Effect of adding fermented split yellow pea flour as a partial replacement of wheat flour in bread

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Abstract
The effect of adding fermented split yellow pea flour (SYPF) as a partial replacement for wheat flour in bread was examined. Three sourdough culture levels (3%, 6.5%, and 10%) and two fermentation times (1 and 4 hr) were evaluated. Total titratable acidity of ferment was measured to determine acid development. Bread was baked using three ferment inclusion levels (25%, 35%, and 45%) for each of the six treatment combinations. Nonfermented control bread was baked for each inclusion and culture level by adding the equivalent amount of SYPF and culture to the formulation. Bread was scored for quality and assessed for specific volume, crumb colour, C-Cell properties, and flavour. Significant main effects were found for inclusion level, culture level, and fermentation time, and a significant Inclusion level × Fermentation time interaction was found for crumb firmness and cell diameter. Breads made with nonfermented SYPF and 10% culture had good flavour with only minor reductions in bread quality compared with a 100% wheat control bread. For the breads made with fermented SYPF, the ferment made with 10% culture fermented for 1 hr and added at an inclusion level of 25% had the most acceptable flavour and bread quality characteristics.

KEYWORDS
fermentation, sourdough culture, bread quality, yellow pea flour

1 | INTRODUCTION

Fermentation is one of the oldest processes used in the production of foods, originating from early times where naturally occurring microorganisms were allowed to grow to bring about the natural fermentation of the raw material, to more recent times where the use of specific microorganisms was developed and maintained by saving part of the ferment for future use. The exact effect fermentation has on the starting material is dependent on the strain of culture used and the types of organic acids produced (Li, 2019). With baking, fermentation is a critical process responsible for leavening and flavour formation. Although the use of white wheat flour and baker’s yeast is the accepted practice in industrial baking, there is renewed interest in using sourdough fermentation in the production of bread. Reported benefits of sourdough fermentation of breads include improved shelf life,
modified flavour, aroma, and texture, as well as enhanced nutritional properties by decreasing glycaemic response, increasing digestibility, and decreasing antinutritional factors (Gobbetti, Rizzello, Di Cagno, & De Angelis, 2013; Kamal-Eldin, 2012; Poutanen, Flander, & Katina, 2009). Studies have shown that sourdough fermentation of whole wheat flour and bran results in bread with improved sensory properties (Hassan, Awad, Alkareem, & Mustafa, 2008; Salmenkallio-Marttila, Katina, & Autio, 2001). The renewed interest in sourdough fermentation has resulted in the development of improved lactic acid cultures for use in breads and new technology around the fermentation process.

Yellow peas, like other pulses, are rich in protein, complex carbohydrates, minerals, and B vitamins. The availability of pulse flours has allowed for the expansion of pulse ingredients in foods, including baked goods, mainly to improve the nutritional content of the product. The partial replacement of wheat flour with pulse flour in bread not only increases the protein and fibre content of bread but also improves the quality of the protein. Consumption of foods made with yellow pea flour has been linked to the reduction in postprandial glucose response, which is beneficial for diabetics, and to improvements in cardiovascular health (Dahl, Foster, & Tyler, 2012; Marinangeli, Kassis, & Jones, 2009). Despite the reported nutritional and health benefits associated with pulse flours, there are limitations to their use. Previous work in our laboratory has shown that pulse flours can successfully replace 20% of the wheat flour in pan bread provided gluten is added (Bourré et al., 2019). The addition of pulse flours can however impact the flavour of the final product with pea and lentil flours having a greater effect on flavour than chickpea and bean flours (Malcolmson & Han, 2019). Colour can also be affected depending on the pulse flour used.

Several studies have been done to examine the impact of partially replacing wheat flour with fermented pulse flours. Naturally fermented chickpea flour added at a level of 20% was shown to improve flavour, and shelf life of bread made with durum wheat flour but bread volume was negatively affected (Kefalas et al., 2009). Sadowska, Fornal, Vidal-Valverde, and Frias (1999) found that good quality breads could be achieved using 5% naturally fermented lentil flour. Rizzello, Calasso, Campanella, De Angelis, and Gobbetti (2014) found that acceptable bread could be achieved with the addition of a blend of 10% fermented pulse flours (chickpea, lentil, and bean). Coda, Varis, Verni, Rizzello, and Katina (2017) reported that crumb porosity was not affected in bread made with 30% fermented faba bean flour. Shrivastava and Chakraborty (2018) found that bread containing 18% fermented chickpea flour and 2% xanthan gum resulted in bread with maximum specific volume and minimum hardness and crust colour. To our knowledge, no research has been done on the addition of fermented split yellow pea flour (SYPF) to bread. However, lactic acid fermentation of pea protein extracts has been shown to significantly reduce or mask undesirable pea aroma compounds (Schindler et al., 2012) suggesting that the use of sourdough culture may be helpful in reducing the off-flavours associated with pea flour. Thus, it was the overall objective of this study to evaluate the effect of adding fermented SYPF as a partial replacement for wheat flour in bread. Specifically, the effects of ferment inclusion level, sourdough culture levels, and fermentation time on bread quality were determined.

2 | MATERIALS AND METHODS

2.1 | Materials

Dehulled and SYPF, fine grind, was obtained from Avena Foods Ltd. (Portage la Prairie, MB). Straight grade wheat flour, milled from a grist of Canadian Western Spring Wheat (CWRIS) and English wheat, was obtained from Nelstrop William & Co Ltd (Stockport, UK). Sourdough culture (Sapore Adelia) was acquired from Puratos (Pennsauken, NJ).

2.2 | Preparation of ferments

Fermentation of SYPF was carried out in a pilot scale fermentation vessel (Briggs of Burton Plc, Staffordshire, UK) using the standard four-stage fermentation cycle at 35°C (Table 1). Three levels of culture (3%, 6.5%, and 10%) and two fermentation times (1 and 4 hr) were used for a total of six treatment combinations. Ferment was prepared using the following ingredients (expressed in baker’s percentage): SYPF (100%), water (120%; 35°C), canola oil (2%), and sourdough culture (3%, 6.5%, or 10%, based on the total amount of SYPF and water in the ferment). To prepare the ferment, all ingredients were added to the fermentation vessel and the ingredients were mixed for a total of 15 min (Stages 1–3), which included two, 2-min stoppages to manually scrape down the agitators to ensure complete incorporation of all ingredients. Fermentation time began in Stage 4 after the initial 15 min of mixing. Two replications of each ferment treatment were performed. Total titratable acidity (TTA) was determined on samples of the ferment, taken every hour, according to the method of Hugo, Rooney, and Taylor (2003). TTA was expressed as the amount (millilitre) of 0.1-M NaOH required to reach a pH of 6.3.

After fermentation, a portion of the ferment (6 kg) was removed from the fermentation vessel for use in baking. The removed ferment was placed in a blast freezer...
(−32°C), allowed to cool for 30 min to approximately 24°C, and then stored in a refrigerator (4°C) until required for baking (0–3 hr). This allowed the ferment to cool and also halted further fermentation. Previous work showed that the ferment was stable when held for this length of time at 4°C.

2.3 | Bread processing

All baking studies were performed in the pilot bakery at Cigi. Pan bread was baked using three ferment inclusion levels (25%, 35%, and 45%, expressed in baker’s percentage) for each treatment combination using the formulation provided in Table 2. A nonfermented control (NFC) bread was baked for each ferment inclusion level and culture level by adding the equivalent amount of SYPF and sourdough culture to the formulation. For the breads containing 25%, 35%, and 45% ferment inclusion, the corresponding NFC breads contained approximately 11%, 15%, and 19% SYPF, respectively.

All ingredients were placed in a spiral mixer (Erka, Germany), mixed on slow speed (2 min), then fast speed until optimum gluten development as determined by an experienced baker. The addition of water for each treatment was optimized at the mixer to obtain a soft dough. The dough was scaled (460-g pieces), rounded using a Glimek CR-310 conical rounder (Glimakra, Sweden), rested on the bench (3 min), and then shaped using a B&B moulder (Oliver Packaging & Equipment Co, Grand Rapids, MI). The dough was then placed in baking pans (19 cm L × 10.9 cm W × 11.5 cm D), proofed (80% RH; 42°C) to a height of 0.7 cm below the top edge of the pan (measurement taken at centre of pan), and baked (200°C, 25 min) in a Picard reel oven (Drummondville, QC). Five loaves were baked from each dough.

2.4 | Evaluation of bread quality

After the loaves had cooled, specific volume (cm³/g) was determined according to AACC 10-14.01 (AACC International, 2010) using the TexVol BVM-L370 (Perten Instruments, Sweden). The remaining loaves were placed in plastic bags overnight. The following day, the breads were scored by two experienced bakers using one loaf that was cut in half crosswise. The identity of the breads was concealed. Breads were scored relative to their NFC bread, which was given a score of 10 for each parameter. The following parameters were scored: crumb colour (determined visually with a higher score given to loaves with whiter and brighter crumb colour), texture (determined visually with a higher score given to loaves with good cell shape, cell uniformity, and cell fineness), softness (determined by finger compression of the crumb with a higher score given to loaves with a softer crumb), resilience (determined by finger compression of the crumb with a higher score given to loaves that exhibited good crumb recovery), and crumb strength (determined by rubbing the surface of the crumb with the fingers with a higher score given to loaves that had good crumb strength). A consensus judgement was reached for each parameter.

The remaining loaves of bread were sliced using a commercial bread slicer (Oliver Machinery, Grand Rapids, MI). Crumb firmness was determined according to AACC 74-09.01 (AACC International, 2010) using the TA.HDplus Texture Analyser (Stable Micro Systems, Godalming, UK) equipped with a 30-kg load cell. A cylindrical probe (TA-4) was used to measure the force required to compress the centre of two stacked slices of

### Table 1: Fermenter processing conditions (standard four-stage fermentation cycle)

| Stage | Agitator 1 (%) | Agitator 2 (%) | Temperature (°C) | Top pressure | Sparge (Air) | Time |
|-------|----------------|----------------|------------------|--------------|--------------|------|
| 1     | 10             | 10             | 35               | OFF          | ON           | 1 min|
| 2     | 35             | 35             | 35               | OFF          | ON           | 5 min + 2 min stoppage |
| 3     | 50             | 50             | 35               | OFF          | ON           | 5 min + 2 min stoppage |
| 4     | 10             | 10             | 35               | ON           | ON           | 1 and 4 hr |

### Table 2: Bread formulation with adjusted levels of wheat flour and water to compensate for addition of ferment

| Ingredient   | Baker’s % | Amount (g) Ferment inclusion level (%) |
|--------------|-----------|----------------------------------------|
| Wheat floura| 100       | 2,619 2,351 2,243 2,136               |
| Water        | 67        | 1,755 1,398 1,255 1,112               |
| Fresh yeast  | 6.5       | 170 170 170 170                        |
| Salt         | 1.5       | 39 39 39 39                           |
| Gluten       | 2         | 52 52 52 52                           |
| Improverb    | 1         | 26 26 26 26                           |
| Fat          | 1         | 26 26 26 26                           |
| Sugar        | 0.5       | 13 13 13 13                           |
| Fermentc     | 0         | 655 917 1,179                         |

*Flour weight based of 14% moisture.

AB Mauri, UK.

Ferment prepared using split yellow pea flour and sourdough culture.
bread taken from the centre of the loaf to 40% of the original height using a constant crosshead speed of 1.7 mm/s. Measurements were done in duplicate.

Crumb colour was evaluated using the Minolta Chroma Meter CR-410 with a D65 illuminant. Colour measurements (CIE L*, a*, and b*) were taken in the centre of two stacked slices of bread taken from the centre of the loaf. Measurements were done in duplicate.

C-Cell (Calibre Control International Ltd., Warrington, UK) imaging was used to measure crumb structure according to AACC 10-18.01 (AACC International, 2010) on a single slice of bread taken from the centre of the loaf. Number of cells per slice area (the number of cells present in a slice per total area of a slice measured in square millimetre with higher values indicating a finer cell structure), cell contrast (the ratio of the average brightness of the cells to the average brightness of the cell walls with higher values indicating more shallow and uniform cells), cell wall thickness (the average cell wall thickness with lower values indicating thinner cell walls), and cell diameter (the average cell diameter with higher values indicating coarser, more open cell structure) were determined. Measurements were done in duplicate using three slices of bread.

2.5 Evaluation of sensory properties of bread

Breads used for sensory analysis were placed in plastic bags and kept frozen (−18 °C) until evaluated for their sensory properties (approximately 6 weeks). Frozen bread was thawed overnight at room temperature. Sliced bread was cut into quarters and coded with random three-digit numbers. Eight experienced and trained panelists evaluated the breads using degree of difference from control tests. Each bread was evaluated for pulse aroma, pulse flavour, sweetness, bitterness, sourness, and aftertaste against its corresponding NFC bread using 7-point degree of difference scales (1 = not different, 7 = extremely different). Informed consent was obtained from each panelist prior to their participation on the panel. Six samples were evaluated at each panel session for a total of nine panel sessions.

2.6 Statistical analysis

Bread quality data were analysed using the Restricted Maximum Likelihood (REML) method as a three-way ANOVA with ferment inclusion level, level of culture, and fermentation time and their interactions as fixed effects using JMP software version 11 (SAS Institute Inc, Cary, NC). Differences among means were determined using Tukey Honestly Significant Difference (HSD) test (p < 0.05). Sensory data were analysed using the REML method as a two-way ANOVA with fermentation time as a fixed effect, panelist and panelist by fermentation time interaction as random effects. Differences between means for fermentation time were determined by the Student’s t test (p < 0.05).

3 RESULTS AND DISCUSSION

3.1 Ferment quality and bread processing properties

TTA was measured over the 4-hr fermentation period to monitor acid development, as a check for culture activity. TTA levels ranged from 5.0 to 1.6 ml, 8.1 to 4.5 ml, and 12.6 to 10.4 ml over the 4-hr fermentation period for the ferments containing 3%, 6.5%, and 10% culture, respectively (Figure 1). As expected, as the level of culture...
increased in the ferment, the levels of TTA also increased. Levels of TTA in the ferment decreased as fermentation time increased, although for the ferment containing 10% culture, TTA levels were found to increase again at 4 hr.

Processing characteristics of the NFC doughs and the doughs containing ferment are presented in Table 3. Baking absorption tended to decrease as the level of culture in the ferment increased and mixing time of the doughs containing ferment tended to be shorter than the NFC doughs. Compared with the NFC doughs, the doughs containing ferment were softer and more extensible, an indication of a weaker dough structure. This was particularly evident as ferment inclusion levels and fermentation time increased. However, at the highest culture level (10%), the dough handling properties improved with the doughs becoming less sticky and less extensible. These findings are consistent with the effects of acidification of wheat sourdoughs on the mixing behaviour and rheological properties of doughs, which was reviewed by Arendt, Ryan, and Dal Bello (2007).

3.2 | Bread scores

Bread scores for the breads made with ferment are provided in Table 3. Crumb colour scores decreased as

**TABLE 3** Processing characteristics \(^a\) and bread scores \(^{ab}\) of nonfermented control (NFC) \(^c\) breads and breads containing ferment \(^d\)

| Culture level/ferment inclusion level | Baking absorption (%) | Mixing time (min) | Bread scores |
|--------------------------------------|-----------------------|------------------|-------------|
|                                       | NFC 1 hr 4 hr NFC 1 hr 4 hr | NFC 1 hr 4 hr NFC 1 hr 4 hr | NFC 1 hr 4 hr NFC 1 hr 4 hr |
| 3% Culture/25% ferment                | 63 63 63 4.9 4.5 4.1 | 10 9 10 7 11 9 11 10 10 8 |
| 3% Culture/35% ferment                | 63 63 63 4.7 4.4 3.9 | 10 8 9 7 11 6 11 11 9 7 |
| 3% Culture/45% ferment                | 62 62 62 4.6 4.4 4.0 | 9 8 7 5 9 7 11 12 8 6 |
| 6.5% Culture/25% ferment              | 63 63 63 5.0 4.5 3.9 | 9 8 10 9 11 9 11 11 9 8 |
| 6.5% Culture/35% ferment              | 62 62 62 5.0 4.3 3.9 | 9 8 8 7 10 9 11 11 8 7 |
| 6.5% Culture/45% ferment              | 61 61 61 5.1 4.3 3.9 | 7 7 7 5 8 7 11 12 7 5 |
| 10% Culture/25% ferment               | 62 62 62 4.6 4.2 4.3 | 9 8 10 9 11 10 11 11 10 8 |
| 10% Culture/35% ferment               | 61 61 61 4.5 4.2 4.1 | 8 7 8 7 11 8 11 11 9 7 |
| 10% Culture/45% ferment               | 60 60 60 4.3 4.2 4.2 | 7 7 8 5 8 7 11 10 7 5 |

\(^a\)Mean of two replications.

\(^b\)Bread was scored in relation to its corresponding NFC, which was assigned a score of 10 for each bread characteristic.

\(^c\)NFC breads were made using the equivalent amount of split yellow pea flour and sourdough culture found in the bread containing ferment.

\(^d\)Ferment made with split yellow pea flour and sourdough culture.

| Parameter | F | C | T | F × C | F × T | C × T | F × C × T |
|-----------|---|---|---|-------|-------|-------|-----------|
| Specific volume | <0.0001 | 0.4076 | <0.0001 | 0.2712 | 0.8817 | 0.9587 | 0.5392 |
| Crumb firmness | <0.0001 | 0.9862 | 0.5053 | 0.1521 | **0.0368** | 0.5061 | 0.1809 |
| Crumb colour | | | | | | | |
| L* | <0.0001 | 0.0463 | <0.0001 | 0.3814 | 0.2759 | 0.6167 | 0.9708 |
| a* | 0.0004 | 0.0038 | 0.0405 | 0.7912 | 0.7235 | 0.9757 | 1.0000 |
| b* | <0.0001 | 0.0010 | 0.3636 | 0.9938 | 0.3260 | 0.9788 | 0.9792 |
| C-Cell characteristics | | | | | | | |
| No. of cells per slice area | <0.0001 | 0.0349 | <0.0001 | 0.6082 | 0.2193 | 0.3181 | 0.7886 |
| Cell contrast | <0.0001 | 0.1477 | <0.0001 | 0.7290 | 0.1123 | 0.6108 | 0.7941 |
| Cell wall thickness | <0.0001 | 0.0177 | <0.0001 | 0.7476 | 0.0986 | 0.2357 | 0.8651 |
| Cell diameter | <0.0001 | 0.0588 | <0.0001 | 0.7608 | **0.0244** | 0.2225 | 0.6161 |

\(^a\)Results shown in bold are significant at \(p < 0.05\).
ferment inclusion levels increased. Bread made with ferment containing 10% culture that was fermented for 4 hr and added at an inclusion level of 35% and breads made with ferment containing both 6.5% and 10% culture that was fermented for 1 and 4 hr and added at an inclusion level of 45% had the lowest crumb colour scores (7). Texture scores decreased as ferment inclusion levels and fermentation time increased. Breads made with ferment that had been fermented for 4 hr and added at an inclusion level of 45% had the lowest texture score (5), regardless of culture level used in the ferment. Softness scores decreased as fermentation time and ferment inclusion level increased. Breads made with ferment that was fermented for 4 hr, regardless of the culture level used in the ferment, and added at an inclusion level of 45% had a low score (7) for softness. Bread made with ferment containing 3% culture that was fermented for 4 hr and added an inclusion level of 35% also had a low score (6) for softness. All the ferment breads scored equal to, or higher than, their control for resilience, regardless of ferment or culture inclusion level or fermentation time. Crumb strength of the breads decreased as ferment inclusion levels and fermentation time increased. The lowest crumb strength scores (5–6) were observed for breads made with ferment that was fermented for 4 hr and added at an inclusion level of 45%, regardless of the culture level used in the ferment. Sadowska et al. (1999) also found that bread made with fermented lentil flour had a lower bread score than bread made with nonfermented lentil flour at the same inclusion level.

### 3.3 Bread quality

Significant main effects were found for ferment inclusion level, culture level, and fermentation time for most bread

![FIGURE 2 Breads made with split yellow pea flour and 10% sourdough culture. (a) 25% ferment inclusion, (b) 35% ferment inclusion, and (c) 45% ferment inclusion. L to R: wheat control, nonfermented control (made with equivalent amount of split yellow pea flour and sourdough culture found in the bread containing ferment), 1-hr fermentation, and 4-hr fermentation.](image)
quality parameters (Table 4). There was also a significant interaction found between ferment inclusion level and fermentation time for crumb firmness and cell diameter. Figure 2 shows the NFC breads and breads made with ferment containing 10% culture that was fermented for both 1 and 4 hr and added at inclusion levels of 25%, 35%, and 45% compared with a 100% wheat flour control bread. As expected, the addition of pea flour and fermented pea flour resulted in lower bread volume compared with the wheat control bread.

3.3.1 Effect of ferment inclusion level

The NFC breads had higher specific volumes than breads made with ferment (Table 5 and Figure 2). This finding is in agreement with Coda et al. (2017) and Kefalas et al. (2009) who found a reduction in loaf volume for breads made with 30% faba bean and 20% chickpea sourdough ferment, respectively. Specific volume of the fermented breads was also found to decrease as ferment inclusion level increased (Table 5 and Figure 2).

As ferment inclusion levels increased, crumb colour became darker (lower L* values) and also had higher values for a* (red) and b* (yellow; Table 5). Compared with the NFC breads, the inclusion of ferment resulted in breads with lower L* values regardless of ferment inclusion levels and higher a* values at 35% and 45% ferment inclusion. Only minor differences in b* values were found between the breads made with ferment and the NFC breads.

3.3.2 Effect of culture level

Breads made with ferment containing 10% culture were found to have a higher a* value and a lower b* value than breads made with ferment containing 3% and 6.5% culture (Table 6). Bread made with ferment containing 10% culture also had a significantly higher L* value compared with the bread made with ferment containing 3% culture. For all levels of culture, L* was higher in the NFC bread than breads made with ferment. In addition, the NFC breads had lower a* than the breads made with ferment containing 6.5% and 10% culture. This suggests that the fermentation process itself also affected crumb colour and it was not just the addition of SYPF and sourdough culture that influenced crumb colour possibly through the oxidation of carotenoid pigments resulting in increased L* and decreased b* values.

**TABLE 5** Effect of ferment inclusion level on bread quality characteristics

| Parameter                  | Nonfermented control bread | Ferment bread |
|----------------------------|----------------------------|---------------|
|                            | 25% | 35% | 45% | 25% | 35% | 45% |
| Specific volume, cm³/g     | 4.8 ± 0.2 | 4.5 ± 0.1 | 4.4 ± 0.1 | 4.5 ± 0.2 | 4.2 ± 0.2 | 3.9 ± 0.2 |
| Crumb colour               |     |     |     |     |     |     |
| L*                         | 76.8 ± 0.8 | 76.3 ± 0.5 | 75.6 ± 1.2 | 75.9 ± 0.9 | 74.3 ± 1.1 | 73.0 ± 0.9 |
| a*                         | 1.70 ± 0.29 | 1.74 ± 0.28 | 1.91 ± 0.28 | 1.68 ± 0.32 | 1.85 ± 0.35 | 2.08 ± 0.35 |
| b*                         | 16.0 ± 1.0 | 17.2 ± 1.0 | 18.2 ± 1.0 | 16.5 ± 0.8 | 17.6 ± 0.8 | 18.5 ± 1.1 |

C-Cell characteristics

|                         | Nonfermented control bread | Ferment bread |
|-------------------------|----------------------------|---------------|
| No. of cells per slice Area, mm² | 0.64 ± 0.04 | 0.62 ± 0.02 | 0.59 ± 0.01 | 0.59 ± 0.04 | 0.53 ± 0.05 | 0.48 ± 0.03 |
| Cell contrast            | 0.78 ± 0.01 | 0.77 ± 0.00 | 0.75 ± 0.01 | 0.76 ± 0.02 | 0.73 ± 0.02 | 0.70 ± 0.02 |
| Cell wall thickness, mm  | 0.44 ± 0.01 | 0.44 ± 0.01 | 0.45 ± 0.00 | 0.46 ± 0.02 | 0.48 ± 0.02 | 0.50 ± 0.02 |

*Nonfermented control breads made using the equivalent amount of split yellow pea flour and sourdough culture found in the bread containing ferment.

Means and SD.

Ferment made with split yellow pea flour and sourdough culture.

LS means in same row with a different letter are significantly different (p < .05).

As ferment inclusion levels increased, values for the number of cells per slice area and cell contrast were found to decrease, whereas values for cell wall thickness increased (Table 5). These results indicate that the crumb structure became coarser and more open and cells were less uniform with thicker cell walls, all of which are an indication of deteriorating quality. This can also be observed in Figure 2. In contrast, the NFC breads had higher values for number of cells per slice area and cell contrast and lower values for cell wall thickness. Coda et al. (2017) also reported that breads made with 30% fava bean sourdough ferment had reduced crumb quality.
The number of cells per slice area was higher, and the cell wall thickness values were lower in the NFC breads compared with the ferment breads at all culture levels (Table 6). However, for the ferment breads containing 10% culture, the number of cells per slice area was higher and cell wall thickness was lower than breads made with 3% and 6.5% culture. This same trend was observed in the NFC breads.

### 3.3.3 Effect of fermentation time

Breads made with ferment that was fermented for 4 hr had lower specific volumes and lower L* and higher a* values than breads made with ferment that was fermented for 1 hr (Table 7 and Figure 2). In addition, a longer fermentation time resulted in breads with a smaller number of cells per slice area, lower values for cell contrast, and higher values for cell wall thickness all of which are an indication of a coarser and more open crumb structure. According to Coda et al. (2017), crumb structure could be altered as a consequence of modification to the intrinsic structure of pulse starch and protein during fermentation suggesting that the longer the fermentation time, the greater the opportunity for modifications to the structure of pulse starch and protein to occur, resulting in a greater impact to crumb structure of the bread.

### 3.3.4 Effect of ferment inclusion level and fermentation time

A significant interaction was found for Ferment inclusion level × Fermentation time for crumb firmness and cell diameter (Table 8). Crumb firmness increased as ferment inclusion level and fermentation time increased. The breads made with ferment had similar crumb firmness values to their corresponding NFC bread, except for the breads made with ferment that was fermented for 4 hr and added at an inclusion level of 35%, which had higher crumb firmness values than its corresponding NFC bread. Other studies have shown an increase in crumb firmness in bread made with fermented pulse flours (Coda et al., 2017; Rizzello et al., 2014; Sadowska et al., 1999;
## TABLE 8
Effect of Ferment Inclusion level (F) × Fermentation time (T) interaction on bread quality characteristics

| Parameter          | Nonfermented control bread | Ferment bread |
|--------------------|-----------------------------|---------------|
|                    | Ferment inclusion level     | Ferment inclusion level/fermentation time |
|                    | 25%                         | 35%           | 45% |
|                    | 45%/1 hr                    | 45%/4 hr      | 45%/8 hr |
| Crumb firmness, g  | 423 ± 25                    | 464 ± 24      | 539 ± 31 |
| Cell characteristics| 1.77 ± 0.13                 | 1.80 ± 0.07   | 1.87 ± 0.04 |
| Cell diameter, mm  | 4.31 ± 0.14                 | 4.30 ± 0.14   | 4.90 ± 0.28 |
|                     | 25%/1 hr                    | 25%/4 hr      | 35%/1 hr |
|                    | 510 ± 28                    | 555 ± 42      | 482 ± 42c |
|                     | 25%                         | 35%           | 45% |
|                    | 45%/1 hr                    | 45%/4 hr      | 45%/8 hr |
| Crumb firmness, g  | 540 ± 51ab                  | 540 ± 51ab    | 540 ± 51ab |
| Cell characteristics| 2.24 ± 0.12b                | 2.24 ± 0.12b  | 2.24 ± 0.12b |

a Nonfermented control bread made using the equivalent amount of split yellow pea flour and culture found in the bread containing ferment.
b Means and SD.
c Ferment made with split yellow pea flour and sourdough culture.
d LS means in same row with a different letter are significantly different (p < .05).

--- 25% Ferment, 1h --- 25% Ferment, 4h
--- 35% Ferment, 1h --- 35% Ferment, 4h
--- 45% Ferment, 1h --- 45% Ferment, 4h

**FIGURE 3** Sensory results for degree of difference from control (1 = not different, 7 = extremely different) for breads containing split yellow pea flour ferment and sourdough culture: (a) 3% culture, (b) 6.5% culture, and (c) 10% culture.
Shrivastava & Chakraborty, 2018). As both ferment inclusion levels and fermentation time increased, the crumb cell diameter also increased indicating a reduction in quality consistent with the results for the other C-Cell parameters previously discussed. Also consistent with the other the C-cell results, the NFC breads showed a reduction in crumb quality (cells with larger cell diameter) at higher levels of SYSP inclusion.

3.4 | Sensory evaluation of breads

The addition of SYSP sourdough ferment improved the flavour of the bread by masking the strong pea flavour associated with yellow pea flour. This was also found in the NFC breads where sourdough culture and SYSP were added without undergoing fermentation. Figure 3 shows the sensory results for the degree of difference for each ferment bread from its corresponding NFC bread. Regardless of the level of culture added, breads made with higher levels of fermentation were found to be of a higher degree of difference from their NFC bread for pulse aroma, pulse flavour, and aftertaste, and in most cases, this was also found for sourness and bitterness. Sweetness appeared to be influenced by fermentation inclusion level and level of culture. Rizzello et al. (2014) reported an increase in the acid flavour of breads made with fermented pulse flours, and Kefalas et al. (2009) found that breads made with a chickpea sourdough ferment had significantly higher hedonic scores for flavour, taste, and overall acceptability compared with wheat bread.

4 | CONCLUSIONS

Partial replacement of wheat flour with nonfermented and fermented SYSP and sourdough culture had an impact on bread quality and flavour characteristics. Breads made with nonfermented SYSP and 10% culture level had good flavour with only minor reductions in bread quality compared with a 100% wheat control bread. Breads made with fermented SYSP were more negatively affected especially when higher fermentation inclusion level and fermentation time were used. As fermentation inclusion level and fermentation time increased, bread quality was found to decrease. At the highest level of fermentation inclusion (45%), pulse aroma and flavour, and aftertaste of the ferment breads were negatively impacted as shown by higher degree of difference scores from the NFC breads. The level of sourdough culture tended to have a positive effect on crumb colour and some C-Cell properties (number of cells per slice area and cell wall thickness), but only when a level of 10% culture was used. Dough handling properties were also found to improve when 10% culture was used, an important requirement for commercial bakeries. Of all the breads made with fermented SYSP, the ferment made with 10% culture fermented for 1 hr and added at an inclusion level of 25% had the most acceptable flavour and bread quality characteristics.

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CONFLICT OF INTEREST

There are no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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