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Effect of Pulse Type and Substitution Level on Dough Rheology and Bread Quality of Whole Wheat-Based Composite Flours

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Abstract: Pulse flours are commonly added to food products to improve the functional properties, nutritional profiles, product quality and health benefits. This study aimed at assessing the effects of the partial replacement (0–25%) of whole wheat flour with diversified whole pulse flours (yellow pea, green pea, red lentil, and chickpea) on dough properties and bread quality. The pulse flours had higher protein contents and ash, but lower moisture content and larger average particle size, compared to whole wheat flour. Increasing the substitution level of pulse flours decreased dough viscosity, stability, development time and bread volume, and accelerated bread retrogradation. The incorporation of 5% yellow pea flour led to a similar bread quality as that with only whole wheat flour. Among all the tested pulse flours, the composite flour containing yellow pea flour or chickpea flour had overall better potential for bread making by providing good dough handling properties and product quality. This study will benefit the development of more nutritious food products by combining cereal and pulse ingredients.

Keywords: whole grain bread; pulse; yellow pea; green pea; lentil; chickpea; Mixolab; dough rheology; bread texture

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1. Introduction

Pulses, such as peas, lentils, chickpeas, and dry beans, are widely consumed as a staple food in many countries, due to their high nutritional values [1]. Pulses contain a high amount of dietary fiber, proteins, vitamins, minerals, and phytochemical antioxidants (e.g., phenolic acids, flavonoids, and isoflavones), which are beneficial to human health [2–4]. Pulses generally contain about 15 to 30% of protein with a high level of lysine, which is a limiting amino acid in cereals [2,5]. The phytonutrients in pulse, such as tannins, flavonoids, and phenolic acids, have high potential for antioxidant, anti-inflammatory, and antimicrobial properties [5]. For example, a study indicated that lentil can provide 0.167 mg thiamin, 0.072 mg riboflavin, 1.049 mg niacin, 0.632 mg pantothenic acid, and 0.176 mg pyridoxine per $\frac{1}{2}$ cup of dry seed [5]. Fully cooked pulses can function as low-glycemic foods that inhibit appetite and glycemia in the short term [5]. Consuming pulses may reduce the risk of cardiovascular disease, gastrointestinal disorders, obesity, type-2 diabetes, and cancer as well as lower cholesterol levels [4,6–9].

Nowadays, consumers are becoming more informed and aware of health and wellness needs [10]. The tendency of including pulses to improve the nutritional value of foods has become more popular. Whole grain foods are considered healthier, as they contain all the original nutrients present in bran, germ, and endosperm. Whole wheat flour contains better nutritional profiles and more health benefits than refined wheat flour, especially because it is rich in vitamins, minerals, fibers, antioxidants, and phytochemicals [11]. The consumption of whole wheat foods can reduce the risk of cardiovascular disease, obesity, cancer, and diabetes, as well as maintain body weight [12]. However, baking with whole wheat flour always leads to bread with a smaller size, bitter taste, and coarser and harder texture, compared to white bread, which is less appealing to consumers. Moreover, wheat contains relatively low concentrations of protein (8–15%), and it is an incomplete protein source, due to the lower amount of the essential amino acid, lysine. Pulses, on the other hand, generally have a protein content of approximately 15–30%, and are rich in lysine (about 64 ± 10 mg/g of protein). Incorporating pulse flours into wheat breads can increase the lysine content and amino acid score [13].

Marchini et al. [14] found that 10% flour substitution with red lentil flour provided the best baking properties, and larger particle size fraction (>200 μm) generated better properties than the finer fractions. Pulse flour blends showed higher water absorption than common wheat flour, due to the high amount of polysaccharides and protein content [15]. A study on white flour/pea flour blends showed that the bread properties (such as specific volume, crumb texture, and density) were positively related to dough rheological properties, and the bread specific volume decreased as the amount of pea flour was increased [16]. Additionally, several studies demonstrated that incorporating pulse flour significantly improved nutritive values of wheat-based bakery products [1,17]. Compared with the continuous network and unique viscoelasticity of the wheat dough protein matrix, the protein matrix of pulse flour was less desirable for bread making. Pulses may also have some negative effects on food products, such as having a strong beany flavor and intense aroma and introducing anti-nutritional compounds. A study showed that the higher fiber content in wheat flour and chickpea flour resulted in lower wheat bread volume, due to the interaction between its hydroxyl groups and water through hydrogen bonding, and posed a negative influence on dough stability [15]. Including pulse flours into bread dough dilutes the gluten protein and affects both gluten development and starch–protein complexes, which are important to the dough rheology and quality of bread [16,18]. Pea flour also interrupted the starch–gluten matrix, resulting in weaker and less elastic dough [16]. Different pretreatments of pulses, such as germination, extrusion, and fermentation, were used to improve the quality of foods containing pulses [19].

So far, there is limited literature on incorporating whole pulse flours into whole wheat bread products. We hypothesized that different pulse flours would have different techno-functions and influences on dough and bread properties. This study aimed to determine the effects of different types and amount of whole pulse flours (e.g., yellow pea, green pea, red lentil, and chickpea) on whole wheat dough properties and bread quality. This research will benefit grain scientists in developing more nutritious and palatable whole grain food products.

2. Materials and Methods

2.1. Materials

Whole wheat flour (protein content 15.1%, moisture content 12.9%) was supplied by Mennel Milling Company (Fostoria, OH, USA). Commercial whole yellow pea flour was obtained from Harvest Innovations (Indianola, IA, USA). Dried whole yellow pea and whole green pea grains were purchased from Rani (Houston, TX, USA). Whole red lentil grain was provided by Food to Live (Brooklyn, NY, USA). Whole chickpea grain was from Palouse Brand (Palouse, WA, USA). Active dry instant yeast, sucrose, salt, and shortening were purchased from a local grocery store.

2.2. Flour Characterization

Pulse grains were ground with a Wiley Mill (Thomas Scientific, Swedesboro, NJ, USA) equipped with a 0.1 mm sieve. The protein, moisture, and ash of the flours were measured following AACC approved methods [20–22]. The lipid content was measured according to AACC approved method 30-10.01 with some modification [23]. Briefly, flour and ethyl ether were mixed at a ratio of 1:20 (*w*:*v*) in a conical flask for 30 min, then centrifuged at $3000\times g$ for 10 min, and the extract was collected. The extraction process was repeated twice. The extract was then pooled and left in a fume hood overnight to evaporate the solvent, and then the weight of the lipids was measured. Total carbohydrate was calculated based on the percentage of ash, total fat, moisture, and protein content, using Equation (1):

$$\text{Carbohydrates } (\%) = 100 - Ash - Total\ Fat - Moisture - Protein \tag{1}$$

The particle size of the flours was measured, using a Ro-Tap sieve shaker (Model B, W.S. Tyler Mentor, OH, USA) with sieve sizes of 53 to 3360 µm. Approximately 100 g of the sample was weighed, transferred to the top of the shaker, and then shaken for 10 min. The weight of the flour on each sieve and the pan was measured. The average particle size was calculated by Equation (2):

$$Avg\ particle\ size\ (\mu m) = \Sigma\left[\frac{\text{Wi}}{\text{Wt}} \times di\right] \tag{2}$$

where Wi is the weight of flour remains in each sieve; Wt is the weight of total flour; di is the diameter of the ith sieve in the stack.

2.3. Mixolab Analysis of Whole Wheat/Pulse Composite Flours

Dough mixing and pasting properties of blends of whole wheat flour with different types (commercial yellow pea flour, yellow pea flour, green pea flour, red lentil flour, and chickpea flour) and amounts (5, 15, and 25%, based on total composite flour weight) of pulse flours were analyzed, using Mixolab (Chopin Technologies, Villeneuve-la-Garenne, France), according to AACC Method 54-60.01 [24]. The substitution level of 5–25% was decided based on our preliminary studies so as to maximize the pulse additions but maintain a processible dough system. Whole wheat flour was also measured for comparison. The flours were pre-mixed to achieve a homogenous composite system in an external mixer before further testing.

2.4. Bread Baking of Whole Wheat/Pulse Blends

Breads from different whole wheat/pulse flour blends were prepared following AACC Method 10-10.03 [25]. The formulation included 100 g flour, 2 g instant dry yeast, 3 g shortening, 6 g sucrose, 1.5 g salt, 0.2 g malt flour, and an optimal amount of water. The amount of water and dough mixing time were determined based on the Mixograph analysis. The bread making was conducted in duplicate for each formulation.

2.5. Bread Quality Analysis

Bread volume and specific volume were determined following AACC Method 10-05.01 [26]. The breads were then cut into slices, approximately 15 mm thick, and stored in foil bags with oxygen absorbers for further analysis. The bread crust color was measured, using a CIE-LAB color system (XITIAN machine equipment Co., Ltd., Huizhou, China) to obtain the Hunter L*, a*, and b* values. The bread crumb structure was determined, using a C-Cell Bread Imaging System (Calibre Control International Ltd., Warrington, U.K.). The central slices from each loaf were used for C-cell testing, and the number of cells, cell wall thickness, and cell diameter were collected.

The texture profiles of the bread crumb were measured, using a TA-XT Plus Texture Analyzer (Stable Micro Systems, Surrey, U.K.) following a previous method [27]. Three slices from each treatment were measured on days 1, 4, and 7, respectively. The first texture profile analysis (TPA) was conducted after 24 h of storage (i.e., day 1).

The moisture content of the bread was determined, following AACC Method 44-15.02. Approximately 2 g crumb was cut from the loaf, accurately weighed, transferred to an aluminum pan, and dried in an air-oven at 135 °C for 3 hr and then weighed again. In order to investigate the effect of different types and amounts of pulse flour on the water retention of the bread, the moisture content was also measured on days 1, 4, and 7, respectively.

2.6. Statistical Analysis

All the experiments and tests were conducted in at least duplicate. Data were analyzed using SAS statistical software, Version 9.4 (SAS Institute, Cary, NC, USA) following Tukey's multiple comparisons test and analysis of variance (ANOVA). The significant level was considered at $p < 0.05$.

3. Results and Discussion

3.1. Flour Properties

The moisture content of the whole wheat flour and pulse flours is summarized in Table 1. The whole wheat flour contained 12.92% moisture, which was much higher than the pulse flours. Among all the pulse flours, green pea flour (8.04%) and chickpea flour (7.95%) had a significantly lower moisture content. The flour moisture content is affected by the post-harvest and environmental condition of the grains and milling process.

Table 1. Proximate composition (as-is) and average particle size of whole wheat and pulse flours.

Flour	Moisture, %	Protein, %	Ash, %	Lipid, %	Total Carb., %	Avg. Particle Size, μm
Whole wheat flour	12.92 ± 0.03^{a}	15.13 ± 0.62^{b}	1.80 ± 0.02^{e}	1.80 ± 0.02^{b}	68.36 ± 0.60^{a}	160.77 ± 1.15^{c}
Commercial yellow pea	10.45 ± 0.10^{b}	24.22 ± 0.31^{a}	$2.18 \pm 0.01^{c,d}$	1.21 ± 0.06^{c}	61.96 ± 0.49^{c}	131.62 ± 12.05^{c}
Yellow pea	9.47 ± 0.04^{c}	$19.82 \pm 0.45^{a,b}$	$2.32 \pm 0.04^{b,c}$	0.84 ± 0.11^{d}	$67.56 \pm 0.33^{a,b}$	$242.55 \pm 6.26^{b,c}$
Green pea	8.04 ± 0.03^{d}	21.78 ± 0.04^{a}	2.38 ± 0.01^{b}	1.18 ± 0.04^{c}	$66.62 \pm 0.10^{a,b,c}$	$331.59 \pm 15.05^{a,b}$
Red lentil	9.80 ± 0.15^{c}	23.72 ± 1.19^{a}	2.10 ± 0.08^{d}	$0.96 \pm 0.06^{c,d}$	$63.43 \pm 1.20^{b,c}$	$236.84 \pm 0.41^{b,c}$
Chickpea	7.95 ± 0.30^{d}	22.19 ± 2.74^{a}	2.66 ± 0.01^{a}	5.10 ± 0.05^{a}	62.10 ± 2.50^{c}	427.01 ± 80.97^{a}

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

The protein, ash, lipid, and total carbohydrate contents are also shown in Table 1. The whole wheat flour had significantly lower protein content (15.13%), compared to the pulse flours. The protein content of pulse flours ranged from 19.82 to 24.22%. The protein contents of the pulse flours are highly variable and determined by their genetic and environmental factors [15]. There was no significant difference in the protein content among the different pulse flours. The ash content of the whole wheat flour and pulse flours ranged from 1.80 to 2.66%. Whole wheat flour possessed the lowest ash content (1.8%), and chickpea flour contained the highest ash content (2.66%) among these six types of flours. The higher ash content in pulse flours could be due to the thicker seed coat of the pulse grains; this can be beneficial by providing more nutrients, such as minerals and fibers [28]. These results were consistent with the previous literature [4], which also showed that pulse flours had a higher protein and fiber content than whole wheat flour. Chickpea presented the highest lipid content (5.10%), similar to the results reported [29]. Chickpea contains highly digestible protein and a high lysine content [18,30]. The carbohydrate content of whole wheat flour was 68.36%, and the pulse flours ranged from 61.96 to 67.56%. Starch and dietary fiber are the two primary components that make up carbohydrates. Most of the polysaccharide is in the form of starch granules in whole wheat flour, and humans have better starch digestibility of cereal products than pulse products [4].

The average particle size of whole wheat and pulse flours is shown in Table 1. Chickpea had a significantly larger particle size (427.0 μm) than the other samples. The average particle size of whole wheat and commercial yellow pea flour was 160.8 and 131.6 μm, respectively, which were much smaller than that of the chickpea flour. There were no significant differences between the average particle size of the yellow pea (242.6 μm), green pea (331.6 μm), and red lentil flour (236.8 μm). The particle size distribution curves are shown in Figure 1. The hull and hardness of the seeds affect the grinding properties of whole pulses. Most of the flours fell in the range of the 53 to 105 μm screen for whole wheat flour, and this is attributed to the endosperm flour fraction [31]. Doblado-Maldonado et al. [31] also indicated that although a smaller particle size of whole wheat flour could release nutrients more effectively, the moderate particle size performed better in the bread structure and quality. Most of the particles of yellow pea (81.95%), green pea (84.23%), and red lentil (76.70%) flour fell between the 149 and 420 µm screen. The chickpea flour had a bimodal distribution, with a smaller peak around 210 µm and a larger peak around 595 µm. The largest average particle size for chickpea flour was due to the higher lipid content, which resulted in the high amount of flour agglomeration on the 595 µm screen, which cannot be sifted during particle size testing. The overall particle size of the lab-ground flour with the hammer mill is larger than the whole wheat flour and commercial yellow pea flour, due to the different milling process and grain properties. The same trend was presented previously [32], and they also found a greater amount of starch damage in the finely ground flours.

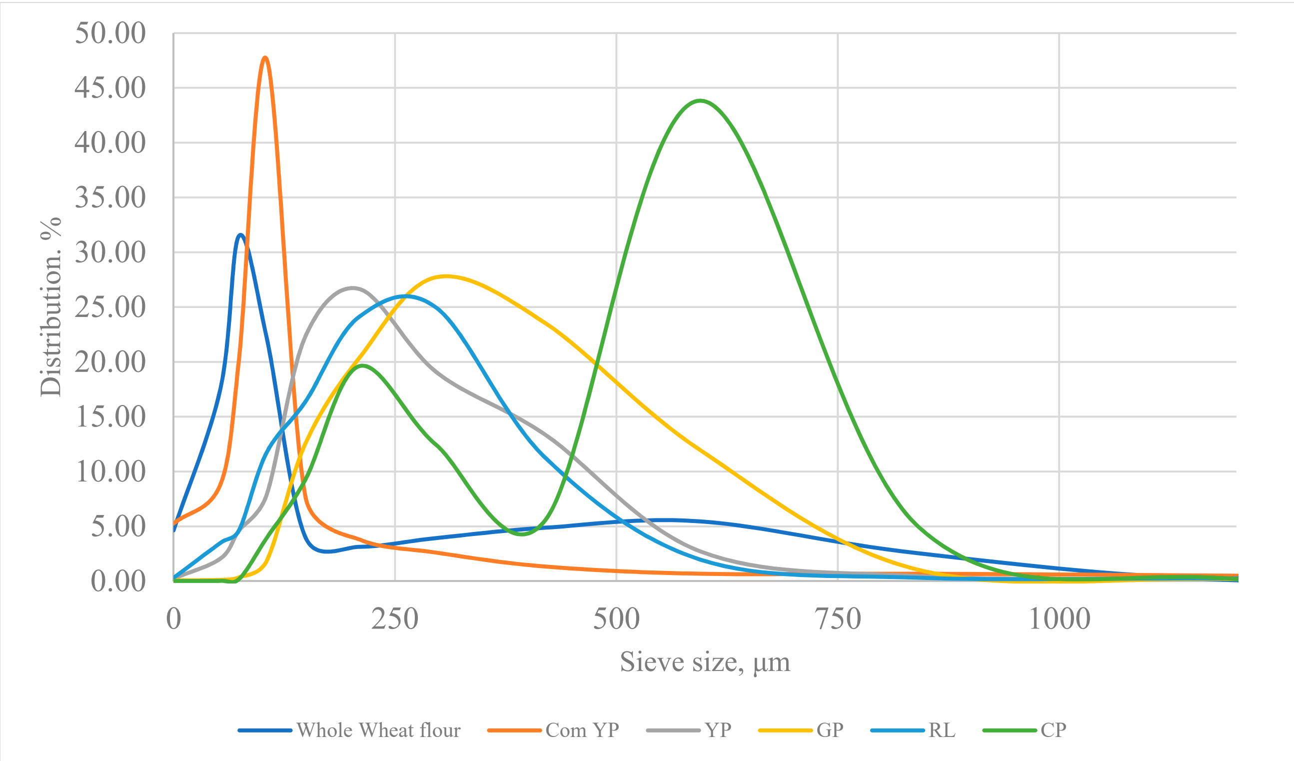

Figure 1. Particle size distribution of whole wheat flour and pulse flour. (CommYP, commercial yellow pea; YP, yellow pea; GP, green pea; RL, red lentil; CP, chickpea.).

3.2. Dough Properties

3.2.1. Mixing Characteristics

The mixing characteristics of the whole wheat dough incorporated with pulse flours are summarized in Table 2. Figure 2 shows an example of the Mixolab graph of composite flours with the addition of 0, 5, 15, and 25% (based on total composite flour weight) yellow pea flour. The mixing properties of dough were determined at 30 °C, and the optimal water absorption was determined by the Mixolab when the mixing torque value reached 1.1 Nm, as specified in the manufacturer's manual. The addition of pulse flours considerably affected the water absorption of the dough. Increasing the amount of pulse flours in the composite presented a higher water absorption value, compared to the whole wheat flour (70.9%), except for 25% commercial yellow pea flour (70.0%). Incorporation of 25% red lentil flour significantly increased the water absorption (74%). This might be due to the larger particle size and non-dehulled coat. There was no significant difference between the yellow pea and chickpea flour on water absorption when the amount of pulse flours increased. The water absorption was significantly increased by adding green pea and red lentil flour, especially with 25% red lentil flour (74%). Adding 25% commercial yellow pea flour presented a lower water absorption value than that with 25% yellow pea flour, which might be due to the smaller particle size. In addition, the proportion of bran in whole wheat flour also influenced the water absorption. Bourré et al. [32] found that the flour and baking properties were affected by the pulse flours' particle size and finer flours presented lower water absorption value, higher viscosities and better crumb texture at 20% substitution of wheat flour. However, this study also indicated that the water absorption is related to the particle size and damaged starch, surface area, protein content, fiber content, and starch content.

Table 2. Mixing characteristics of whole wheat/pulse flour blend from Mixolab.

Sample	Water Absorption, %	Development Time, min	Stability, min	Mechanical Weakening, Nm
Whole wheat	70.90	7.41 ± 0.46 [a,b,c]	9.80 ± 0.42 [a]	0.096 ± 0.00 [a]
5% Comm YP	72.00	7.65 ± 0.57 [a,b,c]	9.10 ± 0.14 [a,b,c]	0.075 ± 0.01 [a]
15% Comm YP	71.80	6.35 ± 0.18 [b,c,d,e]	7.35 ± 0.35 [d,e,f,g]	0.082 ± 0.02 [a]
25% Comm YP	70.00	5.10 ± 0.03 [d,e]	6.10 ± 0.14g [h]	0.076 ± 0.02 [a]
5% YP	71.50	8.09 ± 0.52 [a,b,c]	8.70 ± 0.14 [a,b,c,d,e]	0.081 ± 0.01 [a]
15% YP	71.80	6.77 ± 0.78 [b,c,d]	7.40 ± 0.14 [d,e,f,g]	0.082 ± 0.01 [a]
25% YP	71.80	4.50 ± 0.04 [e]	4.85 ± 0.21 [h]	0.069 ± 0.00 [a]
5% GP	71.80	7.77 ± 0.45 [a,b,c]	8.90 ± 0.28 [a,b,c,d]	0.072 ± 0.02 [a]
15% GP	73.00	7.52 ± 1.06 [a,b,c]	8.15 ± 1.34 [b,c,d,e,f]	0.089 ± 0.01 [a]
25% GP	72.50	4.95 ± 0.32 [d,e]	5.15 ± 0.07 [h]	0.086 ± 0.00 [a]
5% RL	71.80	8.29 ± 0.69 [a,b]	9.65 ± 0.21 [a,b]	0.089 ± 0.01 [a]
15% RL	72.80	6.95 ± 0.21 [a,b,c,d]	7.86 ± 0.07 [d,e,f]	0.106 ± 0.02 [a]
25% RL	74.00	6.18 ± 0.21 [c,d,e]	7.10 ± 0.14 [f,g]	0.110 ± 0.00 [a]
5% CP	71.80	8.88 ± 0.18 [a]	10.05 ± 0.07 [a]	0.091 ± 0.00 [a]
15% CP	72.00	7.21 ± 0.62 [a,b,c]	9.00 ± 0.14 [a,b,c]	0.101 ± 0.01 [a]
25% CP	71.50	6.09 ± 0.54 [c,d,e]	7.20 ± 0.14 [e,f,g]	0.087 ± 0.01 [a]

Means with different letters within each property denote significant differences ($p < 0.05$); CommYP, commercial yellow pea; YP, yellow pea; GP, green pea; RL, red lentil; CP, chickpea.

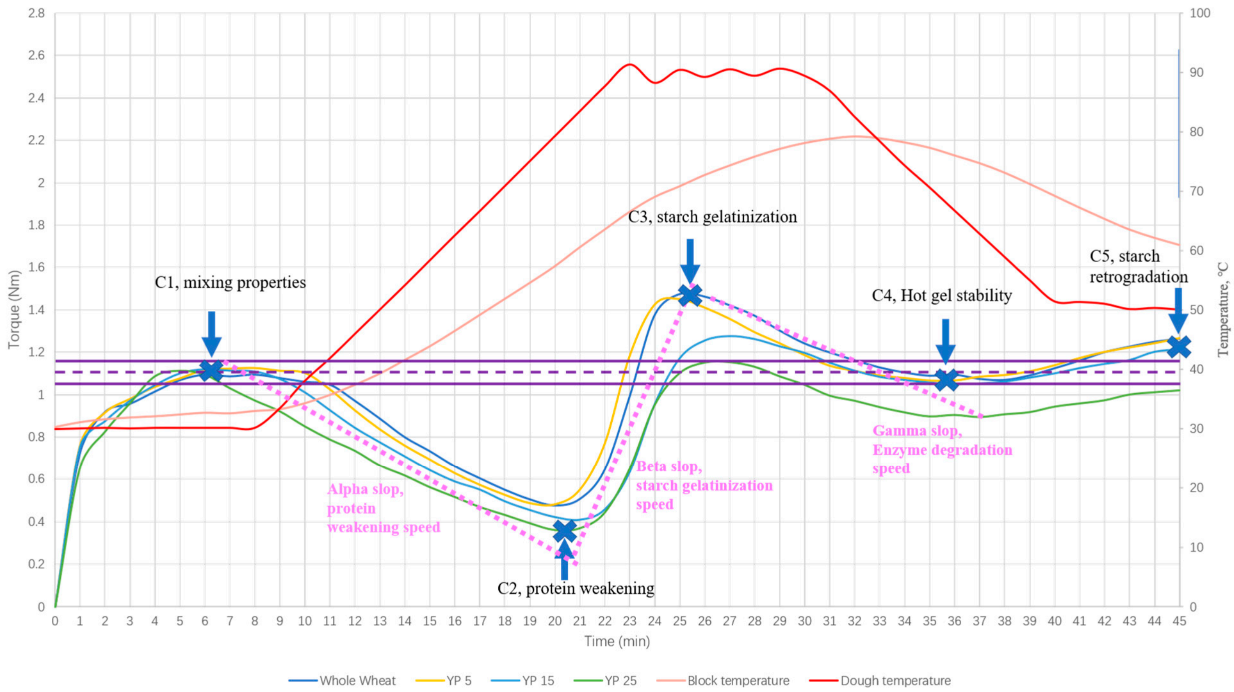

Figure 2. Example Mixolab graph (whole wheat, 5, 15, and 25% yellow pea flour).

The dough development time was affected by the pulse flour addition, especially by adding the yellow pea flour (Table 2). Adding 5% chickpea flour slightly increased the development time of the dough (8.88 min); this result was consistent with a previous study [18]. There was no significant difference between the whole wheat flour (7.41 min) incorporated with 5% of different pulse flours, and no difference was found between adding 15% of pulse flour. Increasing the amount of pulse flour decreased the development time when the dough reached the maximum consistency, especially for the addition of 25% pulse flour; among these, adding 25% of yellow pea flour presented the shortest development time (4.5 min).

The stability of the dough was positively correlated with the development time and affected by the pulse flour addition. The addition of 25% yellow pea flour or green pea flour significantly decreased the dough's stability, and the value was 4.85 and 5.15 min, respectively. These results are also presented in the dough index properties (Figure 3). Yellow pea flour possessed lower protein content than other pulse flours. The addition of 5% chickpea flour presented the highest value of stability (10.05 min), which was similar to the control whole wheat flour (9.80 min). Furthermore, adding 15% of chickpea flour did not significantly affect the stability, and adding chickpea flour showed less influence on dough stability. The stability time of dough indicated the flour strength. Incorporation of pulse flour decreased the dough's strength; this is largely because the dilution of gluten detrimentally affects the development of the gluten network in the whole wheat dough [33]; similar results were also reported by Sadowska et al. [34]. No significant difference was shown in the mechanical weakening value, ranging from 0.069 to 0.110 Nm, which indicated that the protein weakening is similar between different types and amounts of pulse flours in the whole wheat dough. Overall, the addition of 5% pulse flour did not negatively affect the dough mixing properties and demonstrated better potential for the preparation of whole pulse–fortified bakery products.

3.2.2. Pasting Characteristics

The pasting characteristics of the whole wheat dough and whole wheat dough containing pulse flours are shown in Table 3, and some index parameters are presented in Figure 3. The minimum torque values in the protein weakening phase decreased as the amount of pulse flours increased. The highest value of minimum torque was in the whole wheat flour (0.486 Nm). Incorporation with 25% of commercial yellow pea (0.330 Nm), yellow pea (0.351 Nm), green pea (0.376 Nm), red lentil (0.411 Nm), and chickpea flour (0.332 Nm) showed lower minimum torque among different types and amounts of pulse flours. The treatments with commercial yellow pea flour presented lower values in minimum torque than the corresponding incorporation level with lab-ground yellow pea flour. The minimum torque values of lab-ground pulse flours (except for chickpea flour) were positively correlated with particle size. Both flour particle size and substitution level affected the pasting and thermal properties, where increasing the amount of pulse flour decreased the consistency of the dough [14]. Moreover, pulse flour diluted the gluten proteins, which can also result in lower minimum torque value. The thermal weakening parameter was calculated by the torque (C1) in the mixing process minus the minimum torque. There was no significant difference in the value of thermal weakening among treatments containing 5% pulse flour. The extent of thermal weakening was positively correlated with the amount of pulse flour. Tolerance to thermal weakening was important to predict the bread-making quality [35].

During further dough heating in the Mixolab, protein starts unfolding and aggregating; starch starts swelling in the limited available water and ruptures; and amylose, amylopectin, and granule fragments are formed [36]. The addition of pulse flours decreased the paste viscosity of whole wheat doughs as indicated by the minimum torque and peak torque values (Table 3). The peak torque value of whole wheat dough was 1.510 Nm. The peak torque was significantly affected by the substitution level of pulse flours, especially the dough with 25% yellow pea, which had the lowest peak viscosity (1.152 Nm). Increasing the substitution level of pulse flour decreased the peak viscosity (peak torque), due to the higher protein and lower starch content of the pulse flour. The gluten blocks the contact area between separated starch granules and influences the dough gelatinization; gluten absorbs excess water and affects the starch swelling and gelatinization time [37]. The peak viscosity of the pulse flours is in the order of yellow pea flour < green pea flour < chickpea flour < red lentil flour < commercial yellow pea flour. The interaction between starch and protein affects the food matrix through the inter-and intramolecular forces in the macroscopic structure [38].

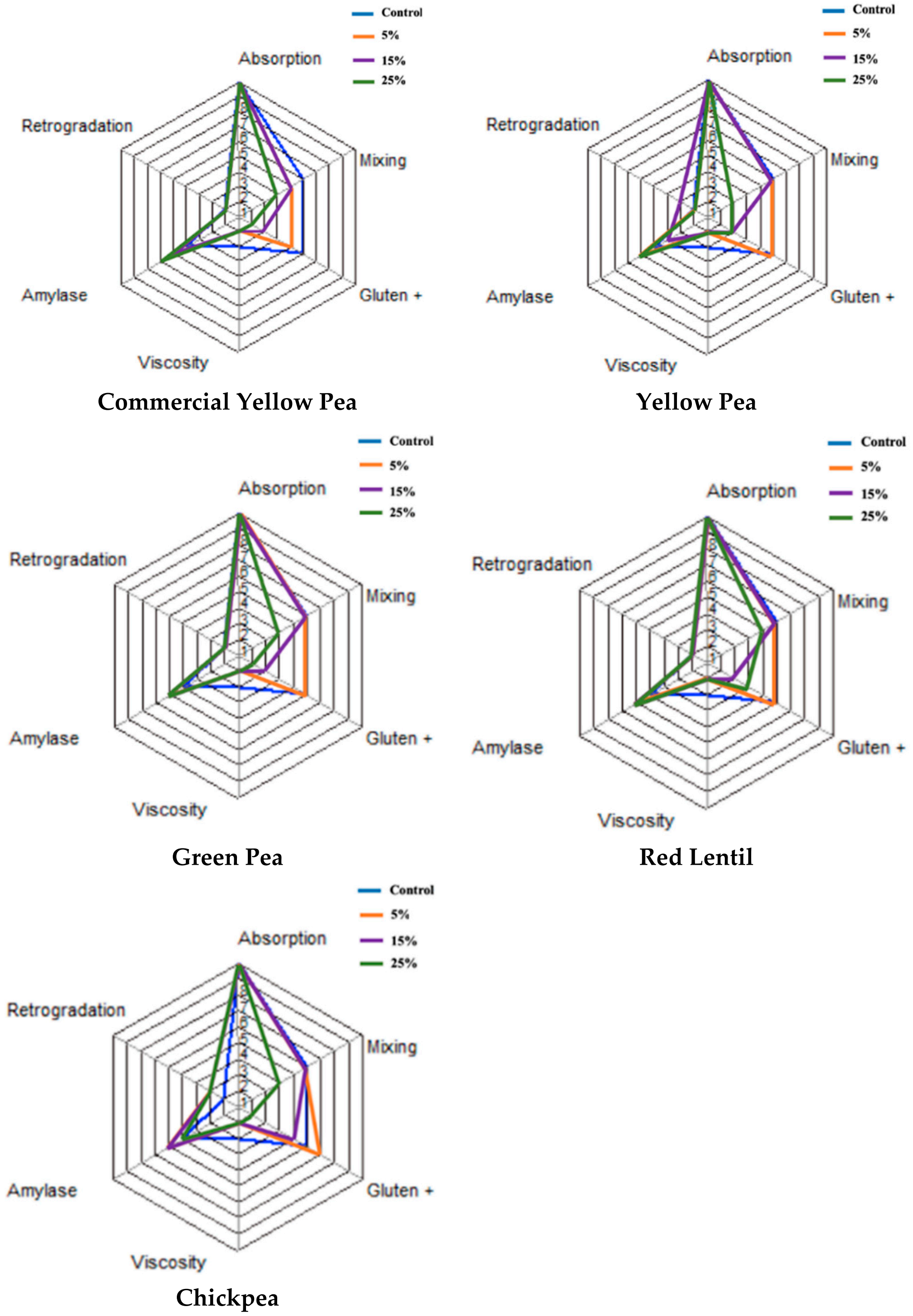

Figure 3. Mixolab index of the whole wheat/pulse flours.

Table 3. Pasting characteristics of whole wheat/pulse flour blend from Mixolab.

Sample	Minimum Torque (Nm)	Thermal Weakening (Nm)	Temperature at Minimum Torque (°C)	Peak Torque (Nm)	Cooking Stability (Nm)	Setback (Nm)
Whole wheat	0.486 ± 0.02 ^{a}	$0.631 \pm 0.00\ 2$ ^{f,g}	58.6 ± 1.6 $_{a}$	1.510 ± 0.03 ^{a}	1.041 ± 0.04 ^{b,c,d,e}	0.213 ± 0.02 ^{a,b,c}
5% Comm YP	0.434 ± 0.01 ^{b,c,d}	0.641 ± 0.004 ^{e,f,g}	58.9 ± 1.3 ^{a}	1.401 ± 0.01 ^{a,b,c,d,e}	1.063 ± 0.01 ^{a,b,c,d}	0.171 ± 0.04 ^{a,b,c}
15% Comm YP	0.379 ± 0.01 ^{e,f}	0.675 ± 0.006 ^{c,d,e,f}	58.2 ± 1.2 ^{a}	1.332 ± 0.00 ^{c,d,e,f,g}	0.980 ± 0.02 ^{c,d,e,f}	0.154 ± 0.00 ^{a,b,c}
25% Comm YP	0.330 ± 0.00 ^{g}	0.741 ± 0.004 ^{a,b}	60.5 ± 2.5 ^{a}	1.322 ± 0.04 ^{d,e,f,g}	1.018 ± 0.00 ^{b,c,d,e,f}	$0.169 \pm 0.0.02$ ^{a,b,c}
5% YP	0.475 ± 0.00 ^{a}	0.654 ± 0.018 ^{e,f}	58.6 ± 2.5 ^{a}	1.425 ± 0.05 ^{a,b,c,d}	1.073 ± 0.02 ^{a,b,c,d}	0.186 ± 0.03 ^{a,b,c}
15% YP	0.423 ± 0.01 ^{c,d}	0.711 ± 0.002 ^{b,c}	61.2 ± 0.7 ^{a}	1.353 ± 0.03 ^{b,c,d,e,f}	0.993 ± 0.02 ^{c,d,e,f}	0.199 ± 0.02 ^{a,b,c}
25% YP	0.351 ± 0.01 ^{f,g}	0.775 ± 0.013 ^{a}	58.8 ± 0.4 ^{a}	1.152 ± 0.02 ^{h}	0.895 ± 0.00 ^{f}	0.128 ± 0.00 ^{c}
5% GP	0.469 ± 0.02 ^{a,b}	0.650 ± 0.012 ^{e,f}	59.5 ± 0.1 ^{a}	1.438 ± 0.06 ^{a,b,c,d}	1.092 ± 0.00 ^{a,b,c}	0.195 ± 0.04 ^{a,b,c}
15% GP	0.430 ± 0.01 ^{b,c,d}	0.678 ± 0.022 ^{c,d,e}	59.6 ± 2.3 ^{a}	1.406 ± 0.05 ^{a,b,c,d,e}	1.077 ± 0.10 ^{a,b,c,d}	0.224 ± 0.06 ^{a,b,c}
25% GP	0.376 ± 0.01 ^{e,f}	0.750 ± 0.004 ^{a,b}	60.4 ± 0.6 ^{a}	1.212 ± 0.00 ^{g,h}	0.954 ± 0.03 ^{d,e,f}	0.147 ± 0.05 ^{b,c}
5% RL	0.477 ± 0.00 ^{a}	0.651 ± 0.015 ^{e,f}	61.1 ± 1.6 ^{a}	1.461 ± 0.03 ^{a,b}	1.054 ± 0.04 ^{a,b,c,d}	0.144 ± 0.02 ^{b,c}
15% RL	0.452 ± 0.01 ^{a,b,c}	0.671 ± 0.018 ^{c,d,e,f}	58.7 ± 1.4 ^{a}	1.399 ± 0.05 ^{a,b,c,d,e}	1.039 ± 0.01 ^{b,c,d,e}	0.183 ± 0.00 ^{a,b,c}
25% RL	0.411 ± 0.01 ^{d,e}	0.706 ± 0.020 ^{b,c,d}	60.7 ± 0.7 ^{a}	1.282 ± 0.03 ^{e,f,g}	0.922 ± 0.04 ^{e,f}	0.135 ± 0.02 ^{b,c}
5% CP	0.467 ± 0.01 ^{a,b}	0.600 ± 0.005 ^{g}	59.8 ± 0.4 ^{a}	1.470 ± 0.01 ^{a,b}	1.174 ± 0.00 ^{a}	0.227 ± 0.01 ^{a,b,c}
15% CP	0.423 ± 0.00 ^{c,d}	0.664 ± 0.002 ^{e,f}	58.9 ± 1.3 ^{a}	1.451 ± 0.01 ^{a,b,c}	1.138 ± 0.01 ^{a,b}	0.260 ± 0.01 ^{a}
25% CP	0.332 ± 0.00 ^{g}	0.727 ± 0.006 ^{b}	61.8 ± 0.4 ^{a}	1.272 ± 0.01 ^{f,g,h}	0.963 ± 0.02 ^{d,e,f}	0.242 ± 0.00 ^{a,b}

Means with different letters within each property denote significant differences ($p < 0.05$); CommYP, commercial yellow pea; YP, yellow pea; GP, green pea; RL, red lentil; CP, chickpea.

The cooking stability was not significantly affected by the different types and substitution levels, except for 25% yellow pea flour (0.895 Nm), and chickpea flour at 5% (1.174 Nm), and 15% (1.138 Nm), compared with the control. The cooking stability, also called hot gel stability, indicates the stability of previously broken starch granules during the heating process [36]. Adding 25% yellow pea flour significantly decreased the hot gel stability, while adding 5 and 15% chickpea flour significantly increased the hot gel stability. The increased cooking stability with chickpea flour might be due to its higher lipid content, which requires further investigation. The setback value was calculated through the torque in starch retrogradation in the cooling phase minus the torque in the hot gel stability phase (C5–C4), and it indicates the potential of straight-chain amylose molecules realigning and forming stable gel structure [39]. The dough incorporated with 25% yellow pea flour had the lowest value (0.128 Nm), while the dough with 15% chickpea flour presented the highest value (0.260 Nm). This might be due to the higher protein content providing better stability for starch granules at high temperatures [40]. The overall tendency of the setback value was slightly increased at the 15% level and then decreased at the 25% level.

3.3. Bread Properties

3.3.1. Bread Volume, C-Cell Structure, and Color Parameters

The specific volume and C-cell properties of whole wheat breads with pulse flours are shown in Table 4, and the pictures of bread products are presented in Figure 4. Increasing the amount of pulse flours slightly decreased the specific volume of the bread, except in the case of 5% yellow pea flour. The bread containing 5% yellow pea flour (3.81 cm^3/g) had a similar specific volume to the control whole wheat bread (3.82 cm^3/g). Among the different pulse flour treatments, the dough containing 5% yellow pea flour presented better pasting properties, good mixing properties and other values similar to the whole wheat control dough, which may explain its better bread volume. The 5% yellow pea bread also had a comparable cell diameter (1.832 mm) and number of cells (2969) as the control bread. Adding 15% of yellow pea flour slightly decreased the specific volume (3.59 cm^3/g) and the number of bread cells (2592), while adding 25% yellow pea flour significantly decreased the number of cells (2220), enlarged the cell volume (2.157 mm), and decreased the bread volume (3.16 cm^3/g). The same trend was also found in other research, which showed that increasing pea flour from 5 to 10% in the formulation decreased the bread volume and cookie spread ratio [41]. The lab-ground yellow pea flour had lower protein content and larger average particle size than the commercial yellow pea flour, which might, in part, contribute to the larger bread specific volume. Adding 25% pulse flours greatly worsened the cell structure (e.g., reduced number of cells, increased cell diameter, thicker cell walls), compared to the control or breads with a lower amount of pulse flours. The number of cells and cell diameter are related to the gluten network quality. Incorporation with higher amount of pulse flours influenced the gluten development and affected the dough stability during the baking process.

Table 4. Baking parameters, specific volume, and C-cell properties of whole wheat/pulse bread.

Sample	Water Abs., %	Mixing Time, min	Specific Volume, cm^3/g	Number of Cells	Cell Diameter/mm	Wall Thickness, mm
Whole wheat	75	4.67	3.82 ± 0.07 [a]	2941 ± 54 [a]	1.88 ± 0.04 [b,c,d]	0.420 ± 0.001 [b,c]
5% Comm YP	73	5.00	3.15 ± 0.12 [a,b]	2867 ± 31 [a,b]	1.83 ± 0.01 [c,d]	0.420 ± 0.003 [b,c]
15% Comm YP	70.5	4.50	3.43 ± 0.03 [a,b]	2818 ± 8 [a,b]	1.82 ± 0.01 [c,d]	0.425 ± 0.002 [a,b,c]
25% Comm YP	68	4.67	3.10 ± 0.05 [a,b]	2425 ± 60 [c,d,e]	2.07 ± 0.01 [a,b]	0.443 ± 0.001 [a,b]
5% YP	75	4.67	3.81 ± 0.22 [a]	2969 ± 109 [a]	1.83 ± 0.06 [c,d]	0.423 ± 0.009 [b,c]
15% YP	72.5	3.75	3.59 ± 0.11 [a,b]	2592 ± 34 [b,c,d]	1.99 ± 0.11 [a,b,c]	0.435 ± 0.009 [a,b,c]
25% YP	70	4.17	3.16 ± 0.05 [a,b]	2220 ± 94 [e]	2.16 ± 0.04 [a]	0.450 ± 0.016 [a]
5% GP	75	4.67	3.54 ± 0.06 [a,b]	2825 ± 60 [a,b]	1.75 ± 0.13 [d]	0.415 ± 0.010 [c]
15% GP	72.5	4.50	3.18 ± 0.13 [a,b]	2682 ± 76 [a,b,c]	1.82 ± 0.03 [c,d]	0.421 ± 0.000 [b,c]
25% GP	70	4.00	2.90 ± 0.11 [b]	2285 ± 43 [d,e]	2.01 ± 0.02 [a,b,c]	0.439 ± 0.004 [a,b,c]
5% RL	75	5.00	3.44 ± 0.24 [a,b]	2780 ± 17 [a,b]	1.86 ± 0.07 [b,c,d]	0.428 ± 0.008 [a,b,c]
15% RL	73.5	4.50	3.00 ± 0.11 [a,b]	2732 ± 161 [a,b,c]	1.81 ± 0.07 [c,d]	0.424 ± 0.005 [b,c]
25% RL	72	4.50	2.84 ± 0.05 [b]	2411 ± 132 [c,d,e]	1.89 ± 0.04 [b,c,d]	0.423 ± 0.001 [b,c]
5% CP	75	5.17	3.50 ± 0.14 [a,b]	2919 ± 154 [a,b]	1.85 ± 0.04 [b,c,d]	0.423 ± 0.003 [b,c]
15% CP	72.5	5.67	3.13 ± 0.11 [a,b]	2738 ± 37 [a,b,c]	1.93 ± 0.03 [a,b,c,d]	0.425 ± 0.000 [a,b,c]
25% CP	68	5.33	3.31 ± 0.14 [a,b]	2663 ± 42 [a,b,c]	1.92 ± 0.02 [b,c,d]	0.430 ± 0.000 [a,b,c]

Means with different letters within each property denote significant differences ($p < 0.05$); CommYP, commercial yellow pea; YP, yellow pea; GP, green pea; RL, red lentil; CP, chickpea.

Adding 25% green pea flour (2.90 cm^3/g) and 25% red lentil flour (2.84 cm^3/g) dramatically decreased the bread volume, compared with the control, which might be because the higher pulse flour content hindered the gluten development. The lower water absorption of pulse flour might also be partially responsible for the lower specific volume of bread. Jekle et al. [38] proposed two interactions between protein and starch in bread baking: the competitive hydration between protein and starch, and formation of the gluten–protein matrix on the starch granule surface. The higher amount of pulse starch resulted in a larger crumb cell wall and a higher amount of open crumb grain [34]. Incorporation of 5 or 15% of green pea flour and red lentil flour into whole wheat flour was acceptable because the volume and structure of bread were not significantly reduced. Unlike the other pulse flours, chickpea flour provided better specific volume and crumb structure at a substitution level of 25% than that of the 15% chickpea level. This might be related to the pasting characteristics of 25% chickpea flour, where the dough had a similar setback value with the whole wheat dough, and the flour had the highest lipid content. Mohammed et al. [42] found that adding 20% of chickpea flour significantly decreased the white bread specific volume. Whole wheat bread dough had a more diluted gluten network than white bread dough, and thus the negative effect might be less obvious in the former system.

Bread crumb color properties in terms of lightness (L*), redness-greenness (a*), and yellowness-blueness (b*) are summarized in Table 5. The addition of pulse flours, especially at 15 or 25%, decreased Hunter L*, which indicates that the breads became darker, such as those containing green pea, red lentil, and chickpea flours. Commercial yellow pea had a smaller particle size and contained the lowest carbohydrate content, showing a lighter color. The color compounds arose from the pigments in the hulls as well as from the Maillard reaction products [42]. The red lentil flour provided a darker red color for the bread crumb, and green pea flour provided a green color for the bread crumb.

3.3.2. Moisture Loss and Texture Properties

The moisture content and moisture loss of bread are shown in Table 6. On days 1, 4 and 7, increasing the substitution level of pulse flours decreased the moisture content. The moisture content of the bread with commercial yellow pea flour significantly decreased with having the storage days increased and was the lowest among all the breads and for all three testing days. The bread supplemented with 5 and 15% yellow pea, green pea, red lentil, and chickpea flour did not differ in moisture content, ranging from 46.02 to 47.06%. Overall, the largest moisture decrease rate was found for the bread with 25% commercial yellow pea flour, and the smallest moisture decrease rate was for 5% chickpea bread. Incorporation with 5% of pulse flour slightly decreased the moisture loss during the one-week storage. This might be due to the slightly higher water absorption requirements of pulse flour. Wang et al. [43] found that protein is more affinitive to water molecules and has stronger water absorption capacity than starch, resulting in the water in the protein being less mobile than in the starch granular. The bread moisture loss was related to several factors, e.g., the gluten content, pulse flours protein content, and pulse flours particle size.

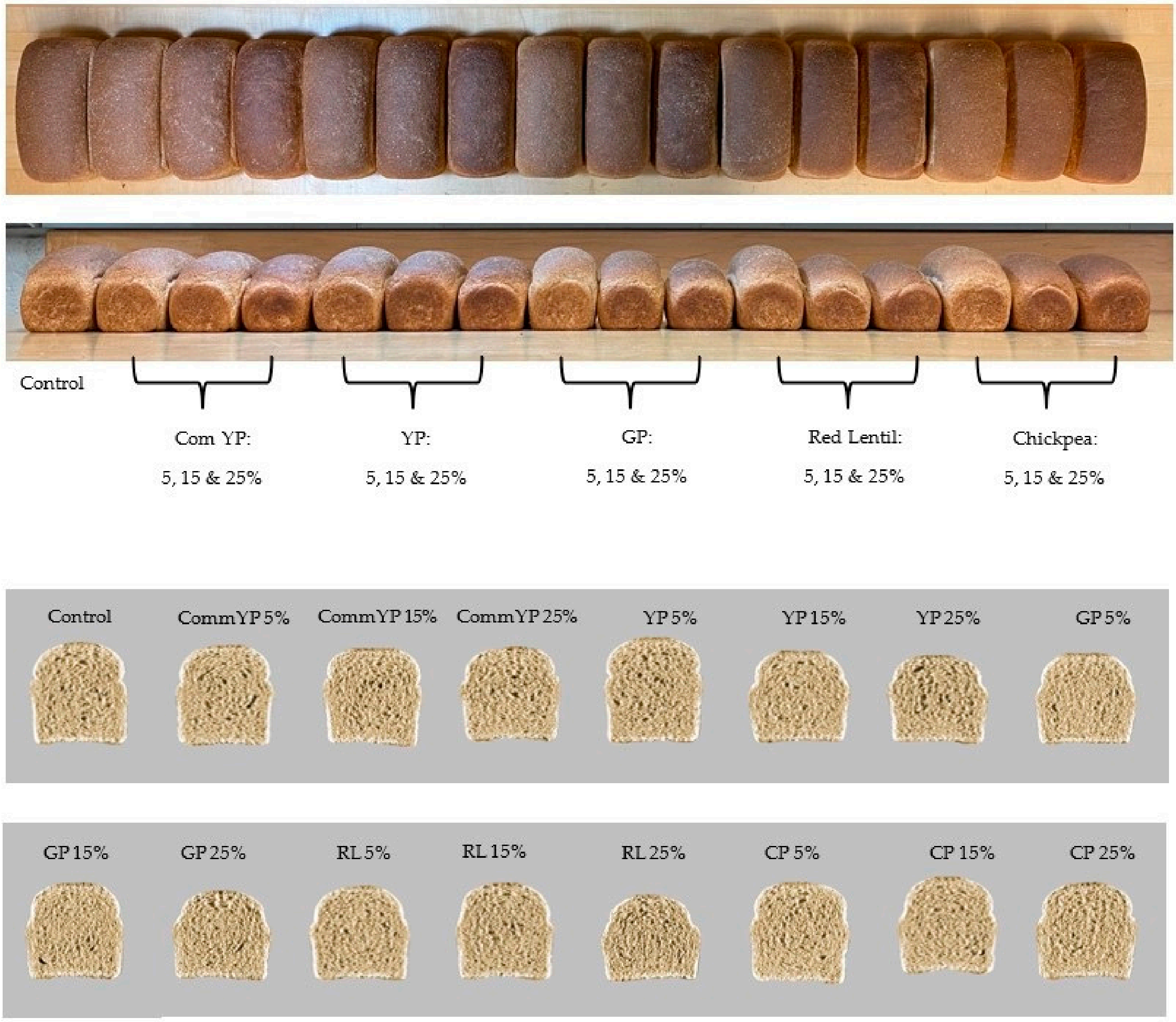

Figure 4. Bread photos and C-cell images. (CommYP, commercial yellow pea; YP, yellow pea; GP, green pea; RL, red lentil; CP, chickpea.).

Table 5. Color parameters of whole wheat/pulse bread crumb.

Bread Sample	L*	a*	b*
Whole wheat	36.25 ± 0.64^{a}	11.46 ± 0.89^{a}	25.90 ± 1.40^{a}
5% Comm YP	36.53 ± 0.69^{a}	12.20 ± 0.12^{a}	26.40 ± 0.54^{a}
15% Comm YP	$34.27 \pm 2.04^{a,b,c,d}$	11.54 ± 0.23^{a}	24.55 ± 0.09^{a}
25% Comm YP	$32.21 \pm 0.48^{b,c,d}$	10.49 ± 1.86^{a}	21.72 ± 1.36^{a}
5% YP	$34.81 \pm 0.42^{a,b,c}$	17.52 ± 8.93^{a}	18.98 ± 10.02^{a}
15% YP	$33.96 \pm 0.78^{a,b,c,d}$	11.45 ± 0.20^{a}	24.05 ± 0.41^{a}
25% YP	$31.56 \pm 0.00^{c,d}$	11.40 ± 0.39^{a}	22.72 ± 0.85^{a}
5% GP	36.21 ± 2.23^{a}	11.65 ± 0.01^{a}	25.20 ± 0.13^{a}
15% GP	$33.13 \pm 0.06^{a,b,c,d}$	11.45 ± 0.39^{a}	23.86 ± 0.88^{a}
25% GP	30.51 ± 0.57^{d}	11.04 ± 0.01^{a}	23.03 ± 0.69^{a}
5% RL	$35.57 \pm 0.04^{a,b}$	11.54 ± 0.37^{a}	24.72 ± 0.04^{a}
15% RL	$33.09 \pm 0.31^{a,b,c,d}$	11.21 ± 0.05^{a}	22.92 ± 0.69^{a}
25% RL	30.59 ± 0.83^{d}	11.29 ± 0.43^{a}	22.45 ± 1.78^{a}
5% CP	36.41 ± 0.09^{a}	12.28 ± 0.76^{a}	25.97 ± 0.23^{a}
15% CP	$33.51 \pm 1.85^{a,b,c,d}$	12.18 ± 0.54^{a}	25.36 ± 1.43^{a}
25% CP	30.74 ± 0.88^{d}	10.94 ± 0.11^{a}	20.68 ± 1.03^{a}

Means with different letters within each property denote significant differences ($p < 0.05$); CommYP, commercial yellow pea; YP, yellow pea; GP, green pea; RL, red lentil; CP chickpea. L*; Lightness; a*; redness-greenness; b*; yellowness-blueness.

Table 6. Moisture content of whole wheat/pulse bread during storage.

Bread Sample	Day 1, %	Day 4, %	Decrease Rate Day 1–Day 4, %	Day 7, %	Decrease Rate Day 4–Day 7, %	Overall Decrease Rate, %
Whole wheat	$46.82 \pm 0.05^{a,b}$	46.37 ± 0.28^{a}	0.96	$42.98 \pm 0.49^{a,b,c,d}$	7.31	8.20
5% Comm YP	$46.45 \pm 0.47^{a,b,c}$	$45.92 \pm 0.28^{a,b}$	1.14	$43.16 \pm 0.78^{a,b,c,d}$	6.01	7.08
15% Comm YP	$45.73 \pm 0.27^{c,d,e}$	$44.38 \pm 1.03^{a,b}$	2.95	$41.12 \pm 1.01^{d,e}$	7.35	10.08
25% Comm YP	44.79 ± 0.14^{f}	43.02 ± 0.94^{b}	3.95	39.67 ± 1.38^{e}	7.79	11.43
5% YP	47.06 ± 0.16^{a}	$45.81 \pm 1.30^{a,b}$	2.66	44.75 ± 1.11^{a}	2.31	4.91
15% YP	$46.17 \pm 0.03^{a,b,c,d}$	$44.24 \pm 1.28^{a,b}$	4.18	$41.73 \pm 0.67^{b,c,d,e}$	5.67	9.62
25% YP	$45.58 \pm 0.30^{c,d,e,f}$	$44.64 \pm 0.02^{a,b}$	2.06	$41.53 \pm 0.35^{c,d,e}$	6.97	8.89
5% GP	$46.77 \pm 0.08^{a,b}$	46.40 ± 0.32^{a}	0.79	$44.29 \pm 0.77^{a,b,c}$	4.55	5.30
15% GP	$46.02 \pm 0.46^{b,c,d}$	$45.61 \pm 0.20^{a,b}$	0.87	$41.01 \pm 0.90^{d,e}$	10.09	10.87
25% GP	$45.27 \pm 0.07^{d,e,f}$	$43.50 \pm 0.64^{a,b}$	3.91	$42.06 \pm 0.29^{a,b,c,d,e}$	3.31	7.09
5% RL	47.00 ± 0.18^{a}	$46.12 \pm 0.69^{a,b}$	1.87	$44.54 \pm 0.24^{a,b}$	3.43	5.23
15% RL	$46.71 \pm 0.30^{a,b}$	$45.77 \pm 0.80^{a,b}$	2.01	44.73 ± 0.03^{a}	2.27	4.24
25% RL	$45.94 \pm 0.25^{b,c,d}$	$45.42 \pm 0.18^{a,b}$	1.13	$42.24 \pm 1.11^{a,b,c,d,e}$	7.00	8.05
5% CP	$46.48 \pm 0.07^{a,b,c}$	$45.94 \pm 0.54^{a,b}$	1.16	45.01 ± 0.50^{a}	2.02	3.16
15% CP	$46.17 \pm 0.00^{a,b,c,d}$	$45.18 \pm 0.27^{a,b}$	2.14	$42.47 \pm 0.56^{a,b,c,d}$	3.78	5.85
25% CP	$44.88 \pm 0.06^{e,f}$	$43.92 \pm 1.65^{a,b}$	2.14	$41.46 \pm 0.25^{c,d,e}$	5.60	7.62

Means with different letters within each property denote significant differences ($p < 0.05$); CommYP, commercial yellow pea; YP, yellow pea; GP, green pea; RL, red lentil; CP, chickpea.

The whole wheat bread hardness was significantly affected by pulse flours and storage time (Table 7). All the breads showed a tendency to increase in hardness as the storage day increased. On the first day, 5% pulse flours and 15% commercial yellow pea flour, yellow pea flour, and green pea flour did not significantly change the hardness of the bread. In particular, adding 5% red lentil flour slightly decreased the hardness of the bread, though not significantly ($p > 0.05$). With an increase in storage time, breads with 5% yellow pea, green pea, red lentil, chickpea flour, and 15% yellow pea did not reveal a significant difference in bread hardness. These results might be related to the starch retrogradation value from the Mixolab analysis since these doughs had a similar starch retrogradation value in the cooling phase. Compared with the bread hardening rate of whole wheat bread, incorporating some pulse flour delayed the hardening change of bread, for example, with 15% yellow pea flour. Increasing the substitution level of pulse flours significantly increased the starch retrogradation value and resulted in a harder texture. Both the polysaccharides and protein in the pulse flour contributed to the bread hardness [44], resulting in the firmer texture of the bread with pulse flour.

Table 7. Hardness of whole wheat/pulse bread during one-week storage.

Bread Sample	Day 1, g	Day 4, g	Increase Rate Day 1–Day 4, %	Day 7, g	Increase Rate Day 4–Day 7, %	Overall Increase Rate, %
Whole wheat	567.06 ± 36.32 ^{f,g}	853.74 ± 43.06 ^{e}	50.56	1199.38 ± 260.09 ^{e}	40.49	111.51
5% Comm YP	712.1 ± 61.83 ^{e,f,g}	973.47 ± 12.43 ^{d,e}	36.70	1663.07 ± 90.51 ^{b,c,d,e}	70.84	133.54
15% Comm YP	725.12 ± 59.52 ^{d,e,f,g}	1122.67 ± 123.00 ^{c,d,e}	54.83	1713.21 ± 96.98 ^{b,c,d,e}	52.60	136.27
25% Comm YP	1056.81 ± 123.45 ^{a,b,c}	1392.67 ± 144.21 ^{a,b,c,d}	31.77	2041.58 ± 258.22 ^{b,c,d}	46.61	93.18
5% YP	580.03 ± 112.71 ^{f,g}	843.91 ± 28.76 ^{e}	45.49	1231.22 ± 173.69 ^{e}	45.89	112.27
15% YP	667.15 ± 112.71 ^{f,g}	897.78 ± 5.82 ^{e}	34.57	1138.07 ± 165.77 ^{e}	26.76	70.59
25% YP	993.23 ± 139.79 ^{b,c,d}	1410.41 ± 68.88 ^{a,b,c}	42.00	2191.13 ± 135.79 ^{b,c}	55.35	120.61
5% GP	722.84 ± 110.58 ^{e,f,g}	1073.61 ± 112.58 ^{c,d,e}	48.53	1163.77 ± 109.99 ^{e}	8.40	61.00
15% GP	822.15 ± 5.88 ^{c,d,e,f}	1219.51 ± 141.75 ^{b,c,d,e}	48.33	1907.13 ± 76.45 ^{b,c,d}	56.38	131.97
25% GP	1219.74 ± 132.70 ^{a,b}	1552.77 ± 283.37 ^{a,b}	27.30	2276.93 ± 220.38 ^{a,b}	46.64	86.67
5% RL	550.99 ± 2.28 ^{g}	1051.97 ± 40.25 ^{c,d,e}	90.92	1460.46 ± 169.68 ^{d,e}	38.83	165.06
15% RL	992.63 ± 94.40 ^{b,c,d}	1362.45 ± 184.44 ^{b,c,d}	37.26	1588.22 ± 66.76 ^{c,d,e}	16.57	60.00
25% RL	1296.06 ± 105.56 ^{a}	1793.29 ± 118.36 ^{a}	38.36	2367.41 ± 81.26 ^{b,c,d}	32.01	82.66
5% CP	734.98 ± 62.23 ^{d,e,f,g}	1131.76 ± 175.65 ^{b,c,d,e}	53.99	1409.70 ± 38.27 ^{d,e}	24.56	91.80
15% CP	963.08 ± 56.84 ^{b,c,d,e}	1460.00 ± 71.59 ^{a,b,c}	51.60	2873.91 ± 249.33 ^{a}	96.84	198.41
25% CP	1029.22 ± 102.67 ^{a,b,c}	1224.73 ± 272.05 ^{b,c,d,e}	19.00	1971.11 ± 72.52 ^{b,c,d}	60.94	91.51

Values are expressed as the mean and SD of three measurements. Means with different letters within each property denote significant differences ($p < 0.05$); CommYP, commercial yellow pea; YP, yellow pea; GP, green pea; RL, red lentil; CP, chickpea.

4. Conclusions

Pulse flour particle size and content of protein and carbohydrate greatly affected the dough mixing and pasting properties. The addition of pulse flours increased the water absorption of the dough compared to whole wheat flour alone, except for 25% commercial yellow pea flour. Increasing substitution level of pulse flours decreased dough stability; however, the dough stability of composite flours containing chickpea was better than the other flours at the same substitution level. Dough thermal weakening increased, and minimum torque values decreased during the protein weakening phase as the amount of pulse flours increased. The smaller particle size of commercial yellow pea flour had a more negative effect on the dough and bread properties, compared to the lab-ground yellow pea flour with a larger particle size. Adding 5% of lab yellow pea flour did not obviously affect the bread volume, structure, or texture. Incorporating 25% of green pea flour or red lentil flour significantly decreased the bread specific volume. Increasing the substitution level of pulse flours decreased the moisture content and increased the hardness of the bread. Overall, adding up to 5% of pulse flours was acceptable, having minimal effect on the dough properties and bread quality and improving the nutritional value of whole grain bread. Compared with commercial yellow pea flour, lab-ground yellow pea flour is considered more suitable for bread preparation; up to 15% of yellow pea flour is acceptable to substitute whole wheat flour. Future studies are recommended to understand the effect of pulse flour particle size on bread-making performance and the sensory properties of composite flour as well as to further elucidate some unique properties of chickpea flour as compared to other pulse flours.

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