough resistance to overmixing. The above results clearly shows that the incorporation of chickpea at levels 7.5% or lower improves the mixing properties of the dough, however, higher incorporation levels are deleterious to the dough. Desi type of chickpea shows better qualities in improving the dough mixing characteristics.

Chickpea fractions effect on the weak wheat flour (W-11) was assessed (Table C3). For all the fractions, there was no significant difference in the peak time when added to W-11 flour. The peak value increased as all fractions were added. The peak width was not affected by the chickpea flour fractions addition. All fractions but the soluble protein increased the curve tail value. For the curve tail width, insoluble protein and defatted chickpea fraction had the drastic increase of the width while starch and soluble protein fraction showed a little increase in the curve tail width compared to the control. The curve tail integral was not significantly affected by chickpea fractions inclusion. Apart from the chickpea starch fraction, others reduced the breakdown tolerance, however, the reduction was marginal when soluble chickpea protein was added while the breakdown reduction was distinct when insoluble chickpea protein was incorporated. The chickpea flour fractions did not influence the mixing stability of the flour during mixing. The above data shows that the insoluble fraction contribute more to increasing the mixing stability of the dough while the soluble fraction does a contrary role during mixing as shown by the above data.

4.3.1.3. Mixograph parameters for a strong flour containing different ratios, particle-sized, and type of chickpea flour

As shown in Table C4, the addition of chickpea flour at different ratios or desi type increased the midline peak time significantly, mixograms are shown in Figure C4. Apart from a 30% chickpea incorporation level, there was no significant difference in peak value, peak width, and tail value when different ratios or type of chickpea flour were incorporated into the W-17 flour. The incorporation of chickpea flour at 30% reduced the peak value, peak width, and tail value significantly. The tail width increased when chickpea flour was added at a ratio of 7.5%, yet further incorporation (above 7.5%) reduced the tail width significantly. Desi chickpea flour increased the tail width higher compared to other incorporation levels. The curve tail integral only reduced when chickpea was added from levels 15 and 30%; other ratios or type of chickpea flour addition did not significantly affect the tail integral value. The breakdown tolerance was not affected by any treatment of the flour. When chickpea flour was added at 30%, the mixing stability increased sharply while other chickpea addition reduced the mixing stability. The increased mixing stability indicated lower stability before and after reaching the optimum mixing time. The observed reduction of the mixing stability on a strong flour indicated that the flour is losing some strength which is undesirable. Other chickpea incorporation level increased the mixing stability which shows that the dough was more stable to work with.

As reported in the literature, the addition of most gluten-free protein-rich grains such as beans, peas, sunflower, and soy weakened the dough (Sosulski & Fleming, 1977); this further shows that chickpea possesses the dough strengthening abilities unlike most other protein-rich grains. Chickpea effect on the dough mixing properties is very similar to sodium stearoyl-2-

lactylate (SSL) and lipoxygenase which increased the mixing tolerance as reported in the literature (Hoseney et al., 1972; Okezie & Dobo, 1980).

For the chickpea fractions effect on the mixing properties (Table C5 and Figure C5), the defatted chickpea flour effect was very similar to chickpea flour alone indicating that the fat portion of the chickpea flour is not the main compound responsible for the increased mixing tolerance observed when chickpea flour is added. The soluble protein fraction did not increase the mixing tolerance which implies that its effect is contrary to the chickpea flour alone. In literature, it was proved that soluble fractions of wheat and rye reduced the mixing tolerance on the mixograph (W. Z. Chen & Hoseney, 1995; Dhaliwal & MacRitchie, 1990). The increased mixing tolerance was vividly observed when the insoluble protein fraction of chickpea flour was added to wheat flour. This means that most of the substances responsible for the increased mixing tolerance is in the insoluble protein fraction. It is possible that the high molecular proteins contained in the insoluble protein fraction are responsible for the increased mixing tolerance, which requires further investigation. Vanhamel et al. (1993) indicated that the high molecular rye pentosans increased the peak height as well as the curve area.

4.3.2. Dough strength and extensibility

4.3.2.1. Extensibility properties for all the 20 flours and blends

As detailed in Table C6 and Figure 4.3, the dough strength increased significantly when chickpea flour was added at 7.5% (w/w) into each wheat flour. The exception was observed when the W-20 flour showed no significant difference between the control and the blended flour. This is believed to be a result of W-20 being a very strong flour. Strong flours generally possess stronger dough. For most of the samples, the extensibility distance decreased as chickpea flour was incorporated while that decrease in extensibility distance was not observed in a few flours (W 6,7,10,19, and 20).

4.3.2.2. Extensibility properties of the weak flour (W-11) containing different ratios, particle-sized, and type of chickpea flour

The dough extensibility data for the flour W-11 and its treatment are shown in Figure S6 and Tables C7 and C8. The dough extensibility distance was recorded as 0 since the highest energy of the dough was at the contact time (0s) making the distance to dough extension be recorded as 0. The current data indicate that the addition of chickpea flour at different ratios till 7.5% increased the dough strength; very high levels of incorporation (30%) dough were too weak to reach the threshold for both distance and strength measurements hence the 0 reading. For both the control and the 15% incorporation level, there was a distance extensibility but the equipment couldn't quantify it due to lower dough strength. Other ratios (1, 3.75, and 7.5%) and desi-type chickpea flour increased both the dough strength and extensibility.

As different fractions of chickpea were added, starch and soluble protein fraction reduced the dough strength significantly but did not affect the distance of dough extension compared to the unfractionated chickpea as shown in Table C8 and Figure C7. The soluble fraction made the dough much weaker to trigger the initial force of 5 g for dough extensibility measurement. Other fractions increased the strength and extensibility. The insoluble fraction led to a much higher increase in the dough strength.

Even for a very weak dough, chickpea showed a significant increase in the strength of the dough. Among the fractions, the insoluble protein fractions influence more the strength of the dough. This result obtained here supports the mixograph data where chickpea increased the increased the mixing stability.

4.3.2.3. Extensibility of the strong flour (W-17) containing different ratios, particle-sized, and type of chickpea flour

As shown in Table C9 and C10, the addition of chickpea flour at a level below or above 7.5% did not significantly affect the dough strength while the highest level of incorporation (30%) decreased the dough strength significantly. Chickpea flour of different types (Desi or Kabuli) incorporated at 7.5% greatly increased the strength of the dough. For all ratio and types of inclusion, the distance before rupture decreased; an extensive decrease of the distance occurred when desi type chickpea flour was added at level 7.5%. The extensibility test here shows that chickpea incorporation should be at optimum (7.5%) to observe the effect on the dough strength. It also shows that excessive chickpea incorporation is destructive to dough strength.

Different chickpea flour fractions had a distinctive effect on the strong dough extensibility properties as shown in Table C10, Figure 4.4, and Figure C7. While the soluble protein fraction reduced sharply the strength of the dough, the insoluble protein fraction had the opposite role. The extensibility of the dough was increased significantly with the insoluble protein fraction. The starch fraction did not have a significant impact, and the defatted chickpea fraction had a similar increase in the dough extensibility as it was for chickpea flour alone. Except for starch and soluble protein fraction that had no effect on the distance to dough rupture, the other chickpea flour fractions reduced the distance. As observed in other tests performed earlier, the insoluble chickpea flour continues to demonstrate more of the extensibility increase properties compared to other fractions.

The current data shows clearly that chickpea flour can improve the strength of wheat dough when incorporated at an appropriate level. Simsek et al. (2016) showed that the addition of salt increased the dough strength with the increased concentration while the distance was mainly reduced with salt. We observed the same phenomenon when chickpea was incorporated at around 7.5% (w/w), the dough strength increased, and the extensibility distance reduced. Chen et al. (2018) observed an increase in dough strength as well when they added potassium salt in wheat flour. Referring to those literatures, chickpea flour can be an alternative for salts (sodium or potassium) regarding to dough strength improvement. Comparing the different chickpea fractions, the insoluble protein fraction showed a much-improved effect on increasing the dough strength. Verbruggen et al. (2001) found out that high molecular weight glutenin subunits (HMW-GS) increased the dough strength while low molecular weight glutenin subunits (LMW-GS) showed an opposite action (dough strength reduction). It is possible that the insoluble protein fraction in chickpea might be comparable to the HMW-GS that both have free sulfhydryl groups for further crosslinking that increased dough strength and mixing tolerance.

4.3.3. Bread properties of wheat/chickpea composite flour

The baking test showed that the incorporation of chickpea at a level of 3.75% produced a significantly larger (4.48 cm^3/g) bread compared to the control (4.25 cm^3/g) and other levels of incorporation (Table 4.1 and Figure C8). Adding 7.5% chickpea resulted in bread with similar volume as the control. When chickpea is incorporated at levels of 15 and 30%, the resultant bread is smaller (4.10 & 3.23 cm^3/g) in size. The overmixing action reduced the bread volume as expected. However, the incorporation of chickpea at 7.5% resisted much better to bread specific volume reduction (4.17 cm^3/g) compared to overmixed control flour (3.77 cm^3/g). During dough mixing, maximum gluten development is achieved at the peak time and the dough is strong. Increased mixing from the peak time disrupts the gluten network and degrades the dough, causing it to weaken as the mixing is continued. If excessive mixing is done, the dough would be very sticky and very weak to make a good bread. This phenomenon has been a challenge to bakers since they always must be cautious not to weaken the dough since it is irreversible (Lancelot et al., 2021; Sadot et al., 2017; Schiraldi & Fessas, 2012). The finding in this study of increased resistance to dough breakdown with chickpea flour addition buffered the bread volume loss significantly. This is a promising observation for bakers since they can have some flexibility in case of overmixing the dough.

The C-cell analysis showed a difference in number of cell when chickpea was incorporated at 30%, and when the control flour was overmixed. Other blends were not significantly different from each other. C-cell parameters such as area of cell was also reduced only when the control flour was overmixed. Other slice properties including wall thickness and cell diameter were not significantly affected by different treatment. The bread physical characteristics shows that the incorporation of chickpea does not affect the quality of the bread but in turn stabilizes the dough during an overmixing event.

The effect of chickpea on the crust color was more noticeable when inclusions above 7.5% were applied (Table C11). The L* value which represents the lightness decreased significantly when levels of 15 and 30% of chickpea were incorporated into refined wheat flour meaning that the crust darkened. This was due to the chickpea pigments and Maillard's reactions which increased due to increased protein addition. Overmixing the dough had a opposite effect on the crust color. The overmixed control bread showed lighter crust color (L * 57) compared to normal mixing control bread (L* 52). This phenomenon may be a result of extensive protein degradation during over mixing which inhibited the formation of color compounds. The 30% chickpea incorporation showed a more green and blue pigmentation (a & b values) which shows further that the crust was much darker. The bread crumb color effect was minimal when chickpea flour was added apart from 30% inclusion which made the crumb to darken compared to other treatments. Other treatments were not significantly different among them.

The texture profile analysis showed that the texture was affected only when chickpea was incorporated at a level of 30% (Table C13). 30% inclusion level increased the hardness of the bread almost twice. Adhesives and springiness were the only texture profiles not to be affected by 30% incorporation. The resilience and cohesion of the bread were reduced significantly, while the gumminess and chewiness increased. This texture changes are attributed to smaller sized bread that was produced when 30% of chickpea was incorporated into refined wheat flour. The texture analysis shows that a higher chickpea incorporation produces bread that are very hard which is usually undesirable to consumers expecting a soft bread.

The sensory study was done for the breads up to the incorporation level of 7.5% because it was where chickpea beneficial properties on the dough were optimum. The response of this sensory study showed that no significant difference could be identified by the consumers when chickpea flour is incorporated up to 7.5% (Table C14). The acceptability for all the bread slices were acceptable (above 5). Previous study conducted by Atudorei et al.(2022) where they used germinated chickpea flour incorporated in white flour at levels 5 to 20%, their sensory evaluation showed that the inclusion of 20% was much less appreciated by the jury. Other chickpea incorporation from 5 to 15% produced acceptable bread qualities according to the jury. In another study performed by Guardado-Felix et al. (2020), they substituted wheat flour with whole chickpea and germinated flour at 15% level. Their sensory study also showed that acceptable loaves of bread were produced at 15% incorporation level. Since in our sensory study the highest incorporation level was 7.5%, we believe that our incorporation level produced consistent data as previous studies. The above findings clearly indicate that chickpea can be incorporated into refined wheat flour at appropriate levels and produce similar quality bread while improving the mixing properties of the dough both beneficial to the baker and the end consumer.

4.4. Conclusion

This research has shown in consistently that adding chickpea flour can improve the mixing tolerance. This means that most of the quality of the dough will be preserved during overmixing when chickpea flour is incorporated. The dough strength was improved significantly by the incorporation of chickpea flour. This study clearly shows that chickpea flour could be used to replace some other industrial dough additives without at levels that will not affect the dough properties negatively. The sensory study conducted showed that chickpea flour incorporation at levels up to 7.5% does not affecting the bread quality. When overmixed, the dough with chickpea incorporation resisted to bread quality loss compared to wheat flour alone. The extensive addition of chickpea flour into wheat flour is not recommended in regard to improve the dough mixing properties. It is suggested that more work should be performed to properly identify the molecules in insoluble protein fraction that are responsible for improving the mixing tolerance and dough strength

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Tables

Table 4.1 Composite bread physical characteristics

Sample	Volume (cm^3)	Specific volume (cm^3/g)	Number of cells	Area of cell (%)	Hardness (g)
Control	612.50±17.68^{ab}	4.25±0.10^{ab}	3555.0±79.90^{a}	50.23±0.04^{ab}	595.21±6.88^{b}
1.75%-CP	622.50±3.54^{ab}	4.31±0.03^{ab}	3515.25±86.62^{a}	49.68±0.11^{ab}	574.50±3.49^{b}
3.75%-CP	640.00±7.07^{a}	4.48±0.06^{a}	3532.25±29.34^{a}	50.58±0.39^{a}	570.16±83.69^{b}
7.5%-CP	620.00±7.07^{ab}	4.27±0.04^{ab}	3560.25±99.35^{a}	50.10±0.00^{ab}	634.63±49.40^{b}
15%-CP	590.00±14.14^{b}	4.10±0.09^{b}	3443.25±31.74^{ab}	50.40±0.07^{a}	708.10±26.34^{b}
30%-CP	435.00±21.21^{d}	3.23±0.11^{d}	2601.75±160.87^{c}	50.23±0.18^{ab}	1269.78±120.51^{a}
OM-Control	545.50±3.54^{c}	3.77±0.03^{c}	3093.75±190.57^{b}	49.20±0.49^{b}	576.40±53.48^{b}
OM-7.5%-CP	602.50±3.54^{ab}	4.17±0.03^{b}	3519.50±30.41^{a}	49.81±0.44^{ab}	682.74±32.41^{b}

Means in the same column with a different superscript letter are significantly different ($p<0.05$)

xx-CP- level of kabuli chickpea incorporation in refined wheat flour

OM- overmixed dough

Table 4.2 Average responses on appearance, aroma, taste, and acceptability determined by sensory evaluation

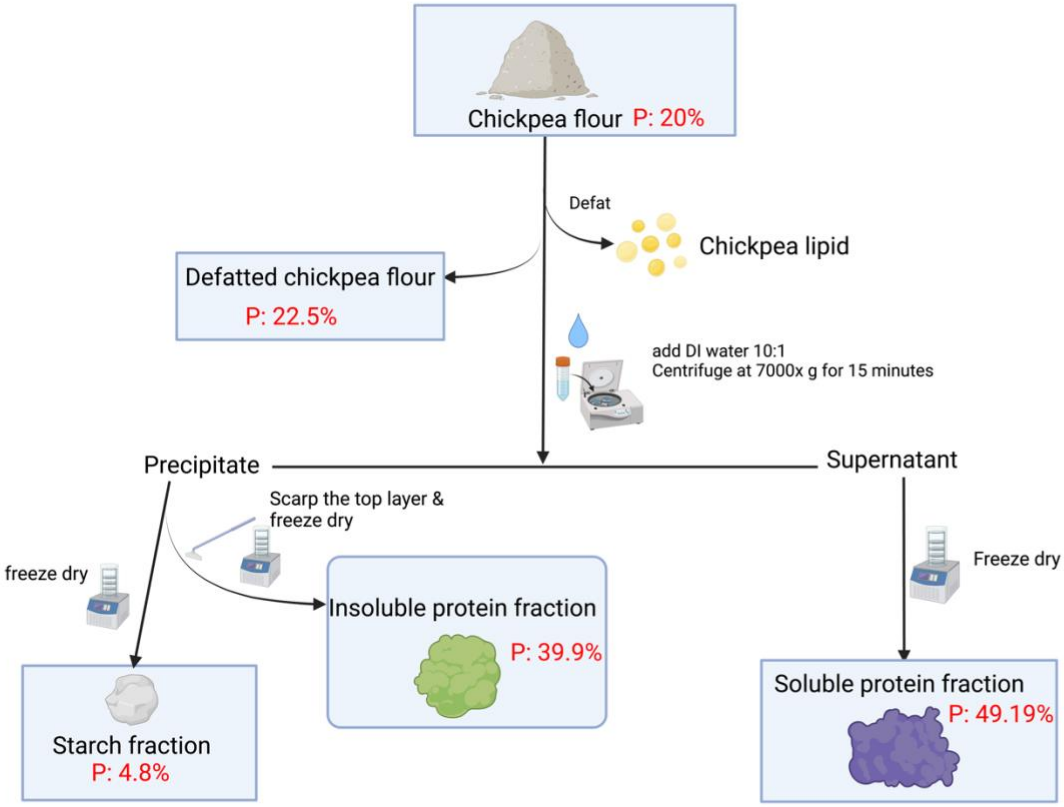
Treatment	Appearance	Aroma	Taste	Acceptability
Control	7.74±0.97[a]	7.36±1.41[a]	7.30±1.04[a]	7.60±0.76[a]
3.75%-CP	7.78±1.22[a]	7.62±1.03[a]	7.22±1.08[a]	7.52±0.87[a]
7.5%-CP	7.66±1.18[a]	7.38±1.30[a]	7.32±1.38[a]	7.24±1.22[a]

Panelists mean response in the same column with a different superscript letter are significantly different ($p<0.05$)

xx-CP- level of kabuli chickpea incorporation in refined wheat flour

Figures

Figure 4.1 Chickpea flour fractionation



P- Protein content

Figure 4.2 Mixograms of different flour before and after chickpea addition

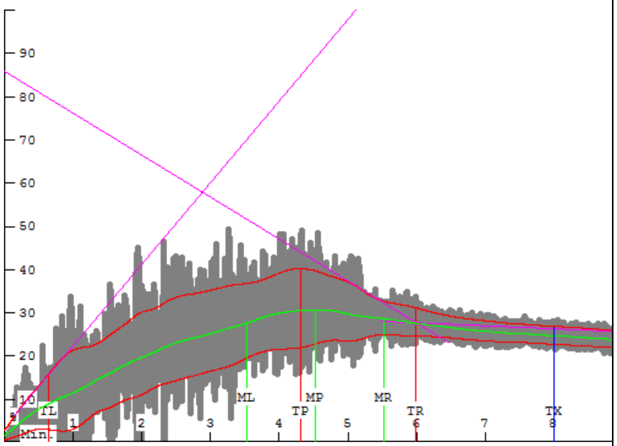
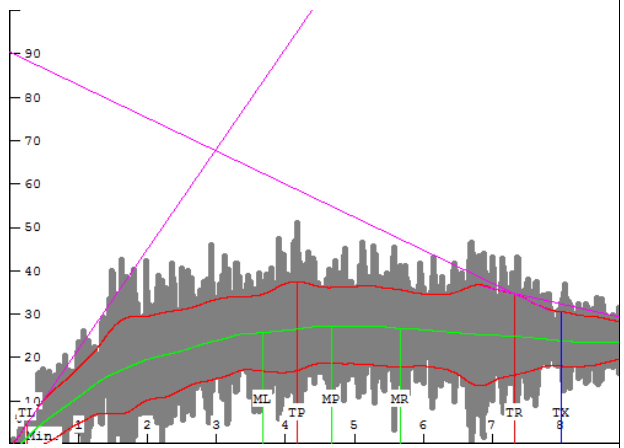
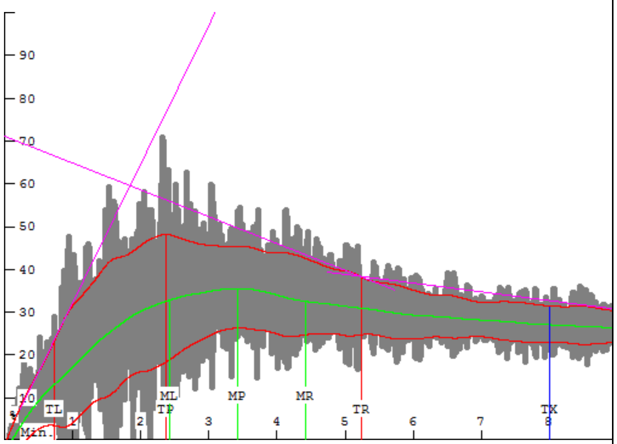
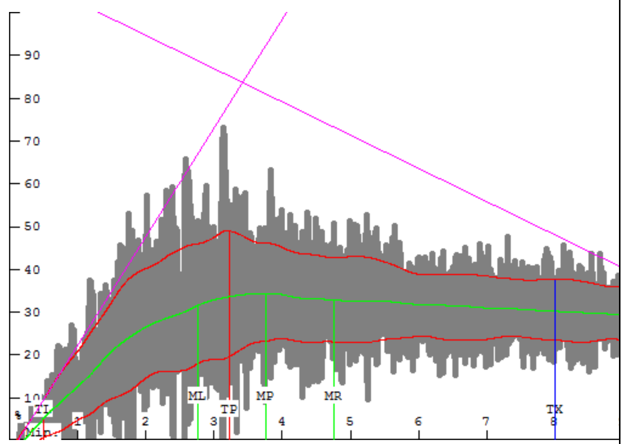
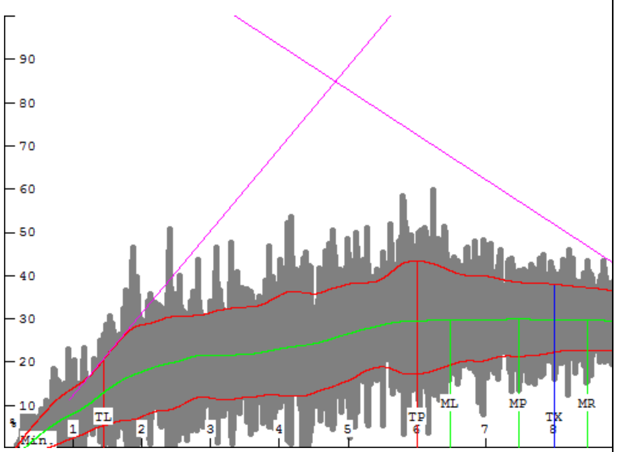
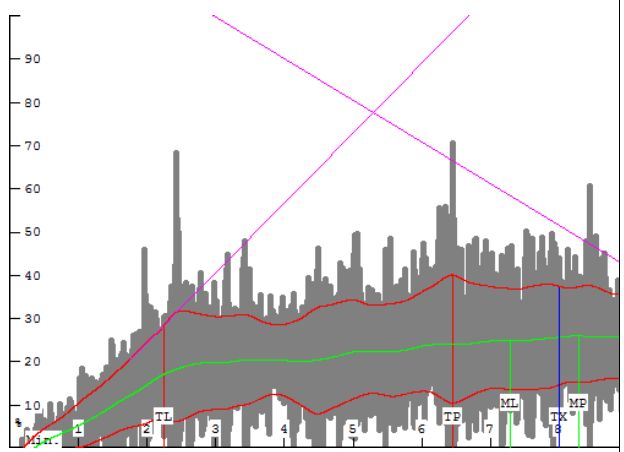
Control	7.5% chickpea flour added
Weak flour (W-11) 	Weak flour (W-11) 
Normal flour (W-7) 	Normal flour (W-7) 
Strong flour (W-17) 	Strong flour (W-17) 

Figure 4.3 Graph showing the dough strength changes as chickpea flour is added to all flour at 7.5%

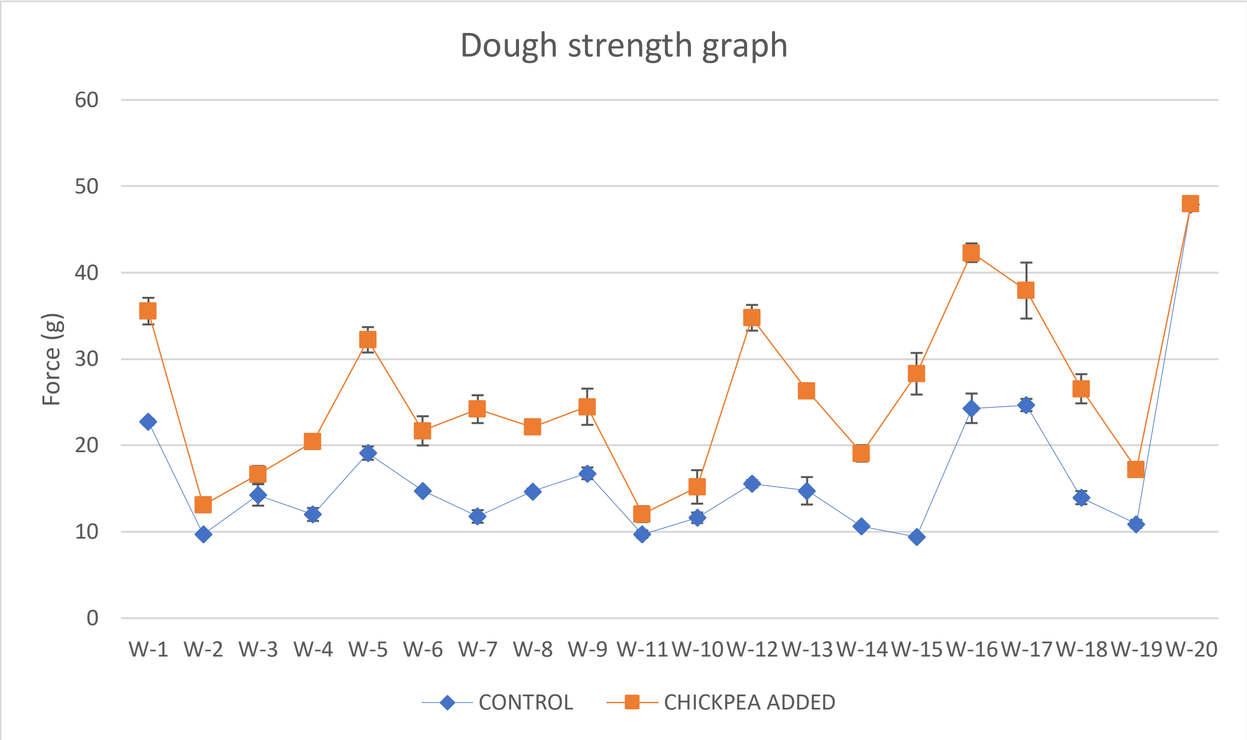
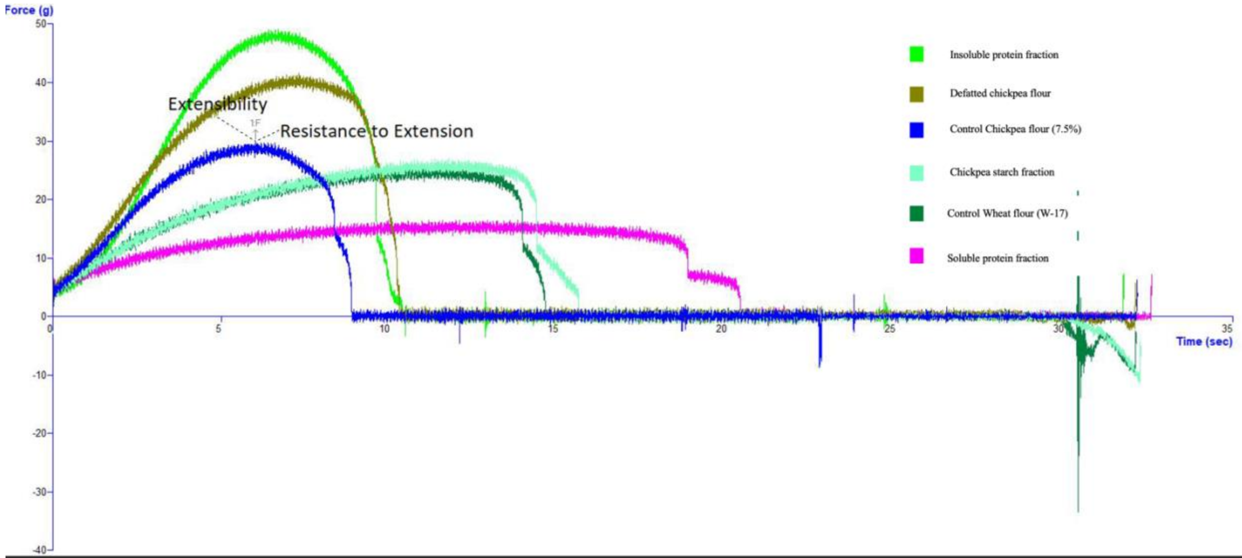


Figure 4.4 Extensibility of the dough when different chickpea flour fractions are added to the strong flour (W-17)



Appendix C - Supplementary materials

Tables

Table C1. mixograph data for all the flour and their blends

Sample ID	water absorption (%)	peak time (min.)	peak value (%)	peak width (%)	8 min. value (%)	8 min. width (%)	8 min. integral %*min	breakdown tolerance %	Mixing stability (%)
W-1-CONTROL (13.96 %)	60.70	6.82±0.69	29.80±0.12	17.87±0.53	28.69±0.40	15.75±1.98	164.63±11.24	1.11±0.28	0.21±0.19
W-1-CP	60.70	6.01±1.97	28.17±3.03	24.49±2.32	26.73±1.18	20.17±0.97*	168.18±34.76	1.44±1.84	1.13±0.84
W-2-CONTROL (9.68 %)	60.10	4.38±0.28	27.18±1.63	14.15±0.14	21.25±1.10	4.62±0.01	168.81±19.43	5.94±0.53	0.35±0.11
W-2-CP	60.10	5.59±0.02	23.55±0.63*	12.41±1.02	21.18±0.05	9.61±0.41*	157.93±0.98	2.37±0.58*	0.49±0.12
W-3-CONTROL (10.70 %)	60.90	4.49±0.25	33.29±0.21	20.26±1.04	27.05±0.44	11.27±0.90	195.18±6.60	6.24±0.65	0.95±0.97
W-3-CP	60.90	4.92±0.23	28.38±0.01*	23.42±1.15	26.19±0.04	17.10±0.59*	168.26±0.94	2.19±0.05*	0.26±0.02
W-4-CONTROL (12.57 %)	64.30	3.44±0.40	42.95±3.90	21.99±2.89	32.33±4.87	9.33±2.99	258.47±33.00	10.63±0.97	2.43±0.99
W-4-CP	64.30	3.05±0.08	36.29±0.21*	23.76±0.69	30.21±0.40	16.22±1.82*	228.08±2.75	6.08±0.18*	4.84±0.35
W-5-CONTROL (9.69 %)	59.10	4.41±0.52	35.78±1.28	22.10±5.80	27.97±0.26	8.64±1.21	218.62±17.92	7.81±1.02	1.26±0.17
W-5-CP	59.10	4.83±0.35	30.15±1.01*	25.93±6.16	28.91±0.73	17.79±1.21*	203.22±4.86	1.24±0.28*	0.77±0.27*
W-6-CONTROL (10.99 %)	61.10	3.00±0.21	40.30±0.96	22.21±1.82	30.84±0.18	8.00±0.04	264.39±4.77	9.46±0.79	0.81±0.40
W-6-CP	61.10	3.37±0.09	36.26±1.78*	27.40±2.77	33.04±0.95	16.88±3.72*	255.57±11.21	3.22±0.84*	1.77±0.79*
W-7-CONTROL (9.74 %)	60.00	3.75±0.01	34.53±0.99	20.33±0.43	28.00±1.11	10.58±1.49	220.33±1.27	7.56±1.33	0.89±0.58
W-7-CP	60.00	3.41±0.37	28.22±0.53*	18.75±1.02	25.06±0.03*	14.34±1.07	201.36±1.05	3.16±0.56*	0.44±0.13
W-8-CONTROL (11.15 %)	60.60	2.78±0.11	38.77±0.56	21.80±2.35	28.24±0.05	8.49±0.45	252.55±0.90	10.52±0.61	0.02±0.02
W-8-CP	60.60	2.99±0.16	33.69±0.47*	26.49±2.77	29.94±0.05	12.71±1.46*	240.20±1.73	3.75±0.43*	0.91±0.22
W-9-CONTROL (10.54 %)	61.30	5.60±0.45	32.79±0.04	20.11±4.47	29.48±1.48	15.54±3.09	198.26±4.23	3.31±1.44	0.16±0.19
W-9-CP	61.30	5.00±0.55	30.64±0.47	25.20±1.31	28.28±1.02	20.93±2.05	185.57±10.17	2.36±0.56	1.64±0.11
W-10-CONTROL (12.40 %)	64.20	3.76±0.02	32.70±0.33	23.18±4.65	24.53±1.20	6.12±0.88	216.18±27.39	8.17±1.53	2.52±0.02
W-10-CP	64.20	4.13±0.09	30.60±0.72	20.69±1.79	27.28±0.18*	15.88±0.71*	192.11±2.24	3.32±0.55*	2.09±0.78
W-11-CONTROL (11.24 %)	62.40	4.35±0.25	30.85±0.17	19.26±3.43	24.33±0.54	4.20±0.05	185.37±1.69	6.52±0.70	1.13±0.34
W-11-CP	62.40	4.81±0.19	26.96±0.52*	16.92±0.78	23.54±0.46	12.08±0.63*	168.44±5.01*	3.42±0.06*	0.52±0.58
W-12-CONTROL (10.01 %)	60.60	3.67±0.53	34.29±1.89	20.65±1.62	27.35±1.58	7.40±0.55	223.59±9.10	6.36±0.52	2.17±1.99
W-12-CP	60.60	4.43±0.02	28.62±1.53*	18.96±1.20	25.58±1.13	17.47±1.03*	178.23±8.94	3.03±0.40*	0.96±0.29
W-13-CONTROL (10.69 %)	61.60	3.54±0.64	36.56±0.46	19.39±0.77	28.30±0.95	11.47±0.57	227.09±16.38	8.26±0.49	1.44±0.58

W-13-CP	61.60	4.95±0.88	28.73±1.89*	20.82±0.27	27.52±0.91	16.27±2.92*	187.15±21.56	1.21±0.97*	0.61±0.56
W-14-CONTROL (10.03 %)	60.60	4.61±0.62	36.08±2.29	19.64±0.58	29.21±1.11	10.42±3.22	201.50±4.17	8.05±0.49	0.30±0.42
W-14-CP	60.60	4.18±0.22	31.70±1.89*	23.24±0.22	29.63±1.15	15.67±0.59	195.60±11.42	2.07±0.74*	1.66±0.79
W-15-CONTROL (9.00 %)	59.00	5.05±0.11	33.16±0.77	20.35±2.21	26.57±0.16	6.36±0.27	183.17±5.93	6.59±0.93	0.36±0.24
W-15-CP	59.00	7.20±2.40*	26.32±1.05*	16.27±4.66	25.61±0.89	16.18±0.79*	149.39±0.28*	0.71±0.16*	1.39±0.03
W-16-CONTROL (13.67 %)	61.00	6.55±1.65	33.39±2.46	21.66±6.70	32.58±1.48	16.83±0.07	182.76±19.68	0.81±0.98	1.10±1.12
W-16-CP	61.00	6.32±0.81	26.45±1.69*	21.20±1.09	25.55±1.03*	22.17±2.68*	162.41±10.32	0.91±0.66	0.81±0.44
W-17-CONTROL (9.18 %)	60.10	6.57±1.30	31.51±2.21	22.59±7.79	30.83±1.47	16.67±1.30	187.55±24.25	0.67±0.74	1.07±1.40
W-17-CP	60.10	8.70±0.57*	25.53±0.60*	23.71±2.52	25.19±0.70*	22.75±0.09*	138.43±4.99*	0.33±0.10	1.13±0.63
W-18-CONTROL (9.88 %)	60.40	4.45±0.16	30.05±0.28	15.28±0.37	25.64±0.26	10.32±2.31	201.40±6.76	4.41±0.02	0.49±0.11
W-18-CP	60.40	3.96±0.11	26.59±0.41*	17.10±0.01	24.74±0.10	15.03±0.17*	186.29±1.96	1.86±0.51*	0.52±0.06
W-19-CONTROL (11.08 %)	62.30	3.72±0.06	38.03±2.07	23.96±6.31	27.45±0.21	5.14±0.62	226.97±12.95	10.58±2.28	3.56±2.04
W-19-CP	62.30	5.96±0.55*	34.49±1.06*	18.98±3.14	32.65±0.62*	18.59±5.17*	223.70±10.51	1.84±0.44*	0.32±0.03
W-20-CONTROL (14.22 %)	63.80	5.82±0.01	38.16±0.44	31.82±7.91	35.56±0.86	24.13±1.84	227.76±12.92	2.60±0.41	2.22±0.03
W-20-CP	63.80	8.11±0.36*	33.17±0.07*	31.14±2.50	32.91±0.11*	35.24±5.49*	188.26±15.15	0.26±0.18*	0.19±0.18

*Significantly ($p<0.05$) from the control flour

W-xx-CP: denotes the flour (xx) incorporated with kabuli chickpea flour at 7.5% (w/w)

(xx %): protein content of the control flour

Table C2. Mixograph data of chickpea flour at different ratio blended in the weak wheat flour

Sample ID	peak time (min.)	peak value (%)	peak width (%)	8 min. value (%)	8 min. width (%)	8 min. integral %*min	breakdown tolerance %	Mixing stability (%)
Control (W-11)	4.35 ± 0.25^{b}	30.85 ± 0.17^{a}	19.26 ± 3.43^{a}	24.33 ± 0.54^{c}	4.20 ± 0.05^{c}	185.37 ± 1.69^{ab}	6.52 ± 0.70^{a}	1.13 ± 0.34^{a}
1% CHICKPEA	5.07 ± 0.25^{ab}	24.64 ± 0.04^{d}	14.46 ± 1.66^{a}	22.04 ± 0.11^{e}	7.51 ± 0.30^{bc}	150.49 ± 3.93^{cd}	2.60 ± 0.15^{b}	1.18 ± 0.57^{a}
3.75% CHICKPEA	5.60 ± 0.19^{a}	24.62 ± 0.86^{d}	13.70 ± 0.68^{a}	22.61 ± 0.56^{de}	13.51 ± 0.74^{ab}	152.31 ± 6.30^{cd}	2.01 ± 0.30^{b}	0.72 ± 0.17^{a}
7.5% CHICKPEA	4.81 ± 0.19^{ab}	26.96 ± 0.52^{c}	16.92 ± 0.78^{a}	23.54 ± 0.46^{cd}	12.08 ± 0.63^{abc}	168.44 ± 5.01^{cb}	3.42 ± 0.06^{b}	0.52 ± 0.58^{a}
15% CHICKPEA	5.29 ± 0.17^{ab}	21.96 ± 0.31^{e}	11.22 ± 0.62^{a}	19.79 ± 0.15^{f}	10.85 ± 0.88^{abc}	136.67 ± 3.59^{de}	2.17 ± 0.16^{b}	0.25 ± 0.21^{a}
30% CHICKPEA	5.19 ± 0.03^{ab}	19.90 ± 0.04^{f}	11.57 ± 1.03^{a}	17.01 ± 0.06^{g}	8.34 ± 1.07^{bc}	113.24 ± 0.92^{e}	2.89 ± 0.02^{b}	0.91 ± 0.07^{a}
7.5% DESI CHICKPEA	5.74 ± 0.05^{a}	30.44 ± 0.52^{ab}	18.89 ± 3.78^{a}	27.99 ± 0.22^{a}	16.96 ± 3.57^{a}	194.75 ± 10.52^{a}	2.45 ± 0.74^{b}	0.39 ± 0.24^{a}
7.5% S CHICKPEA	5.55 ± 0.59^{a}	30.40 ± 0.12^{ab}	16.44 ± 0.83^{a}	27.66 ± 0.58^{a}	16.59 ± 4.16^{a}	187.43 ± 2.48^{ab}	2.74 ± 0.46^{b}	0.17 ± 0.05^{a}
7.5% M CHICKPEA	4.81 ± 0.19^{ab}	26.96 ± 0.52^{c}	16.92 ± 0.78^{a}	23.54 ± 0.46^{cd}	12.08 ± 0.63^{abc}	168.44 ± 5.01^{cb}	3.42 ± 0.06^{b}	0.52 ± 0.58^{a}
7.5% L CHICKPEA	5.43 ± 0.25^{a}	28.72 ± 0.57^{bc}	17.48 ± 1.97^{a}	26.11 ± 0.06^{b}	17.20 ± 1.11^{a}	179.42 ± 7.04^{ab}	2.61 ± 0.63^{b}	0.54 ± 0.09^{a}

S: Small-sized, M: Medium-sized, L: Large-sized

Kabuli chickpea flour was used for all the tests except stated otherwise

Means in the same column with a different superscript letter are significantly different ($p<0.05$)

Water absorption: 62.40%

Table C3. Mixograph data of chickpea flour fractions blended in the weak wheat flour

Sample ID	peak time (min.)	peak value (%)	peak width (%)	8 min. value (%)	8 min. width (%)	8 min. integral %*min	breakdown tolerance %	Mixing stability (%)
Control (W-11)	4.35±0.25[a]	30.85±0.17[b]	19.26±3.43[a]	24.33±0.54[c]	4.20±0.05[e]	185.37±1.69[bc]	6.52±0.70[a]	1.13±0.34[a]
7.5% CHICKPEA FLOUR	4.81±0.19[a]	26.96±0.52[c]	16.92±0.78[a]	23.54±0.46[c]	12.08±0.63[bc]	168.44±5.01[c]	3.42±0.06[bc]	0.52±0.58[a]
7.5% DEFATTED CHICKPEA	5.48±0.57[a]	31.86±1.05[ab]	18.61±0.66[a]	29.74±0.36[ab]	16.62±0.68[a]	200.40±3.06[ab]	2.12±0.68[cd]	1.14±1.05[a]
7.5% CHICKPEA STARCH	4.71±0.04[a]	34.28±0.08[a]	21.61±2.61[a]	28.01±0.07[ab]	7.19±0.19[d]	213.52±1.28[a]	6.28±0.02[a]	0.35±0.26[a]
7.5% SOLUBLE PROTEIN	3.99±0.62[a]	31.78±0.91[ab]	19.56±0.01[a]	27.36±0.77[b]	9.56±0.64[cd]	189.31±5.93[bc]	4.42±0.13[b]	2.35±1.11[a]
7.5% INSOLUBLE PROTEIN	5.55±0.35[a]	31.78±1.12[ab]	18.19±1.09[a]	30.52±1.08[a]	12.66±1.28[b]	196.79±10.68[ab]	1.26±0.04[d]	0.68±0.85[a]

Means in the same column with a different superscript letter are significantly different ($p<0.05$)

Water absorption: 62.40%

Kabuli chickpea flour was used for all the tests except stated otherwise

Table C4. Mixograph data of chickpea flour at different ratio blended in the strong wheat flour

Sample ID	peak time (min.)	peak value (%)	peak width (%)	8 min. value (%)	8 min. width (%)	8 min. integral %*min	breakdown tolerance %	Mixing stability (%)
W-17 (Control)	5.63±0.03^{b}	31.69±1.95^{ab}	27.67±0.67^{a}	31.00±1.47^{a}	16.67±1.30^{cd}	202.425±3.21^{a}	0.67±0.71^{a}	2.54±0.67^{b}
1% CHICKPEA	7.69±0.21^{a}	32.39±0.15^{ab}	22.50±0.07^{a}	29.96±0.62^{a}	18.88±0.20^{bc}	199.68±0.65^{ab}	1.20±0.47^{a}	0.34±0.07^{c}
3.75% CHICKPEA	9.08±0.78^{a}	31.69±0.63^{ab}	22.71±0.81^{a}	29.61±0.91^{a}	24.16±1.05^{ab}	173.88±0.51^{bc}	2.08±0.28^{a}	0.43±0.48^{c}
7.5% CHICKPEA	8.63±0.67^{a}	31.16±1.62^{ab}	27.48±4.26^{a}	30.83±1.98^{a}	26.04±2.26^{a}	179.16±12.60^{abc}	0.33±0.35^{a}	0.58±0.31^{c}
15% CHICKPEA	8.88±0.19^{a}	27.31±1.34^{ab}	18.94±0.96^{ab}	26.96±1.41^{a}	17.95±1.14^{c}	157.76±4.92^{c}	0.35±0.06^{a}	0.34±0.00^{c}
30% CHICKPEA	9.11±0.05^{a}	20.92±1.10^{c}	11.95±1.31^{b}	19.35±1.74^{b}	11.99±1.22^{d}	105.87±2.28^{d}	1.57±0.64^{a}	5.29±0.00^{a}
7.5% DESI CHICKPEA	8.78±0.46^{a}	32.16±0.24^{ab}	21.18±0.35^{a}	31.13±0.74^{a}	27.70±0.37^{a}	185.75±3.71^{ab}	1.04±0.50^{a}	0.84±0.91^{bc}
7.5% S CHICKPEA	8.66±0.43^{a}	33.26±0.28^{ab}	24.87±0.72^{a}	31.93±0.67^{a}	25.64±0.46^{a}	173.50±2.63^{bc}	1.33±0.95^{a}	1.54±0.28^{bc}
7.5% M CHICKPEA	8.63±0.67^{a}	31.16±1.62^{ab}	27.48±4.26^{a}	30.83±1.98^{a}	26.04±2.26^{a}	179.16±12.60^{abc}	0.33±0.35^{a}	0.58±0.31^{c}
7.5% L CHICKPEA	8.41±0.32^{a}	31.96±1.01^{ab}	25.55±0.59^{a}	31.82±1.03^{a}	24.43±0.61^{a}	182.28±1.23^{abc}	0.14±0.03^{a}	0.71±0.43^{c}

S: Small-sized, M: Medium-sized, L: Large-sized

Kabuli chickpea flour was used for all the tests except stated otherwise

Means in the same column with a different superscript letter are significantly different ($p<0.05$)

Water absorption: 60.10%

Table C5. Mixograph data of chickpea flour fractions blended in the strong wheat flour

Sample ID	peak time (min.)	peak value (%)	peak width (%)	8 min. value (%)	8 min. width (%)	8 min. integral %*min	breakdown tolerance %	Mixing stability (%)
W-17 (Control)	6.57 ± 1.30^{c}	31.51 ± 2.21^{a}	27.67 ± 0.67^{a}	31.00 ± 1.47^{a}	16.67 ± 1.30^{b}	202.425 ± 3.21^{ab}	0.67 ± 0.71^{a}	2.54 ± 0.67^{b}
7.5% CHICKPEA	8.63 ± 0.67^{a}	31.16 ± 1.62^{a}	27.48 ± 4.26^{ab}	30.83 ± 1.98^{a}	26.04 ± 2.26^{a}	179.16 ± 12.60^{b}	0.33 ± 0.35^{a}	0.58 ± 0.31^{c}
7.5% DEFATTED CHICKPEA	8.63 ± 0.25^{a}	31.88 ± 0.77^{a}	21.15 ± 0.26^{ab}	31.14 ± 1.42^{a}	21.13 ± 0.48^{b}	184.84 ± 4.83^{ab}	0.74 ± 0.65^{a}	1.77 ± 1.0^{a}
7.5% CHICKPEA STARCH	6.92 ± 0.13^{bc}	34.65 ± 0.54^{a}	20.95 ± 1.14^{ab}	33.09 ± 1.24^{a}	19.08 ± 0.54^{b}	208.33 ± 1.15^{a}	1.56 ± 0.69^{a}	0.63 ± 0.18^{c}
7.5% SOLUBLE PROTEIN	6.74 ± 0.22^{bc}	31.73 ± 0.58^{a}	20.28 ± 0.20^{b}	30.71 ± 0.38^{a}	16.90 ± 1.11^{b}	178.19 ± 4.28^{b}	1.02 ± 0.20^{a}	0.84 ± 0.23^{bc}
7.5% INSOLUBLE PROTEIN	7.44 ± 0.55^{ab}	31.77 ± 0.53^{a}	20.72 ± 0.38^{ab}	31.62 ± 0.49^{a}	20.11 ± 0.93^{b}	185.36 ± 4.24^{ab}	0.15 ± 0.04^{a}	1.26 ± 0.44^{bc}

Means in the same column with a different superscript letter are significantly different ($p<0.05$)

Water absorption: 60.10%

Kabuli chickpea flour was used for all the tests except stated otherwise

Table C6. Effect of chickpea flour addition to the wheat dough extensibility

Sample ID	Strength (g)	Extensibility (mm)
W-1	22.82±0.34	33.73±5.12
W-1-CP	35.55±1.54*	20.60±0.98*
W-2	9.73±0.01	0.00±0.00#
W-2-CP	12.26±1.16*	17.77±1.62*
W-3	13.38±1.00	25.66±1.46
W-3-CP	16.65±1.01*	35.16±0.65*
W-4	12.01±0.75	25.73±10.13
W-4-CP	20.37±0.62*	30.23±5.35
W-5	19.74±0.86	45.07±9.39
W-5-CP	30.30±1.44*	30.79±3.16*
W-6	15.17±0.87	26.79±5.57
W-6-CP	21.69±1.70*	25.63±3.16
W-7	12.42±0.85	27.35±7.23
W-7-CP	22.70±2.38*	23.55±5.63
W-8	15.03±0.29	33.53±0.25
W-8-CP	20.14±2.02*	25.07±3.00*
W-9	15.68±2.28	22.59±2.84
W-9-CP	24.48±2.10*	34.37±2.24*
W-10	11.63±0.61	44.01±4.59
W-10-CP	15.20±1.94*	39.93±4.61
W-11	9.73±0.43	0.00±0.00#
W-11-CP	12.05±0.92*	32.43±2.34*
W-12	15.56±0.43	34.78±1.50
W-12-CP	21.78±2.26*	20.21±2.04*
W-13	14.95±1.91	35.21±5.85
W-13-CP	24.77±2.24*	25.34±1.97*
W-14	10.69±0.09	25.65±7.66
W-14-CP	18.04±1.03*	37.20±1.04*
W-15	9.88±0.53	0.00±0.00
W-15-CP	26.96±2.63*	22.82±1.86*
W-16	23.19±2.00	31.70±2.31

W-16-CP	39.74±2.45*	21.49±1.33*
W-17	27.94±4.09	29.25±4.95
W-17-CP	40.11±3.22*	25.32±1.25*
W-18	14.77±1.07	34.45±3.86
W-18-CP	25.12±2.46*	20.80±1.11*
W-19	10.76±0.50	37.85±8.05
W-19-CP	16.44±1.35*	40.17±2.43
W-20	47.92±3.20	15.05±0.74
W-20-CP	47.99±3.18	18.63±1.63

*Significantly ($p<0.05$) from the control flour

[#]dough extensibility couldn't be quantified since the dough was too weak to trigger (10 g) the measuring sensors

W-xx-CP: denotes the flour incorporated with kabuli chickpea flour at 7.5% (w/w)

Table C7. Extensibility of the dough when different ratio of chickpea flour are added to a weak flour

Sample ID	Dough strength (g)	Extensibility (mm)
W-11	9.73 ± 0.43^{b}	$0.00\pm0.00^{\#c}$
1% CP	10.75 ± 0.92^{ab}	16 ± 2.06^{b}
3.75% CP	11.91 ± 0.68^{a}	36.82 ± 2.53^{a}
7.5% CP	11.51 ± 0.59^{ab}	33.66 ± 2.51^{a}
15% CP	10.26 ± 0.28^{ab}	$0.00\pm0.00^{\#c}$
30% CP	0.00 ± 0.00^{c}	0.00 ± 0.00^{c}
7.5% DESI	12.06 ± 0.95^{a}	28.98 ± 6.27^{a}
7.5% KABULI	11.51 ± 0.59^{bc}	33.66 ± 2.51^{a}
7.5% SCP	11.10 ± 0.46^{ab}	35.29 ± 2.52^{a}
7.5% MCP	11.51 ± 0.59^{a}	33.66 ± 2.51^{a}
7.5% LCP	11.58 ± 1.43^{a}	31.37 ± 4.11^{a}

S: Small-sized, M: Medium-sized, L: Large-sized

[#]dough extensibility couldn't be quantified since the dough was too weak to trigger (10 g) the measuring sensors

Means in the same column with a different superscript letter are significantly different ($p<0.05$)

0 value indicate a very weak dough that didn't reach the threshold level (10g) to trigger the sensor

CP- chickpea flour incorporation

Kabuli chickpea flour was used for all the tests except stated otherwise

Table C8. Dough extensibility when chickpea flour fractions are added to a weak flour

Sample ID	Dough strength (g)	Extensibility (mm)
W-11	9.73±0.43[c]	0.00±0.00[#b]
7.5% CHICKPEA	11.51±0.59[b]	33.66±2.51[a]
7.5% DEFAT	12.47±1.79[b]	32.43±1.73[a]
7.5% STARCH CPF	9.64±0.49[bc]	0.00±0.00[#b]
7.5% SOLUBLE P CPF	0.00±0.00[d]	0.00±0.00[#b]
7.5% INSOLUBLE P CPF	15.56±1.81[a]	30.96±0.82[a]

Means in the same column with a different superscript letter are significantly different (p<0.05)

[#]dough extensibility couldn't be quantified since the dough was too weak to trigger (10 g) the measuring sensors

0 value indicate a very weak dough that didn't reach the threshold level (10g) to trigger the sensor

PCPF- Protein chickpea fraction; CPF-Chickpea fraction

Kabuli chickpea flour was used for all the tests except stated otherwise

Table C9. Dough extensibility when chickpea is added to a strong flour at different ratios

Sample ID	Dough strength (g)	Extensibility (mm)
W-17	27.94±4.09[d]	29.25±4.95[a]
1% CP	30.46±3.25[bcd]	20.97±3.06[ab]
3.75% CP	29.91±4.27[cd]	19.61±1.66[bc]
7.5% CP	40.11±3.22[a]	25.32±1.25[ab]
15% CP	31.77±2.46[bcd]	24.81±2.61[ab]
30% CP	15.72±0.33[e]	24.71±1.92[ab]
7.5% DESI	40.72±3.98[a]	17.10±0.98[c]
7.5% KABULI	40.11±3.22[a]	25.32±1.25[ab]
7.5% SCP	37.18±1.28[abc]	19.93±039[bc]
7.5% MCP	40.11±3.22[b]	25.32±1.25[ab]
7.5% LCP	37.99±1.41[ab]	24.27±1.66[ab]

S: Small-sized, M: Medium-sized, L: Large-sized

Means in the same column with a different superscript letter are significantly different ($p<0.05$)

CP- Kabuli chickpea incorporation

Table C10. Dough extensibility when chickpea flour fractions are added to a strong flour

Sample ID	Dough strength (g)	Extensibility (mm)
W-17	27.94±4.09^{c}	29.25±4.95^{ab}
7.5% CHICKPEA	40.11±3.22^{b}	25.32±1.25^{ab}
7.5% DEFAT	37.11±1.81^{b}	19.38±0.92^{b}
7.5% STARCH CPF	27.11±1.02^{c}	35.07±1.80^{a}
7.5% SOLUBLE PCPF	15.08±1.52^{d}	32.58±9.62^{a}
7.5% INSOLUBLE PCPF	48.98±2.68^{a}	21.45±0.73^{b}

Means in the same column with a different superscript letter are significantly different ($p<0.05$)

PCPF- protein chickpea fraction; CPF: chickpea fraction

Kabuli chickpea flour was used for all the tests except stated otherwise

Table C11. Composite bread physical characteristics

Sample	Volume (cm^3)	Specific volume (cm^3/g)	Number of cells	Area of cell (%)	Wall thickness (mm)	Cell diameter (mm)
Control	612.50±17.68^{ab}	4.25±0.10^{ab}	3555.0±79.90^{a}	50.23±0.04^{ab}	0.42±0.00^{a}	1.69±0.00^{a}
1.75%-CP	622.50±3.54^{ab}	4.31±0.03^{ab}	3515.25±86.62^{a}	49.68±0.11^{ab}	0.42±0.00^{a}	1.66±0.01^{a}
3.75%-CP	640.00±7.07^{a}	4.48±0.06^{a}	3532.25±29.34^{a}	50.58±0.39^{a}	0.42±0.00^{a}	1.76±0.04^{a}
7.5%-CP	620.00±7.07^{ab}	4.27±0.04^{ab}	3560.25±99.35^{a}	50.10±0.00^{ab}	0.42±0.00^{a}	1.67±0.01^{a}
15%-CP	590.00±14.14^{b}	4.10±0.09^{b}	3443.25±31.74^{ab}	50.40±0.07^{a}	0.42±0.00^{a}	1.69±0.01^{a}
30%-CP	435.00±21.21^{d}	3.23±0.11^{d}	2601.75±160.87^{c}	50.23±0.18^{ab}	0.42±0.00^{a}	1.68±0.00^{a}
OM-Control	545.50±3.54^{c}	3.77±0.03^{c}	3093.75±190.57^{b}	49.20±0.49^{b}	0.43±0.02^{a}	1.74±0.15^{a}
OM-7.5%-CP	602.50±3.54^{ab}	4.17±0.03^{b}	3519.50±30.41^{a}	49.81±0.44^{ab}	0.42±0.00^{a}	1.64±0.01^{a}

Means in the same column with a different superscript letter are significantly different ($p<0.05$)

xx-CP- level of kabuli chickpea incorporation in refined wheat flour

OM- overmixed dough

Table C12. Bread Crust and crumb color

	Crust			Crumb		
Sample	L*	a	b	L*	a	b
Control	52.10±2.02^{bc}	13.38±0.18^{ab}	29.86±1.45^{b}	61.41±2.52^{ab}	1.36±0.15^{d}	13.96±0.44^{bc}
1.75%-CP	52.02±1.27^{bc}	13.08±1.24^{ab}	29.31±1.49^{bc}	64.15±0.58^{a}	1.46±0.07^{cd}	11.92±0.47^{e}
3.75%-CP	51.41±1.23^{bc}	12.66±0.35^{bc}	27.45±0.81^{cd}	61.99±2.21^{ab}	1.54±0.08^{bcd}	12.21±0.19^{de}
7.5%-CP	51.08±0.89^{bc}	14.19±0.36^{a}	30.48±0.61^{b}	61.25±1.48^{ab}	1.62±0.12^{bc}	13.23±0.13^{cd}
15%-CP	49.11±1.02^{c}	13.40±0.41^{ab}	26.94±0.54^{d}	62.22±0.71^{ab}	1.59±0.05^{bcd}	14.64±0.50^{b}
30%-CP	40.99±0.74^{d}	11.63±0.13^{c}	20.15±0.49^{e}	58.48±1.38^{b}	2.24±0.12^{a}	20.68±0.70^{a}
OM-Control	57.85±1.80^{a}	12.49±0.54^{ab}	33.71±0.30^{a}	61.75±0.71^{ab}	1.40±0.06^{cd}	13.02±0.15^{cd}
OM-7.5%-CP	52.66±1.36^{b}	13.52±0.56^{ab}	31.10±0.59^{b}	60.17±2.98^{ab}	1.74±0.16^{b}	13.31±0.57^{c}

Means in the same column with a different superscript letter are significantly different ($p<0.05$)

xx-CP- level of kabuli chickpea incorporation in refined wheat flour

OM- overmixed dough

Table C13. Texture profile analysis of different loaves of bread at different incorporation level and different mixing times

Sample	Hardness (g)	Adhesiveness (g*sec)	Resilience (%)	Cohesion	Springiness (%)	Gumminess	Chewiness
Control	595.21±6.88[b]	0.11±0.04[a]	32.77±0.33[a]	0.68±0.00[a]	95.16±0.02[ab]	406.29±4.85[b]	386.62±4.52[b]
1.75%-CP	574.50±3.49[b]	0.15±0.02[a]	32.65±1.13[ab]	0.69±0.02[a]	97.60±0.09[a]	393.52±8.90[b]	384.09±8.33[b]
3.75%-CP	570.16±83.69[b]	0.12±0.00[a]	31.95±1.09[ab]	0.68±0.02[a]	96.46±1.35[ab]	386.95±46.16[b]	372.94±39.30[b]
7.5%-CP	634.63±49.40[b]	0.10±0.09[a]	31.46±0.02[ab]	0.67±0.00[a]	96.89±0.51[ab]	422.89±33.65[b]	409.84±34.76[b]
15%-CP	708.10±26.34[b]	0.00±0.03[a]	28.50±0.76[b]	0.63±0.01[a]	94.98±0.21[ab]	445.21±23.26[b]	422.82±21.18[b]
30%-CP	1269.78±120.51[a]	-0.68±0.88[a]	19.28±2.22[c]	0.49±0.03[b]	92.40±0.31[b]	613.54±20.54[a]	566.86±17.05[a]
OM-Control	576.40±53.48[b]	0.17±0.06[a]	31.60±0.76[ab]	0.65±0.02[a]	95.98±2.13[ab]	373.71±25.59[b]	358.41±16.62[b]
OM-7.5%-CP	682.74±32.41[b]	0.09±0.03[a]	32.91±0.37[a]	0.67±0.00[a]	96.73±2.01[ab]	455.97±23.08[b]	440.85±13.15[b]

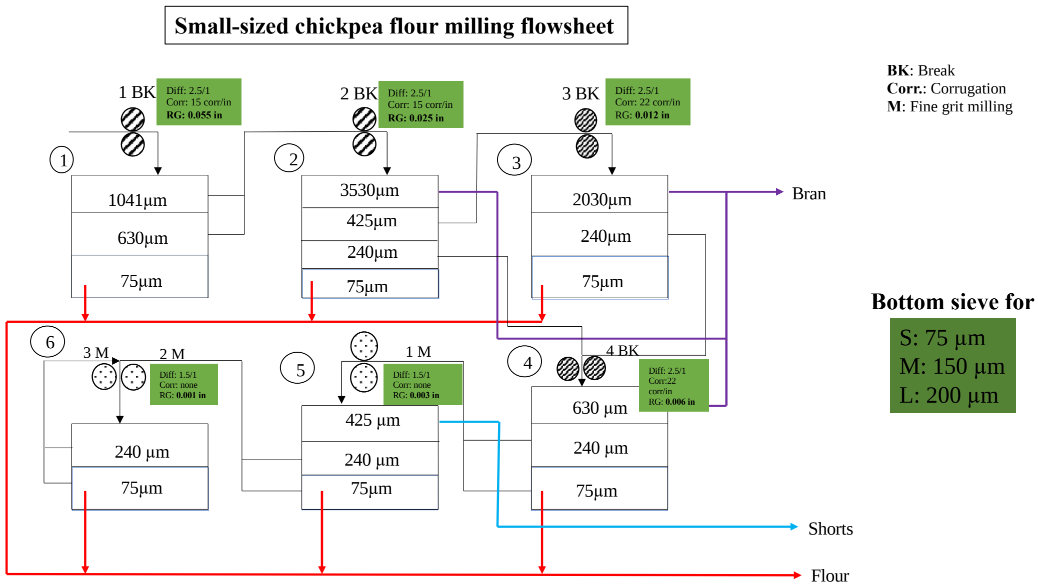
Means in the same column with a different superscript letter are significantly different ($p<0.05$)

xx-CP- level of kabuli chickpea incorporation in refined wheat flour

OM- overmixed dough

Figures

Figure C1. Chickpea milling flow sheet



S: Small-sized, M: Medium-sized, L: Large-sized

Figure C2. Mixogram parameters

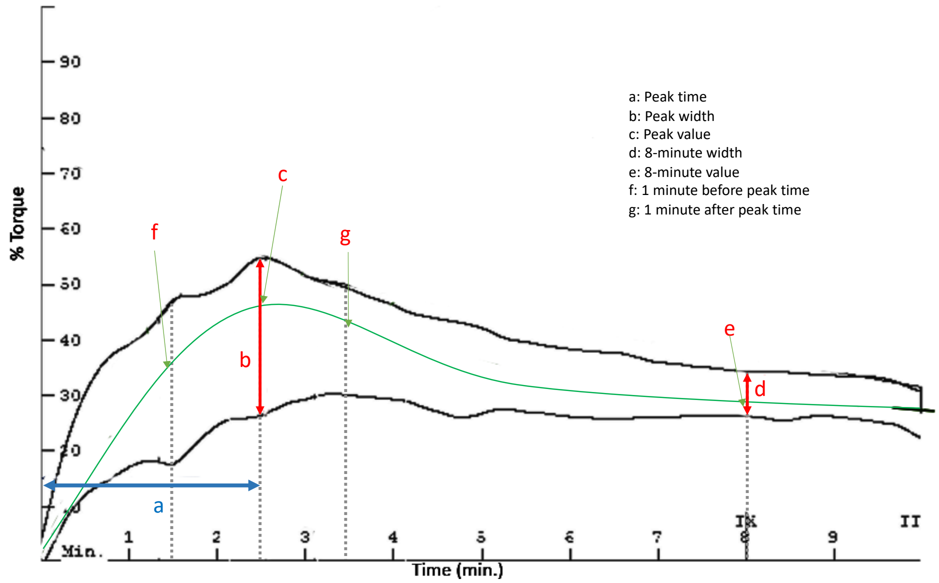


Figure C3. Mixogram of all the 20 flours before and after chickpea flour addition at level of 7.5% (w/w)

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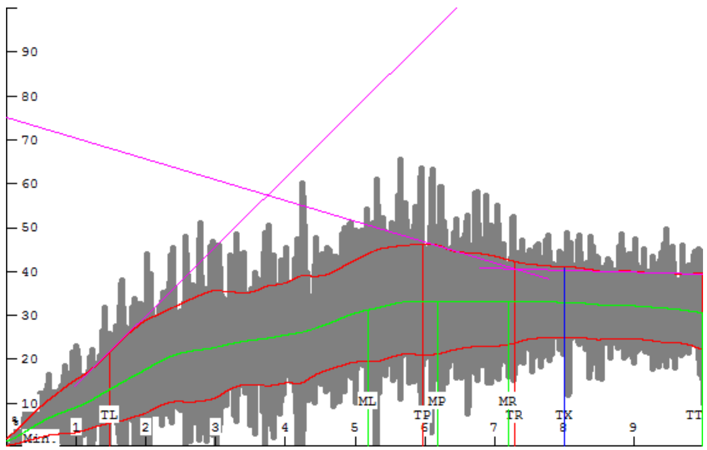

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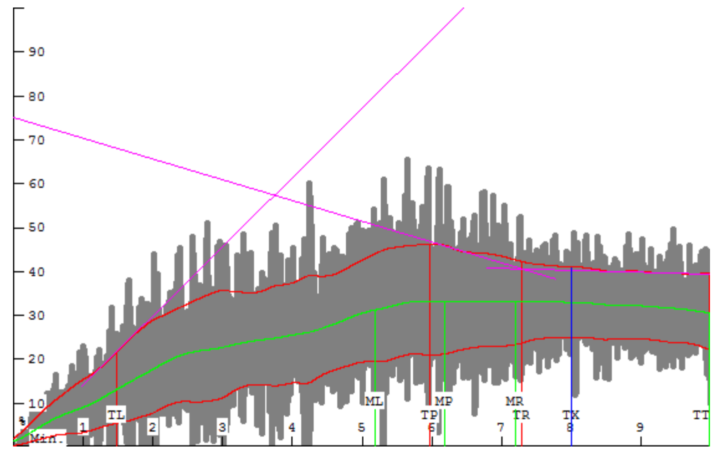

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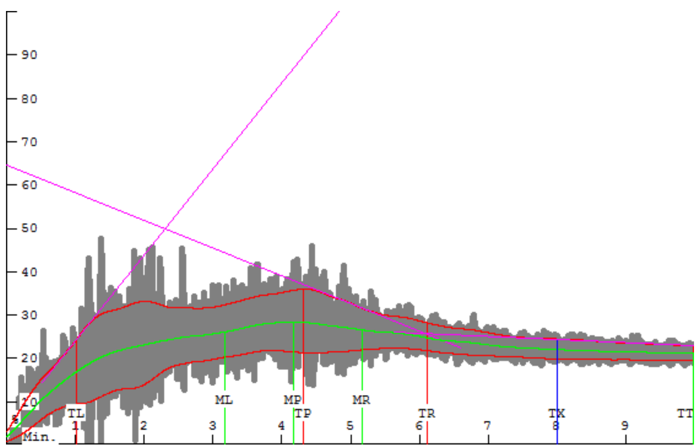

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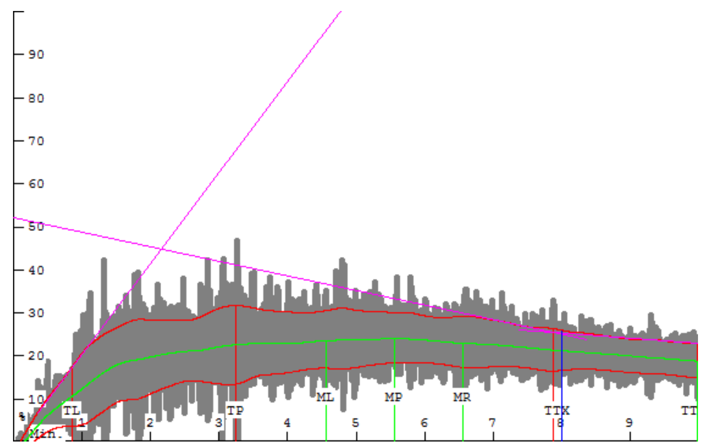

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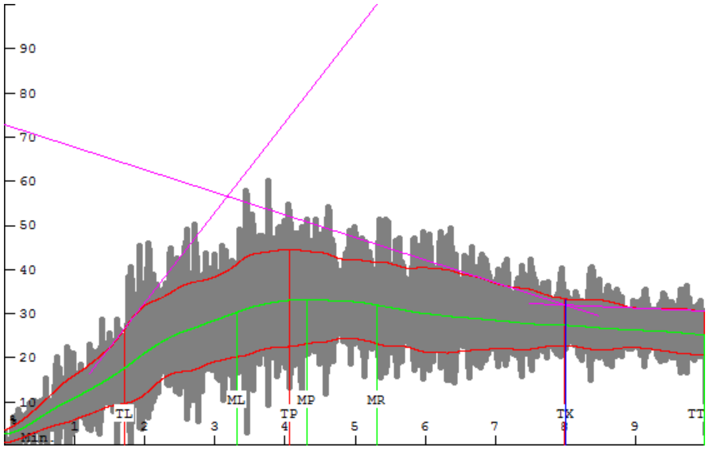

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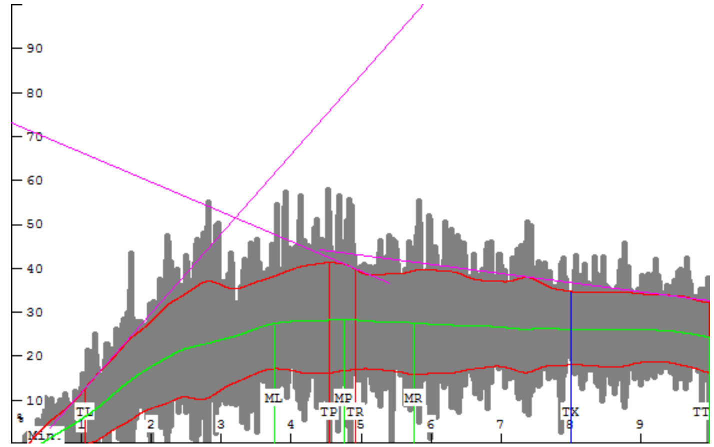

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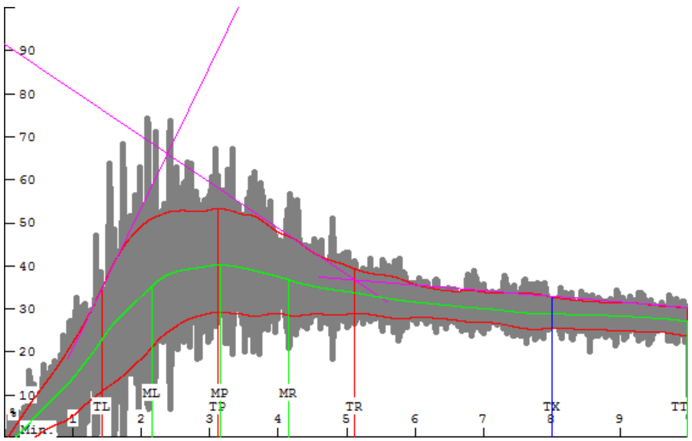

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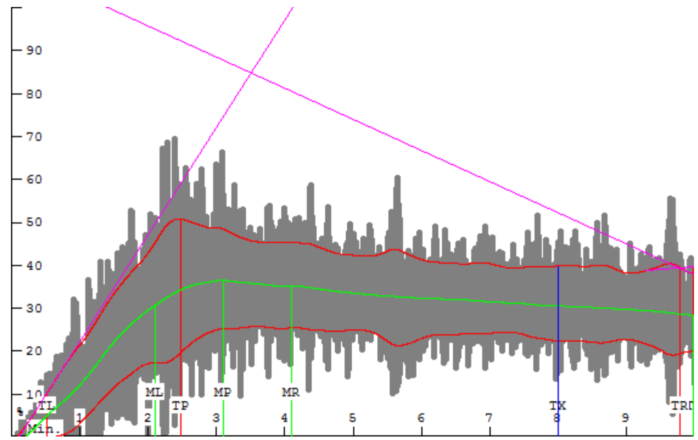

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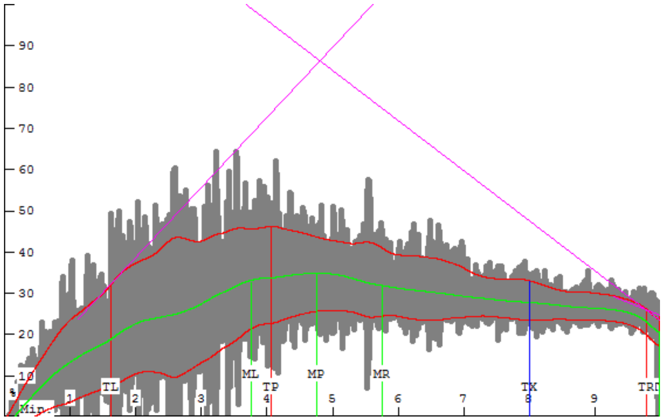
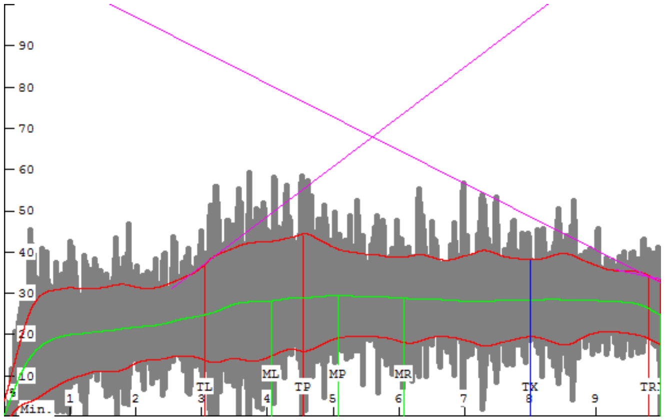
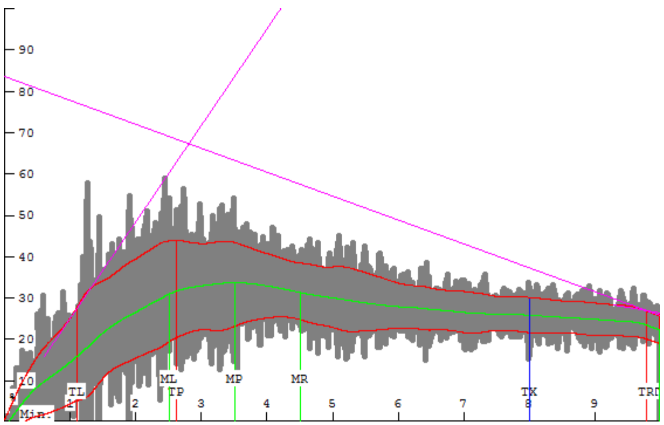
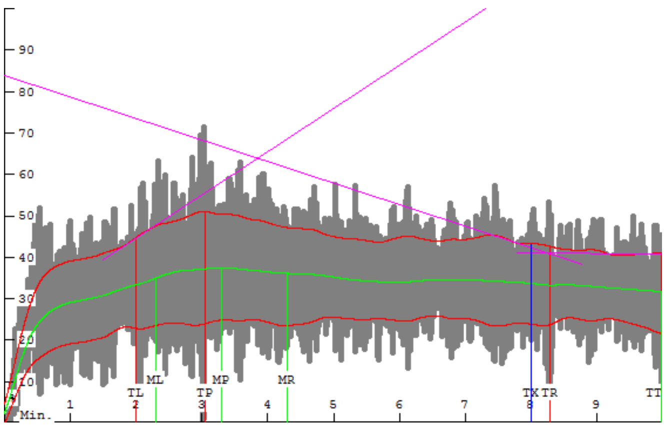
W-5 	W-5 
W-6 	W-6 

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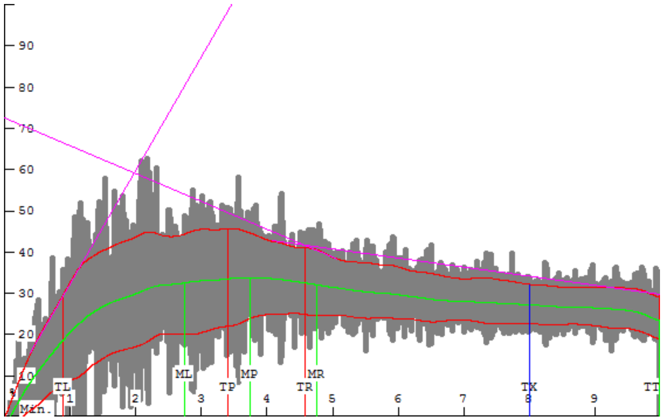
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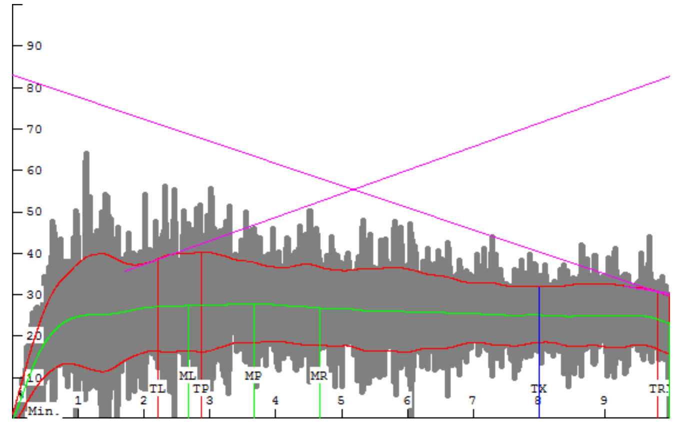
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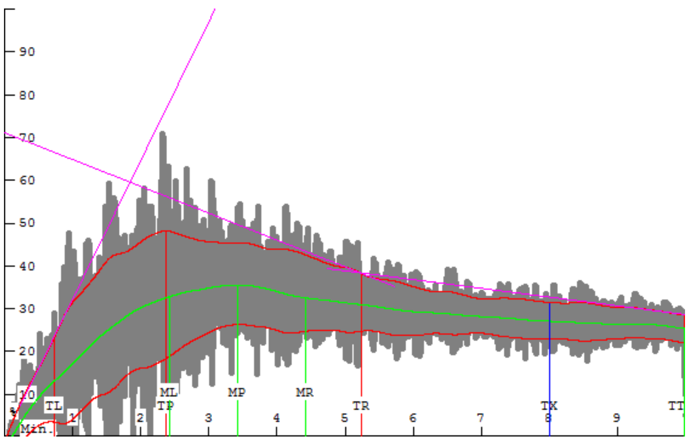
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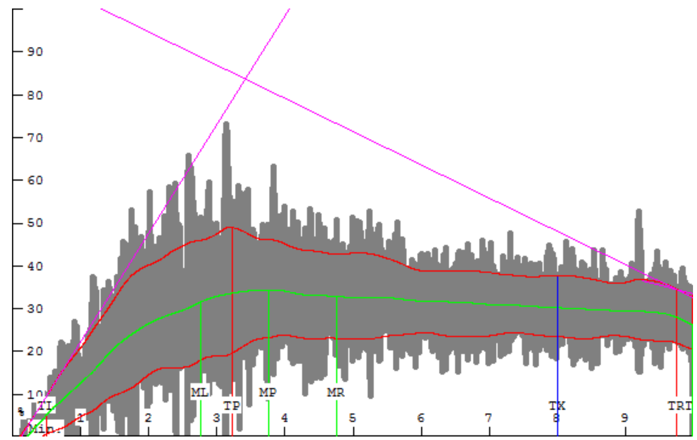
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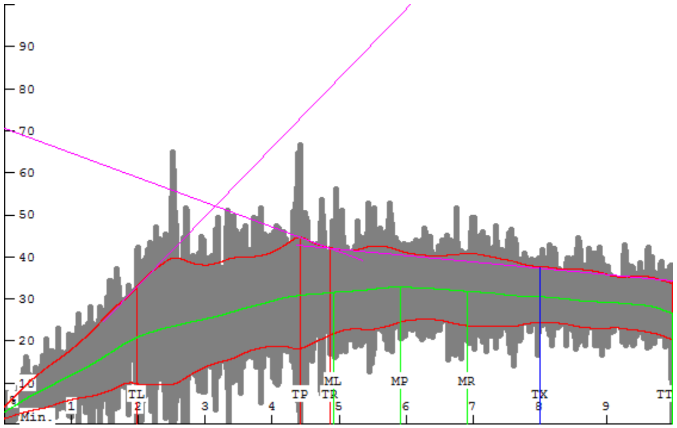

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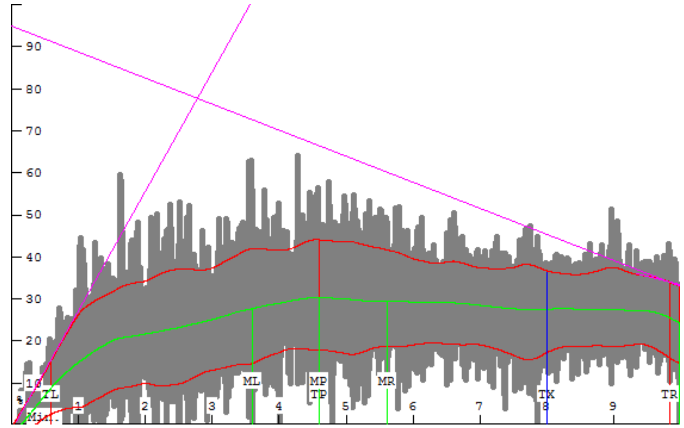

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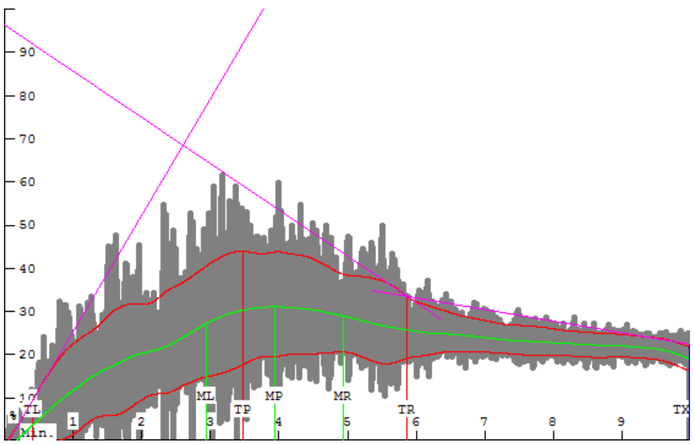

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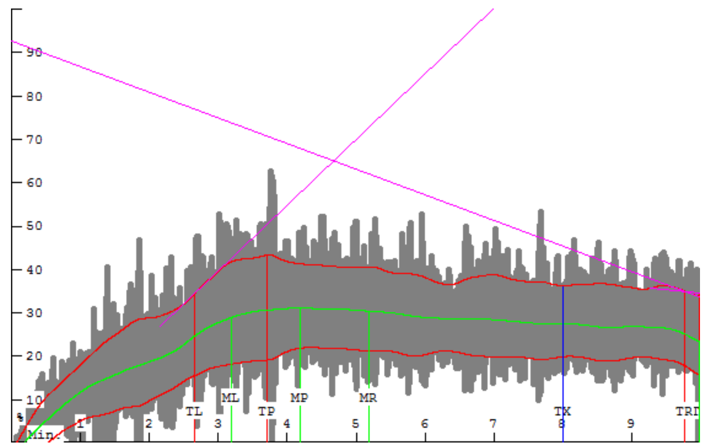

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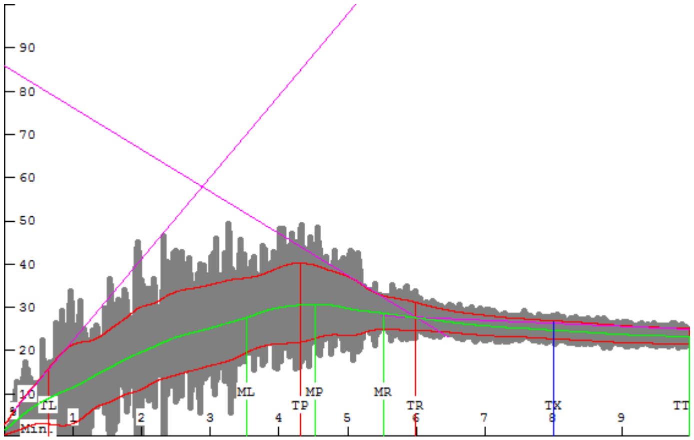

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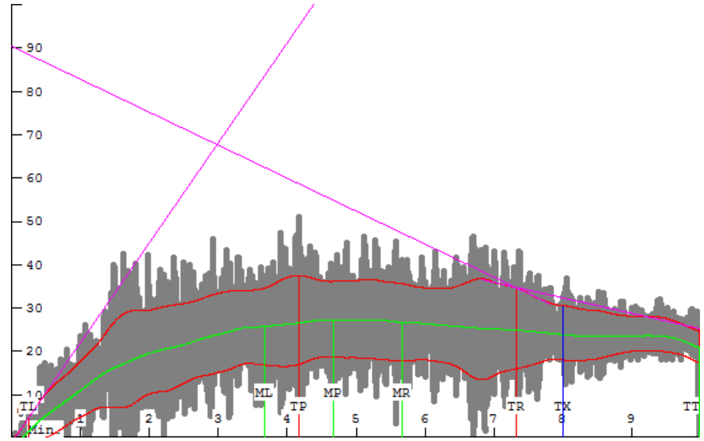

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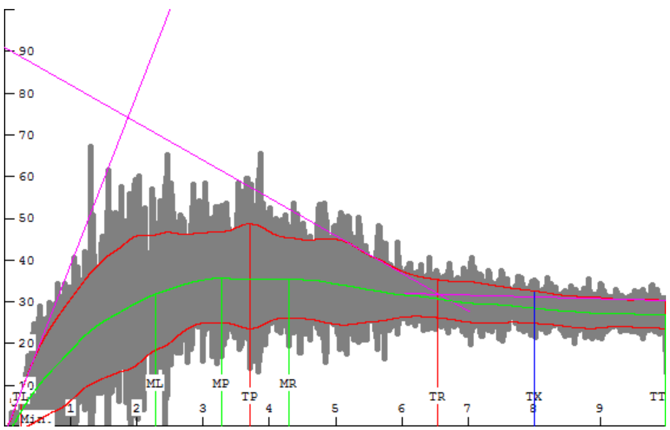

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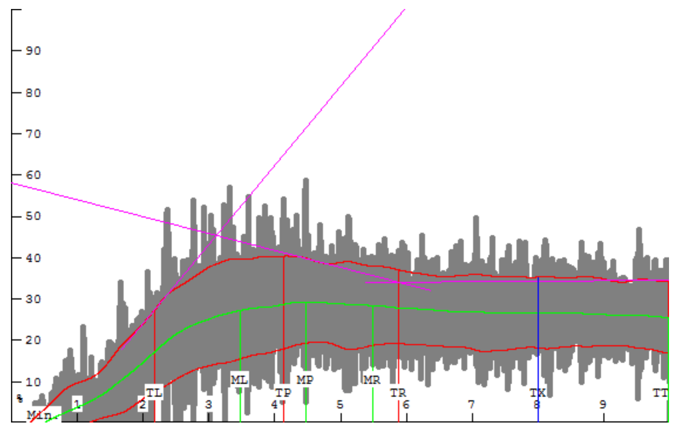

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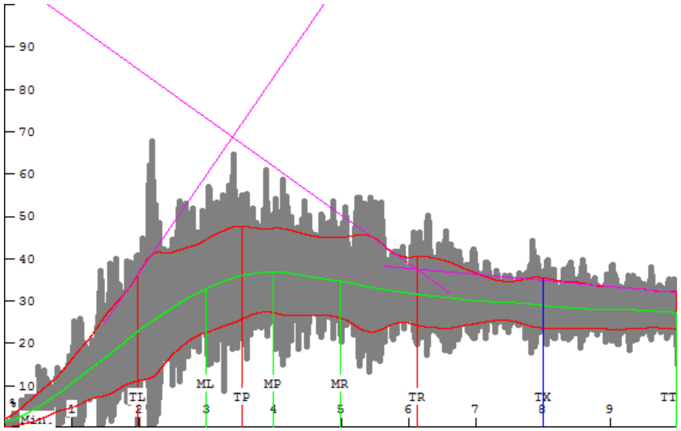

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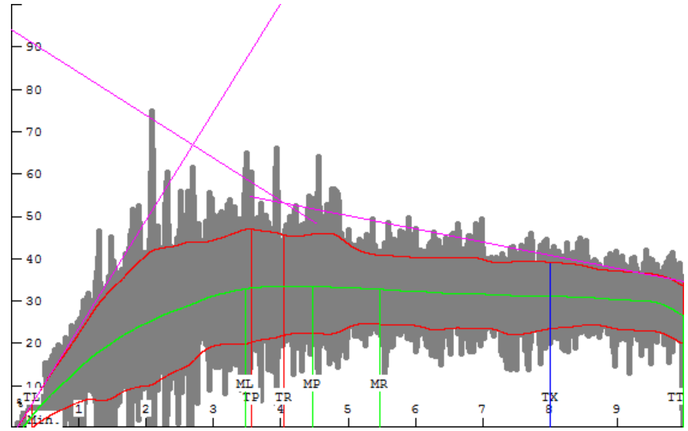

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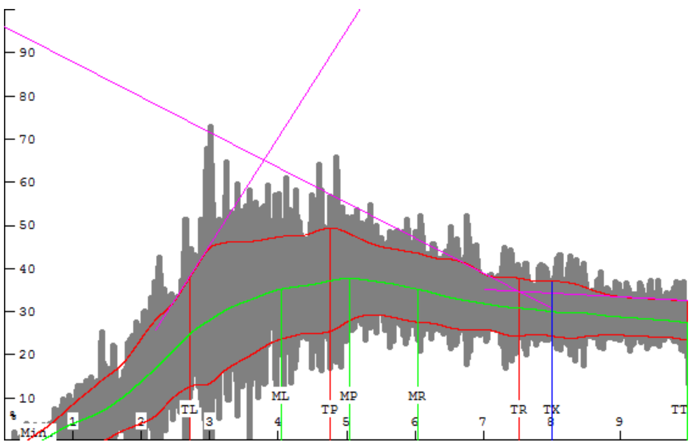

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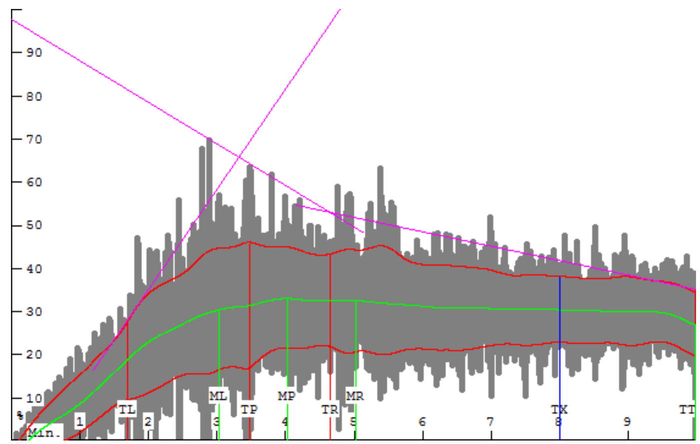

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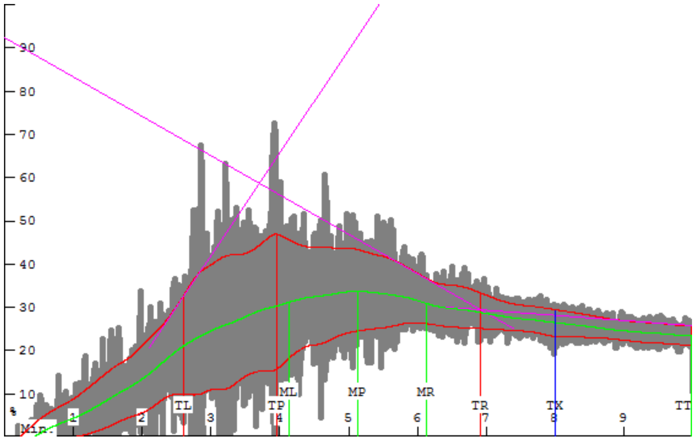

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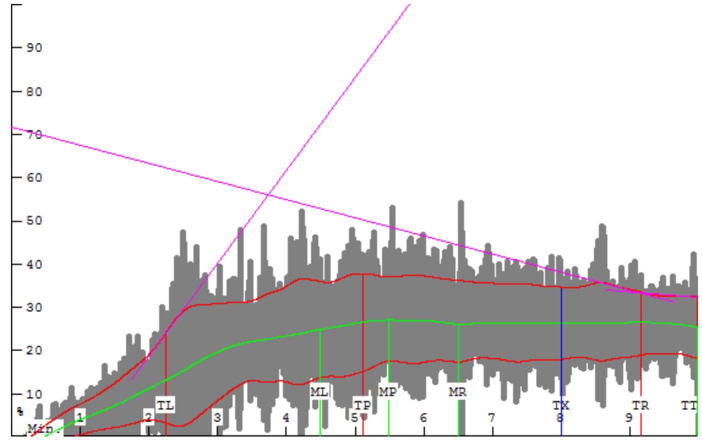

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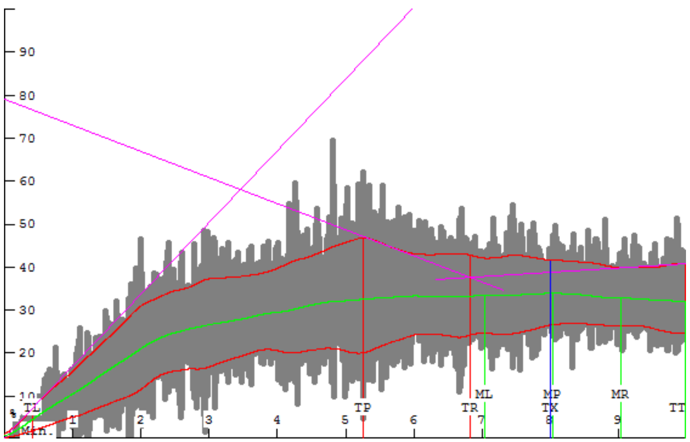

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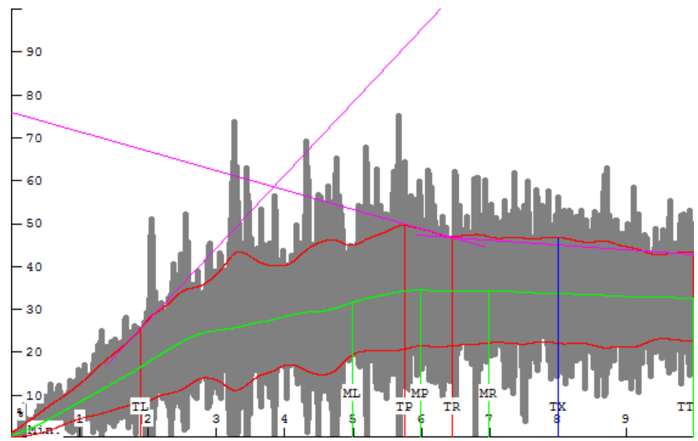

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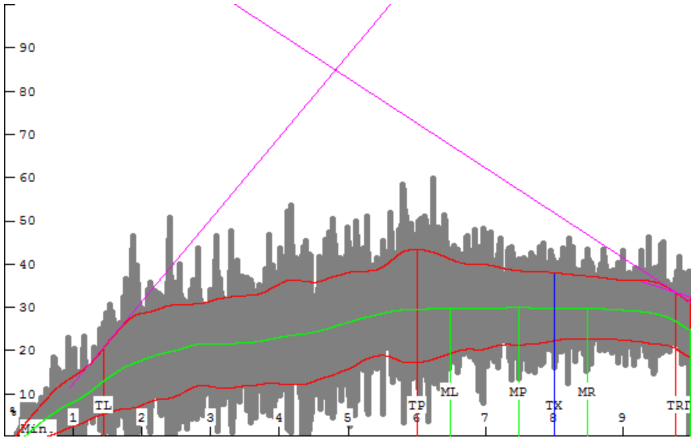

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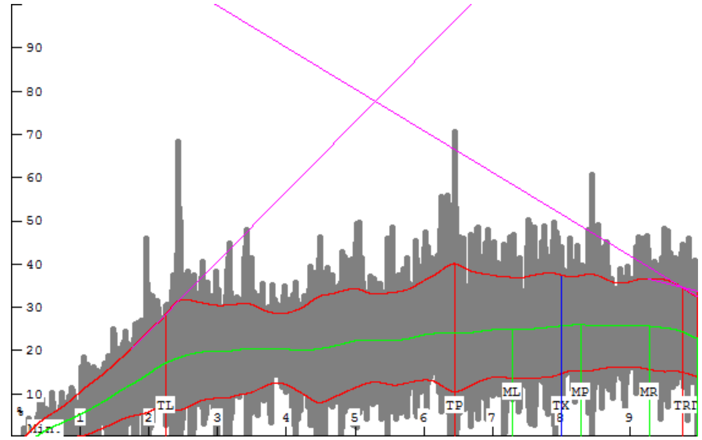

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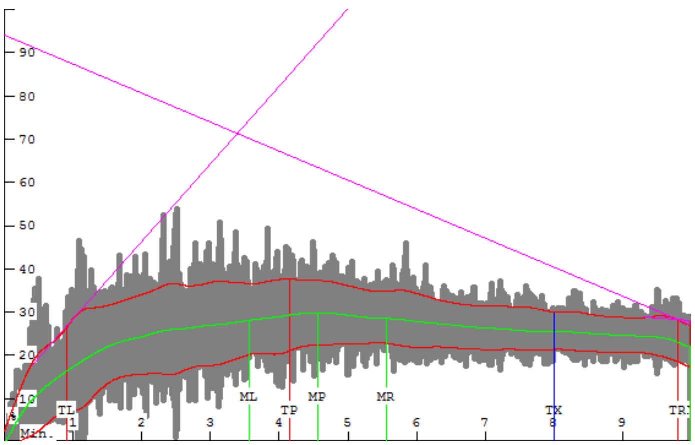

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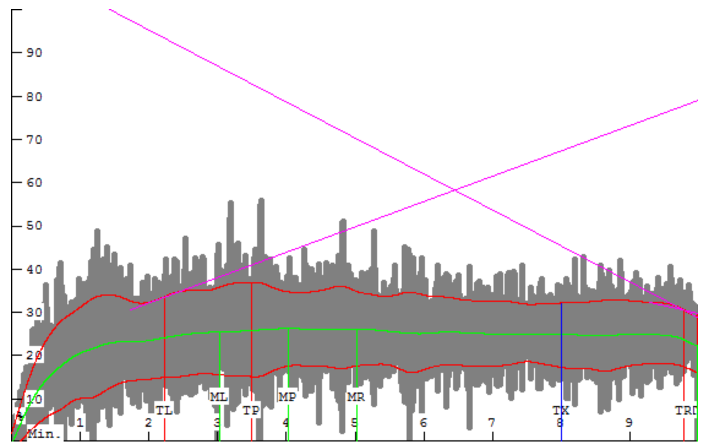

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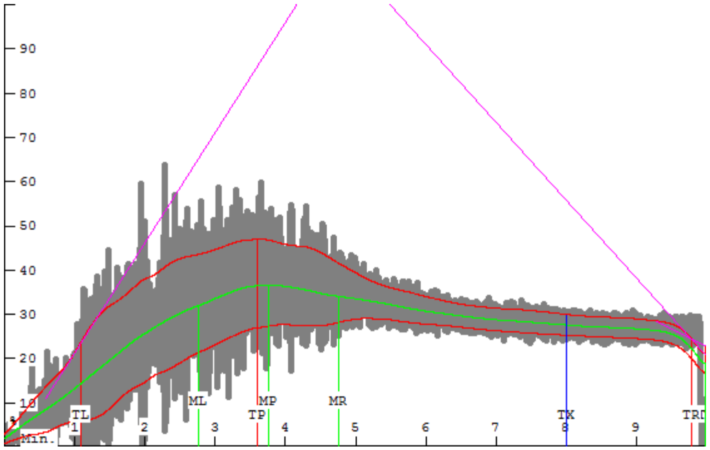

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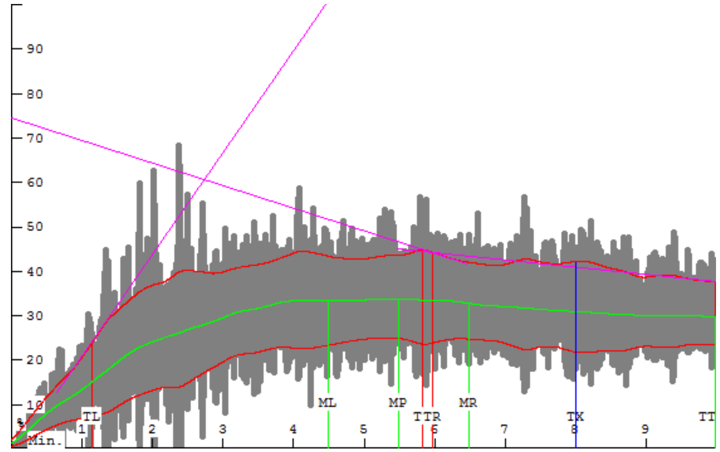

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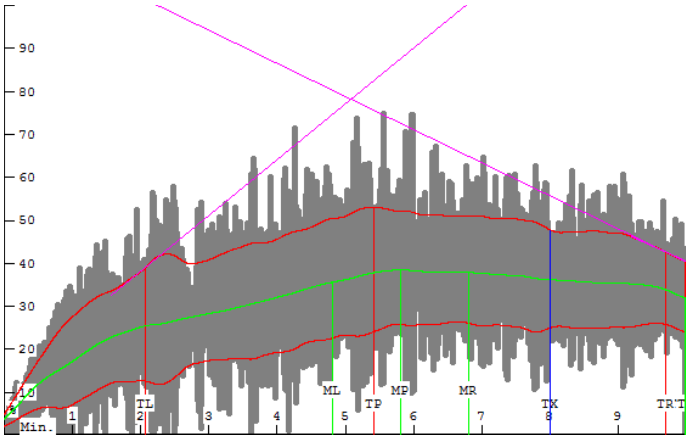

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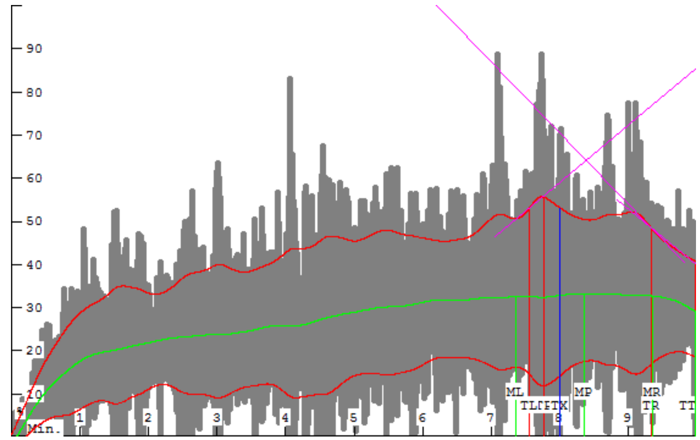
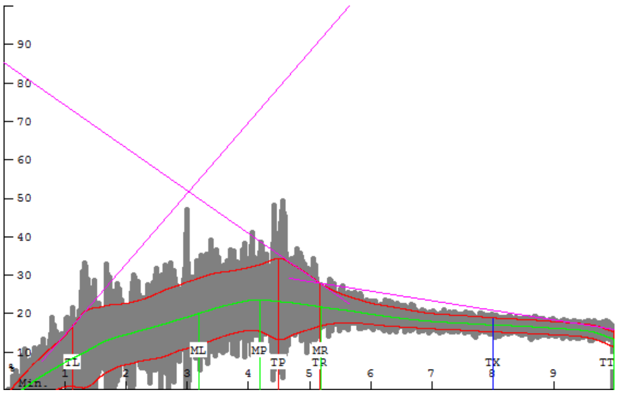
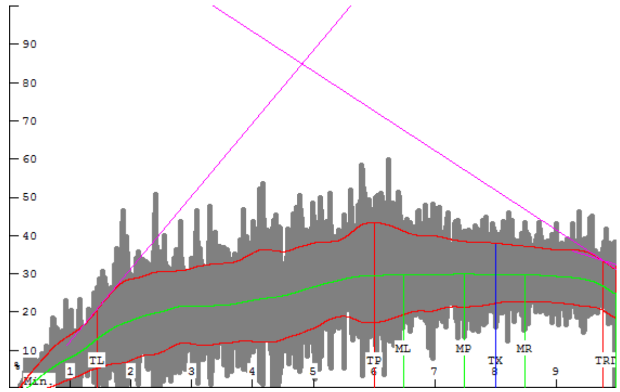
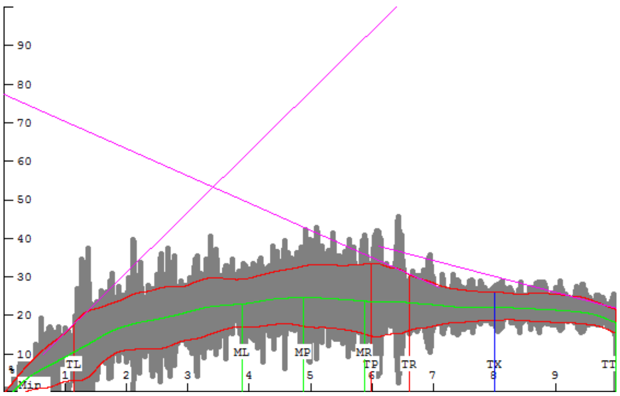
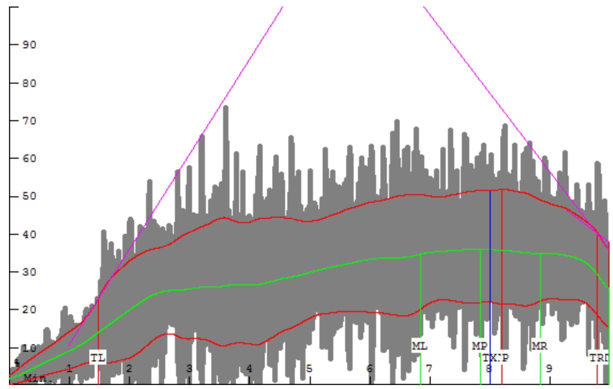
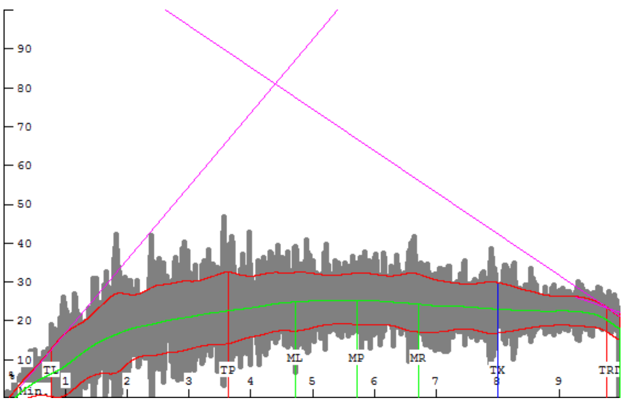
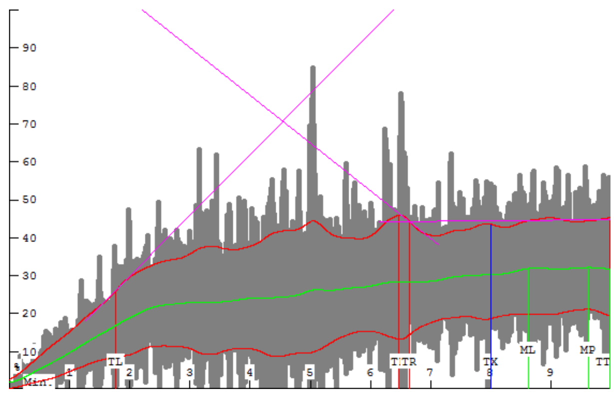
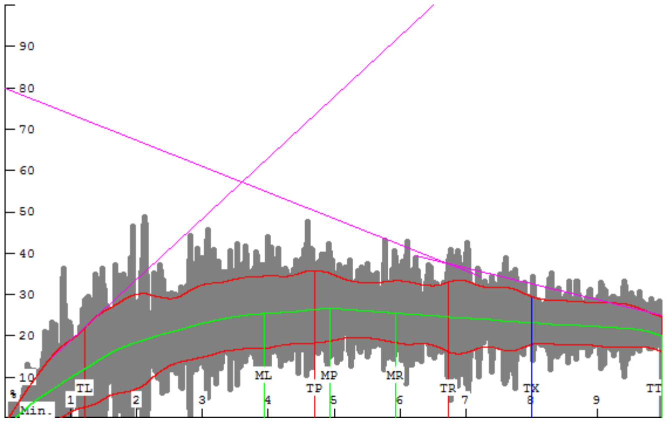


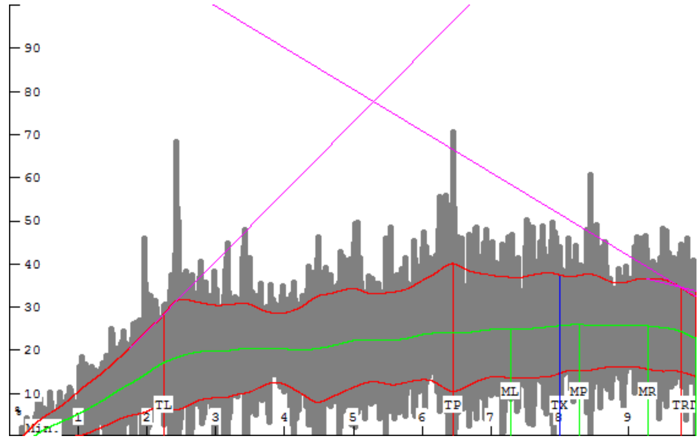
Figure S4. Mixograms changes as kabuli chickpea flour is added at different ratios

W-11	W-17
CONTROL 	CONTROL 
1% CHICKPEA 	1% CHICKPEA 
3.75% CHICKPEA 	3.75% CHICKPEA 

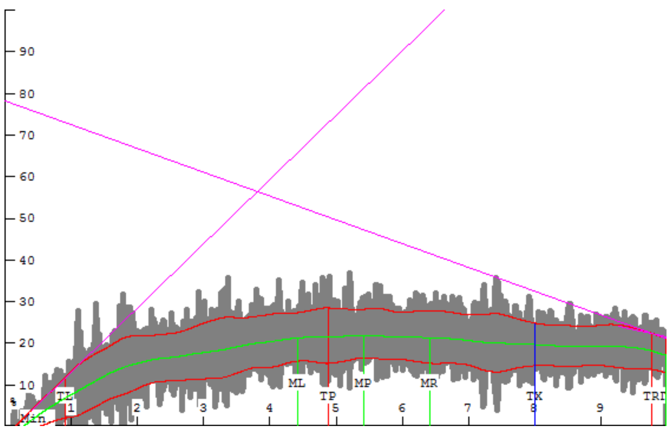
7.5% CHICKPEA



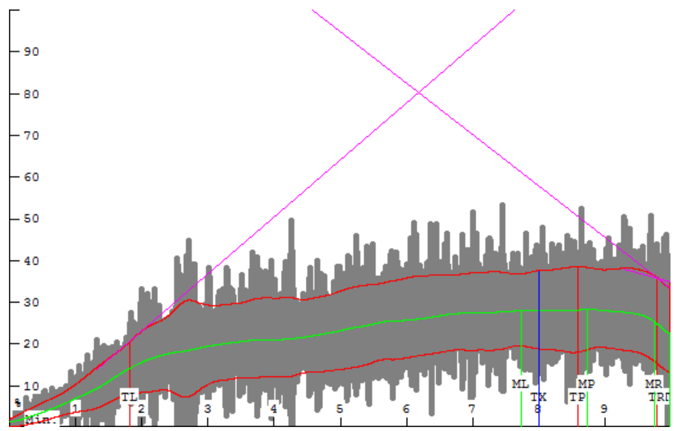
7.5% CHICKPEA



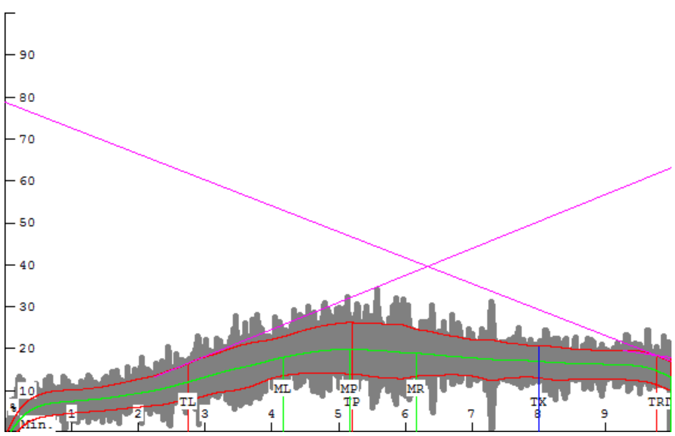
15% CHICKPEA



15% CHICKPEA



30% CHICKPEA



30% CHICKPEA

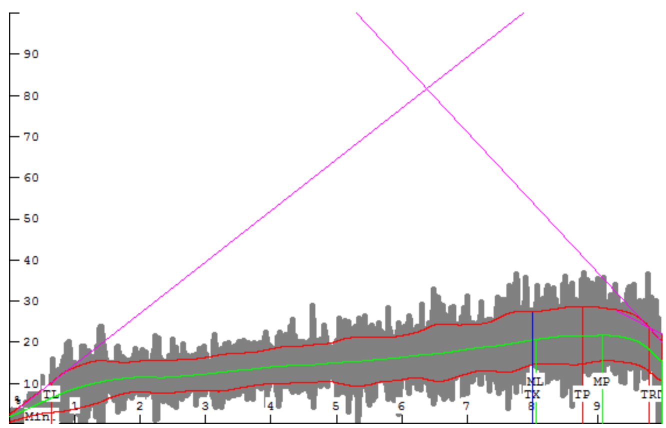
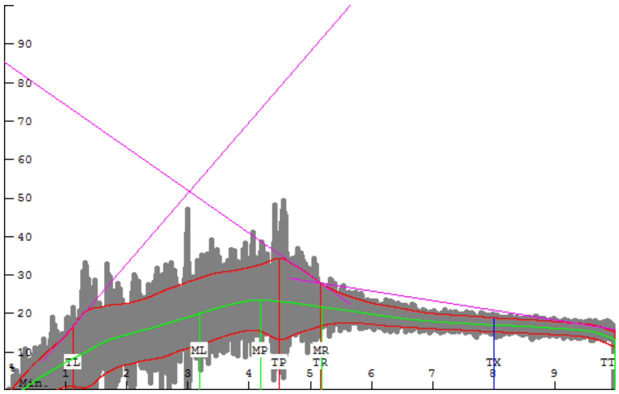
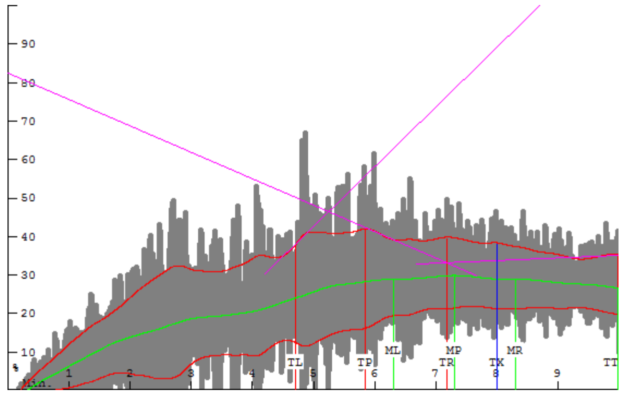
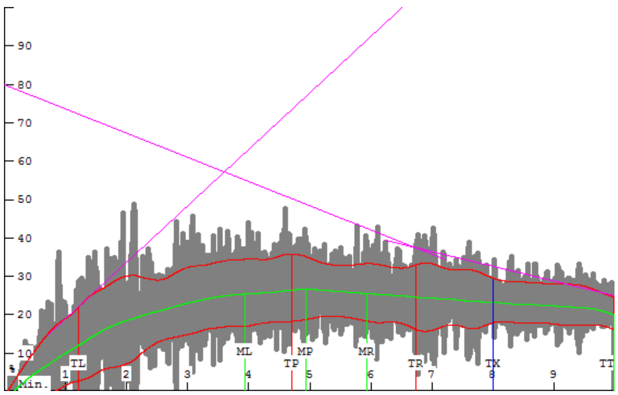
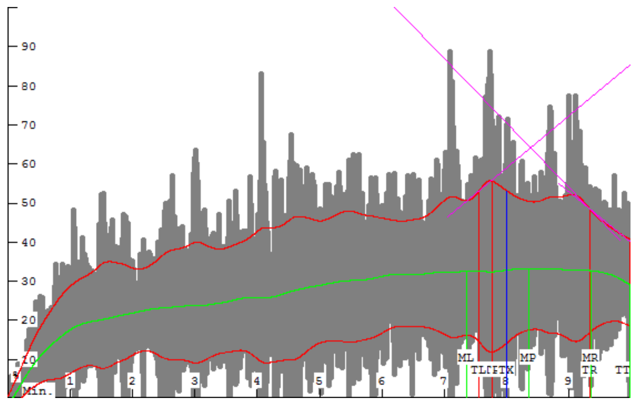
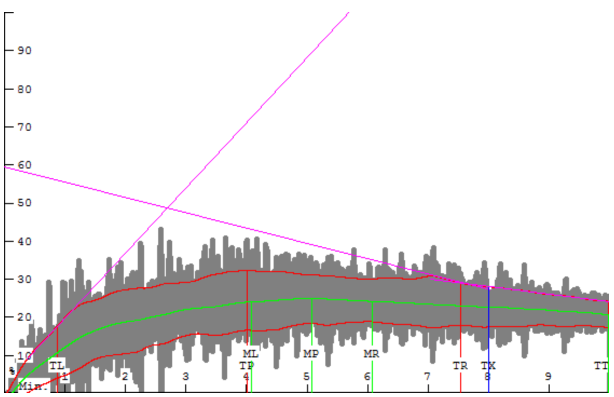
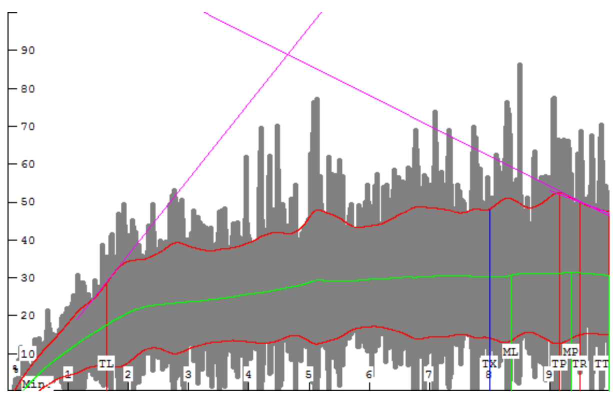
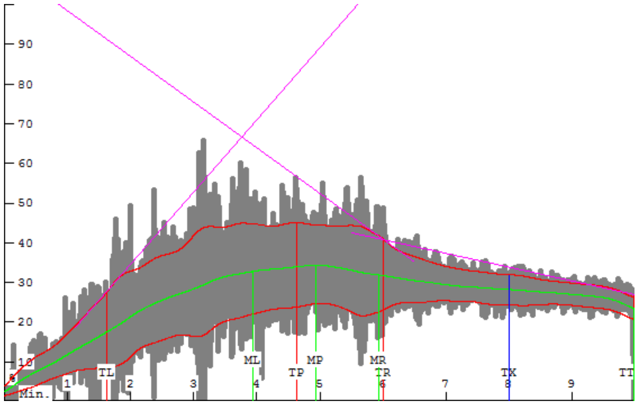


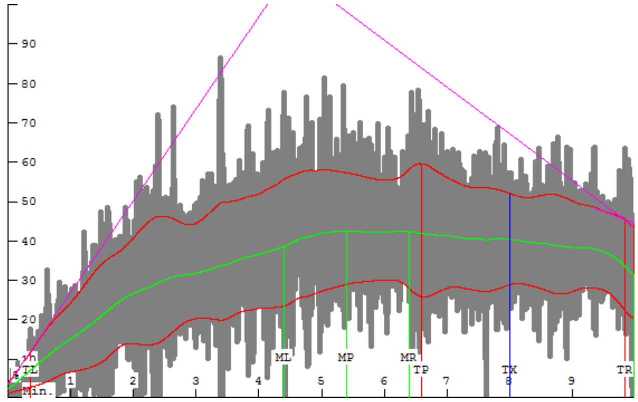
Figure C5. Mixograms for the weak (W-11) and strong (W-17) flour when different fractions of chickpea flour are added

W-11	W-17
CONTROL 	CONTROL 
7.5% CHICKPEA FLOUR 	7.5% CHICKPEA FLOUR 
7.5% CHICKPEA DEFAT 	7.5% CHICKPEA DEFAT 

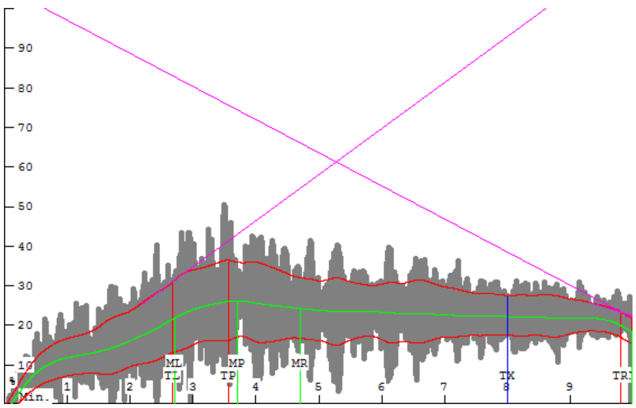
7.5% CHICKPEA-STARCH



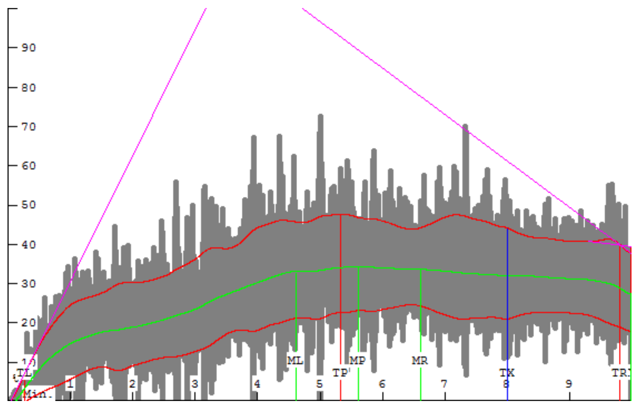
7.5% CHICKPEA-STARCH



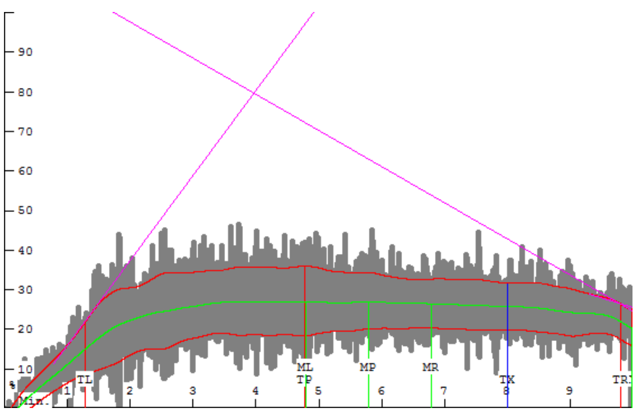
7.5% CHICKPEA SOLUBLE PROTEIN



7.5% CHICKPEA SOLUBLE PROTEIN



7.5% CHICKPEA INSOLUBLE PROTEIN



7.5% CHICKPEA INSOLUBLE PROTEIN

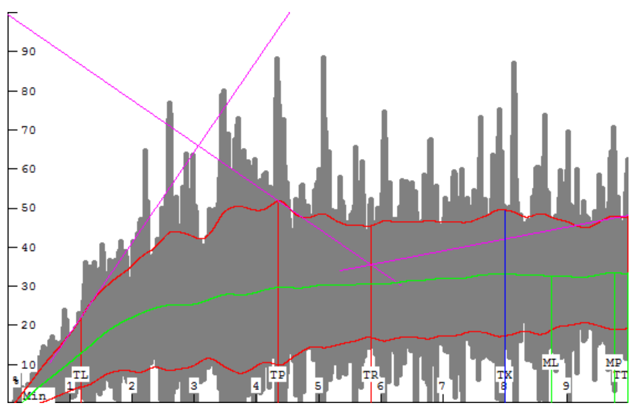


Figure C6. Dough strength changes as chickpea flour added at different ratios

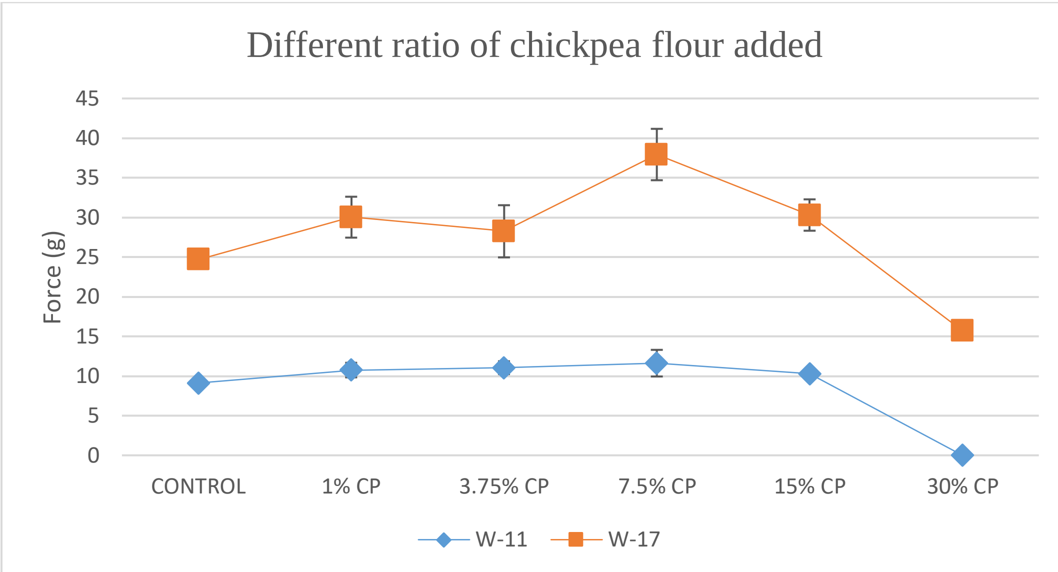


Figure C7. Dough strength changes as different chickpea flour fractions added to wheat flour

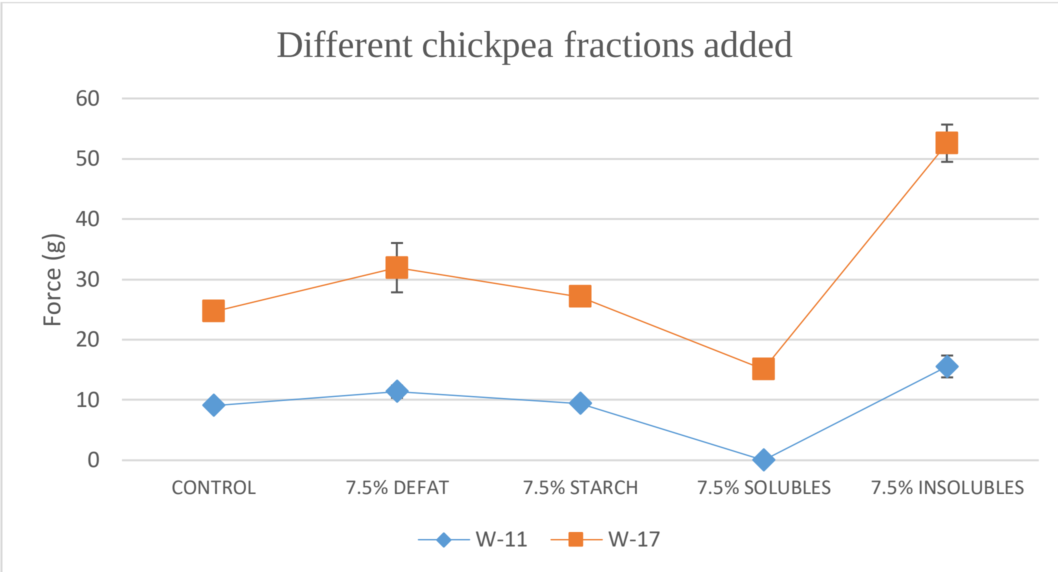
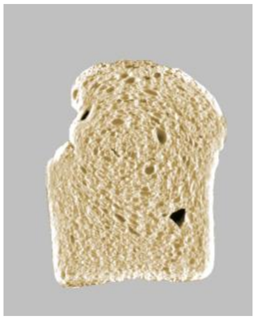


Figure C8. Bread slice pictures taken by the C-cell

Control bread	1.5% CP	3.75% CP	7.5% CP
			
15% CP	30% CP	Control OM	7.5% CP OM
			

xx % CP- kabuli chickpea level of incorporation

OM- overmixed

Chapter 5 - Summary and conclusion

Flour flowability properties Summary

- The performed experiments showed that the refined pulse flours can be produced from whole pulse grain using commonly used milling equipment.
- Flours of different particle sizes and similar proximate compositions were successfully produced for each pulse grain.
- The flours produced showed bimodal distribution as it is often for common cereals such as wheat.
- The performed experiments demonstrated that the production of fine flours involves extensive damage of the starch which is not desired often.
- The pulse flours proximate composition indicated that they are very rich in protein and ash compared to wheat. Chickpea flours was very high in lipid content.
- The small-sized flours were very cohesive regarding the flow properties of the pulse flours.
- Chickpea flour was the most cohesive and most compressible among the pulse flours which was caused by the high lipid content.
- Medium and large-sized lentil flours exhibited better flowing properties; they were very comparable to wheat flour.

Pulse flours bread-baking summary

- The physical flour properties showed that the particle size differences did not have a significant impact on the water holding capacity of the flour.
- The particle size differences also did not have a significant impact on the bread quality.

- Chickpea showed better bread-baking properties compared to lentil and yellow pea at all levels of incorporation.
- It was noticed that the increased incorporation reduces the bread's specific volume and increases the hardness of the bread. As the incorporation increased, the crust-darkening effect was more observed.
- Generally, the 12.5% incorporation level produced acceptable bread quality. The chickpea better bread baking properties were further confirmed when the rheology tests were done on the chickpea-wheat composite flours.

Chickpea flour enhancing the mixing properties of dough summary

- Chickpea improved considerably the mixing tolerance of the wheat flours tested. When added at different ratios, 7.5% or below incorporation levels increased the mixing tolerance while higher incorporation showed deleterious effect on the dough mixing properties.
- The dough extensibility tests further confirmed the chickpea dough strengthening effect.
- When chickpea was incorporated at 7.5%, the dough strength of all the wheat flours tested increased significantly.
- Both kabuli and desi type chickpea flours showed similar effect on the dough extensibility and mixing properties when incorporated in refined wheat flour.
- The chickpea flour fractionation demonstrated that the insoluble protein fraction is more responsible for the dough rheology and mixing properties improvement.
- It was observed that the soluble protein fraction was deleterious to dough rheology and mixing properties when incorporated in wheat flour.
- At 7.5% of incorporation, chickpea flour did not affect the physical quality of the bread.

- The sensory study survey showed that the consumers couldn't detect a significant difference between the bread infused with chickpea and the regular wheat bread.

This report showed that pulses could be incorporated into wheat to produce healthier bread. The report also showed that chickpea has higher potential to be applied in the baking industry by improving the mixing properties of wheat flour with no negative effect on the final product.

Gaps and suggestions

The result in this report shows clearly that pulses are not understood. More studies are needed to first understand the physicochemical properties of the flours produced from other pulses. Pulses effect on wheat flour rheology is also needed since it is believed that chickpea is not the only pulse that would improve the mixing properties of wheat flour. Chickpea flour should be further studied to identify the compound in insoluble protein fraction that is responsible for the improved mixing properties observed. The production of small-sized flour is highly not suggested since it will be hard to process and transport, plus, the difference in particle size was not functional regarding product quality. Conditioning of the chickpea flour will be necessary to effectively process the chickpea flour in milling and baking facilities. Chickpea flour is better suited for wheat incorporation than lentil and yellow pea. The result presented will be beneficial to further understanding pulses and their incorporation in the baking industry. The bakers will benefit from this report by trying a natural alternative to dough improvers.