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RESEARCH ARTICLE

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

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Abstract

Background and Objective: Dough mixing properties are crucial in determining the usability of wheat flour. Currently, many industrial sourced chemicals are used as additives to improve the mixing stability of dough. This study aims to evaluate the effect of adding chickpea flour on mixing tolerance and dough strength improvement based on 20 different wheat genotypes. The effects of different types (i.e., kabuli and desi) and amounts (1.5%, 3.75%, 7.5%, 15%, and 30%, w/w) of chickpea flours and kabuli chickpea fractions (7.5%) were further studied. Mixograph, dough strength and extensibility, and baking test of selected treatments were performed.

Findings: Incorporating chickpea flour at a level of 7.5% (w/w flour basis) or lower significantly improved ($p < .05$) the mixing stability and dough strength of different wheat flours. Adding the insoluble fraction of the chickpea flour resulted in better stability and dough strength compared to other fractions, while adding the soluble fraction of chickpea flour weakened the dough. At the optimum incorporation level (7.5%) or lower, the inclusion of chickpea flour did not negatively alter the physical (bread volume), texture (hardness), or taste attributes of the bread.

Conclusion: The results demonstrate that adding chickpea flour can improve dough mixing properties, particularly for weak/normal wheat flour, without compromising the quality of bread. The optimal chickpea flour incorporation level in refined wheat flour is 7.5%. Chickpea flour incorporation could also assist bakers in case of overmixing the dough.

Significance and Novelty: This study portrays the use of natural ingredients to improve dough mixing properties, providing bakers and scientific community with natural alternatives to enhance wheat flour mixing properties while improving the quality and nutrition of the flour as chickpea is a protein-rich legume.

KEYWORDS
chickpea, dough strength, extensibility, mixing stability, mixograph, sensory

1 | INTRODUCTION

Dough properties are often used to evaluate the bread-making performance of wheat flour. There are three categories of dough/flour based on mixing properties: weak, normal, and strong dough/flour. A weak dough is very sticky. Breaks down quickly during mixing, and produces bread with a smaller loaf volume compared to normal dough. A weak dough is undesirable for bread-baking purpose. Different additives are used to improve the mixing properties of dough, mostly for weak flour (Jazaeri et al., 2015; Lang et al., 1992; Nash et al., 2006). The mixograph is often used to determine the dough mixing properties (Durmus et al., 2023; Nkurikiye et al., 2023; Tebben et al., 2022).

Mixograph is a crucial tool for evaluating the functionality of wheat flour and dough additives. Mixograph has been used to evaluate the functions of different additives in the flour dough system 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). That study found that the formation of lipid-free radical created by lipoxygenase was the main contributor to the increased mixing tolerance of the dough. In another study by Weak et al. (1977), mixograph test was used to assess mixing time reduction properties of ascorbic acid.

Dough extensibility using the extensograph is another commonly used method to assess the functionality of wheat flour. In this test, the dough is stretched until it ruptures, and 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 between extensibility and mixograph results, the effects of additives such as hydrocolloids, resistant starch, potassium chloride, and gluten protein 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 (Chen et al., 2018; Chen & Li, 2019; Miller & Bianchi, 2017; Rosell et al., 2001).

Chickpea (*Cicer arietinum L.*) is a pulse grain which is nutritionally rich and agronomically adaptable. Kabuli (cream colored) and desi (dark green) are the main types of chickpeas globally available. The main difference between them is their color and kernel size, as well as protein and fiber contents. Chickpea is a good source of proteins, fibers, and bioactive compounds including antioxidants and anti-inflammatory polyphenols and peptides (Grasso et al., 2022). Incorporation of chickpea flour into wheat flour can make bread healthier due to the additional protein and fiber in chickpea. Chickpea flour is a "natural" ingredient, making it a clean label option when used as an ingredient in any food product.

Previous studies have shown that some legume flour can improve the dough mixing tolerance. Hoseney et al. (1972) demonstrated how the enzyme-active soybean flour increased the mixing tolerance of dough. In a study performed by Saad et al. (2015), chickpea steep liquor showed potential for increasing dough stability. The study conducted by Nkurikiye et al. (2023) showed that incorporating chickpea flour into refined wheat flour resulted in better baking properties compared with lentil and yellow pea flour when incorporated at the same level. A separate study showed that the incorporation of chickpea at low levels (10%) along with emulsifiers in white and whole wheat resulted in loaves of bread of similar physical and texture properties with wheat bread (Yamsaengsung et al., 2010). These studies imply that chickpea flour may have the potential to improve the properties of wheat dough (Mohammed et al., 2012).

To better understand the potential dough strengthening abilities of chickpea flour, this study aimed to investigate the effect of incorporating chickpea flour on the mixing tolerance and dough extensibility of wheat flour using 20 different wheat genotypes. The effect of adding different types of chickpea flour of varying particle sizes (small, medium, large ranging from 60.0 to 95.6 μm), and different fractions was also evaluated. In addition, the bread-baking quality of wheat/chickpea composite flour was studied. The findings of this study could benefit bakers seeking an easy-to-use and fortified flour option.

2 | MATERIALS AND METHODS

2.1 | Wheat grains and flours

Twenty different hard red winter wheat genotypes from the 2021 Kansas wheat breeding program were used in this study. The wheat samples were milled using a Quadrumat Senior mill (Brabender GmbH & Co. KG), following AACC approved method 26-50.01 (1999). The bran and shorts were discarded, and the refined flour was collected. The 20 flours (labeled as W-1 to W-20) had protein content ranging from 9% to 14% measured using NIR DA 7250 (Perten Instruments). They were selected representing different protein content and mixogram properties. Chickpea seeds were purchased from the Food to Live Amazon online store (purchased in 2021) and milled using a laboratory roller mill as described below.

2.2 | Milling of chickpea seeds

The chickpea seeds were milled using a Ross Roller mill according to the procedure developed by Pulivarthi et al. (2021) with minor modifications. The seeds were tempered to 13% moisture content and allowed to equilibrate overnight. They were then passed through a set of three different rolls and sieves with adjusted setting to control the particle size of the final flour. Three different flours were produced and named small (S, geometric mean diameter, GMD of 60.0 µm), medium (M, GMD 74.7 µm), and large (L, GMD 95.6 µm) based on the size of base sieves of 75, 150, 200 µm, respectively (Nkurikiye et al., 2023). Supporting Information: Figure S1 provides a detailed milling flow sheet.

2.3 | Chickpea flour fractionation

The chickpea flour was fractionated based on a modified water-washing 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 and stirred for 30 min in a fume hood. The mixture was then centrifuged at 7000g for 25 min using Avanti J-E centrifuge (BeckmanCoulter Life Sciences). The supernatant containing the fat was discarded. The process was repeated twice. The defatted flour was kept in the fume hood for 3 days for complete ethyl ether evaporation. A portion of the flour was collected and named *defatted chickpea flour*. The remaining flour was mixed with deionized (DI) water at a ratio of 1:10 (w/v) for 30 min, and the mixture was centrifuged at 7000g for 15 min. The supernatant was collected and freeze-dried using FreeZone 4.5-L freeze dryer (Labconco Corporation), named *soluble protein fraction*. For the precipitate, the top slimy colored layer was scrapped off and lyophilized, named *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 1, and the yield and protein content of each fraction are also listed.

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, based on the preliminary tests showing that 7.5% addition was more promising compared with other higher-level additions. 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), and desi type chickpea flour was also tested at 7.5% incorporation with those selected flours (W 11 & W-17). For these two selected wheat flours, 7.5% (w/w) of the fractionated KM chickpea flour (i.e., defatted, starch, soluble proteins, and insoluble proteins) was added, and dough tests were performed. For all the composite flours, a portion of the wheat flour was replaced with the specific amount of chickpea flour for each treatment (e.g., 7.5% addition represents a composite with 7.5% chickpea flour and 92.5% wheat flour).

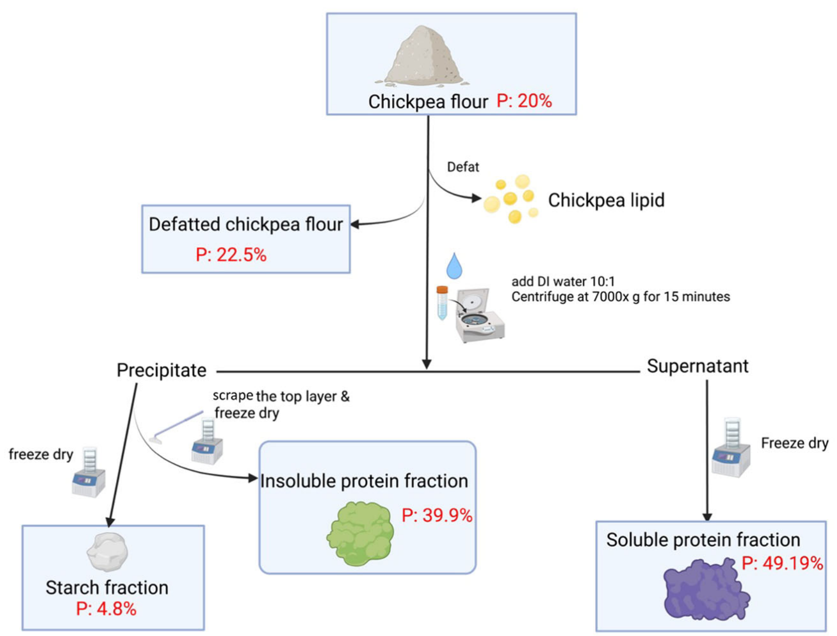

FIGURE 1 Flowchart of chickpea flour fractionation. DI, deionized water; P, protein content. [Color figure can be viewed at wileyonlinelibrary.com]

2.5 | Mixograph test

A 10-g mixograph (National Manufacturing Div., TMCO, Inc.) was used to perform the mixograph test following the AACC Approved Method 54-40.02 (1995). The initial water absorption for wheat flour was estimated using the following, and then adjusted if needed based on the mixograms.

$$\text{Absorption}\ (\%) = 1.5X + 43.6, \tag{1}$$

where X is the percent flour protein content (14% mb).

MixSmart software was utilized to analyze the mixograph data, which was then used to calculate mixing tolerance and breakdown tolerance values.

Mixing tolerance was measured by calculating the percentage difference at peak time and at 8 min of mixing.

$$\text{Mixing tolerance index}\ (\%) = Ptv(\%) - xv(\%), \tag{2}$$

where Ptv is the mixograph value at Peak time value (%), xv-mixograph value at "8 min" (%).

The breakdown tolerance was measured by the absolute value of the difference between 1 min before and after reaching the peak time.

$$\text{Breakdown tolerance index}\ (\%) = |(1\ min.\ bpt - 1\ min.\ apt)|, \tag{3}$$

where *1 min. bpt* is the mixograph value 1 min before peak time (%), *1 min. apt* is the mixograph value 1 min after peak time (%).

The detailed definition for mixogram parameters is shown in Supporting Information: Figure S2.

2.6 | Dough strength and extensibility test

The dough extensibility test was performed at room temperature using a TA-XT2 Texture Analyzer with an SMS/Keiffer rig (Keiffer et al., 1998). 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 entire assembly was allowed to rest for 30 min at room temperature 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 and pulled up till ruptured. The strength and the distance to rupture were measured. The testing settings were: 5.0 mm/s pretest speed, 3.3 mm/s test speed, 10.0 mm/s posttest speed, and 5 g trigger force. Dough strength represents the highest energy of the dough before rupture. Extensibility is the distance to which the dough can be stretched before breaking (at the highest strength). The total distance for dough extension was set to 75 mm. Five strips from each treatment were tested.

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 wheat flour (Organic Arrowhead all-purpose flour, lot# 219380810, 11.27% protein content wb, 13.56% moisture content). The baking test was conducted in triplicate for each treatment, following the standard 90-min fermentation time method (AACC method 10-10.03, 1999). The 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 (based on the mixograph data). All the ingredients were mixed to the optimized time according to mixograph data. In addition, overmixing of the control and the composite flour (7.5% KM chickpea incorporation level) for 8 min was also performed to understand the overmixing effect on bread quality. The bread loaves were baked at 205°C for 24 min and allowed to cool for 2 h on racks at room temperature before measurements were taken.

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 obtained 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.) by measuring three points on the crust. Each bread loaf was sliced into 25-mm-thick slices, and crumb color was measured using a colorimeter on three different points on the crumb. The middle slice was used for breadcrumb structure analysis using C-Cell Bread Imaging System (Calibre Control International Ltd.) following the AACC-approved method 10-18.01 (2017); number of cells, cell wall thickness, and cell diameter were recorded.

For texture profile analysis (TPA), the central slices were measured using the TA-XT2 Texture Analyzer (Stable Micro Systems) with a 30 kg load cell and 25 mm cylindrical probe. Each slice was subjected to 50% compression at a speed of 1.0 mm/s and a trigger force of 5 g. Texture Exponent software was then used to analyze the data. The tests were repeated at least six times for each treatment.

2.9 | Bread sensory evaluation

A consumer hedonic test was conducted to evaluate the sensory quality of the bread (Azami et al., 2018; Fellendorf et al., 2018). Thirty 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 received three bread slices, with the slices labeled with three random digits to reduce bias. Water was consumed between tests to minimize any carryover influence. Participants rated 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.

2.10 | Statistical analysis

All tests in this study were performed in duplicate 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) with a significance level of $p < .05$.

3 | RESULTS AND DISCUSSION

3.1 | Mixograph

3.1.1 | Mixograph of 20 control wheat flour samples and their blends containing 7.5% chickpea flour

Supporting Information: Table S1 provides details of the mixograph midline parameters for the 20 wheat flour samples before (control) and after chickpea flour substitution (treatments). The corresponding mixograms are provided in Figure 2 and Supporting Information: Figure S3. Generally, the midline peak time, which indicates the optimum time for dough development, was not significantly affected by the addition of chickpea flour, except for W-15, W-17, W-19, and W-20, which showed a significant increase in 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 chickpea flour decreased the midline peak value. This is likely due to the substitution of wheat flour with gluten-free flour which diluted the gluten content hence lowering the peak value (Lazaridou & Biliaderis, 2009). However, for flours W-1, W-9, and W-10, the peak value was not significantly affected. Moreover, the peak width for all the flours was not significantly affected, demonstrating that despite the reduction of the peak value, the dough consistency was not significantly altered.

The curve tail (8-min mixing) mid-line value, which indicates the dough strength after 8 min of continuous mixing, showed no significant difference in general between the control flours and the treated flour; however, the curve tail (8-min mixing) width increased considerably when chickpea was added. This suggests that the addition of the chickpea flour better preserved 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 not negatively affected by the addition of chickpea flours.

The mixing tolerance index indicates the tolerance of the dough to overmixing. We observed a general reduction of the mixing tolerance index when chickpea flour was added. Higher values of the mixing tolerance index indicate a higher dough tendency towards breakdown when overmixing, while lower values indicate greater tolerance to dough breakdown when overmixed (Hoseney et al., 1972). The findings in this study show that generally, the addition of refined chickpea flour to the refined wheat flour increases the dough resistance to overmixing. This trend was observed in all the flour tested, which represented significant range of protein contents and mixing quality.

On the other hand, the breakdown tolerance index was not significantly affected by the addition of chickpea flour. The breakdown tolerance was measured by the difference in the dough strength 1 min before and 1 min after the peak. Higher values indicate a dough which is not stable and breaks down easily, while lower values indicate a dough that maintains consistency before and after reaching the optimum gluten development (Khatkar et al., 2002).

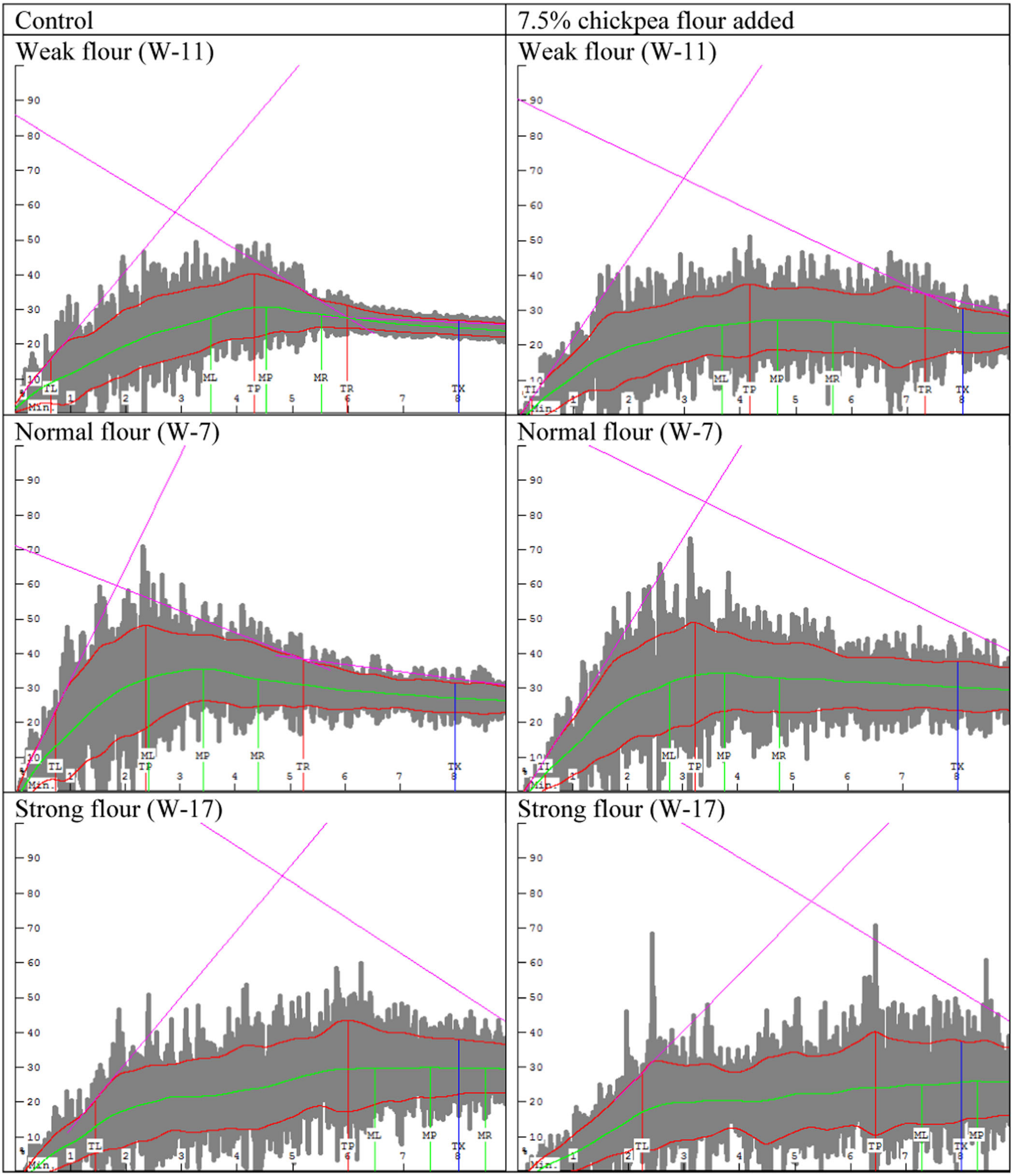

FIGURE 2 Selected mixograms of wheat flour with and without chickpea addition. Control: Weak flour (W-11); Normal flour (W-7); Strong flour (W-17). 7.5% chickpea flour added: Weak flour (W-11); Normal flour (W-7); Strong flour (W-17). [Color figure can be viewed at wileyonlinelibrary.com]

3.1.2 | Mixograph parameters of a weak wheat flour (W-11) containing different ratios, particle-sizes, and types of chickpea flour

Supporting Information: Table S2 shows the mixograph parameter of the weak wheat flour (W-11) with different ratios, particle-sizes, and type of chickpea flour substituted the wheat flour, and the mixograms are shown in Supporting Information: Figure S4. The addition of desi-type, small-sized, and large-sized chickpea flour increased the peak time significantly while all other different ratios or types of chickpea flours did not affect the peak time. As observed before, the peak value was significantly reduced with the addition of 1%–7.5% chickpea flour; when the ratio increased to 15% or 30%, there was a further reduction of the peak value. However, 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 different ratios or of different types. The curve tail value was higher when desi or SCP were added, followed by large-sized chickpea (LCP) than 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 slightly higher when desi-type chickpea was added, and it was the lowest when chickpea was added to a level of 30% (w/w). The substitution of wheat flour with chickpea flour decreased the mixing tolerance index significantly, but did not affect the breakdown tolerance index. This infers that the addition of chickpea flour increases the dough resistance to overmixing without affecting the stability of the dough after reaching the peak. The above results clearly shows that the incorporation of chickpea at levels 7.5% or lower improves the overmixing resistance; however, higher incorporation levels are deleterious to the dough. Desi type of chickpea exhibits better qualities in improving the dough mixing characteristics compared with kabuli types.

The effect of different chickpea fractions on the weak wheat flour (W-11) was evaluated (Supporting Information: Table S3). With all the fractions, there was no significant difference in the peak time when added to W-11 flour. However, the peak value slightly increased as all fractions were added except for chickpea flour alone. The peak width was not affected by the chickpea flour fractions addition. Apart from chickpea flour alone, adding all other fractions increased the curve tail value significantly. For the curve tail width, the insoluble protein and defatted chickpea fraction had the most drastic increase of the width. The incorporation of the starch and soluble protein fraction showed smaller increase in the curve tail width but were still significant compared to the control. Chickpea flour alone reduced the curve tail integral while the starch fraction increased it significantly. The defatted and insoluble fraction did not significantly affect the dough curve tail integral. Apart from the chickpea starch fraction, others fractions significantly reduced the mixing tolerance index, however, the reduction was marginal when soluble chickpea protein was added. The mixing tolerance index reduction was distinct when insoluble chickpea protein was incorporated. The chickpea flour fractions did not influence the breakdown tolerance index of the flour during mixing. The above data show that the insoluble fraction contributes to increased resistance to overmixing of the dough while the soluble fraction has an adverse effect.

3.1.3 | Mixograph parameters for a strong flour (W-17) containing different ratios, particle-sized, and type of chickpea flour

Supporting Information: Table S4 shows the mixograph parameters of the strong flour W-17 with different chickpea incorporation, the addition of chickpea flour at different ratios or desi type increased the midline peak time significantly, and the mixograms are shown in Supporting Information: Figure S4. Apart from the 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 up to the ratio of 15%, yet further incorporation (above 15%) reduced the tail width significantly. Desi-type, small and large-sized chickpea flour increased the curve tail width more compared to other kabuli-type chickpea flour incorporation levels. The curve tail integral only reduced when chickpea was added at 15% or 30%; other ratios or type of chickpea flour addition did not significantly affect the tail integral value with the exception of 3.5% and the small-size chickpea flour at 7.5% that significantly reduced the integral. The mixing tolerance index was not affected by any treatment of the flour. When chickpea flour was added at 30%, the breakdown tolerance index value increased sharply, while other levels of chickpea addition reduced the breakdown tolerance index value. The increased breakdown tolerance index indicated lower mixing stability, which implies that the flour is losing strength which is undesirable. Other chickpea incorporation levels improved 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 seeds such as beans, peas, sunflower, and soy lessened the dough resistance to overmixing (Sosulski & Fleming, 1977). Our findings showed that chickpea flour, unlike most other protein-rich grains, possesses dough-strengthening abilities. The effect of chickpea flour on the dough mixing properties is 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).

Different chickpea fractions were prepared as shown in Figure 1, and their effect on the mixing properties of wheat composite flour is presented in Supporting Information: Table S5 and Figure S5. The defatted chickpea flour effect was very similar to chickpea flour alone, which indicates that the fat portion of the chickpea flour is not the main compound responsible for the improved mixing tolerance observed when chickpea flour is added. The soluble protein fraction deteriorates the mixing tolerance which implies that its effect is contrary to the chickpea flour alone. Previous literature showed that soluble fractions of wheat and rye reduced the mixing tolerance on the mixograph (Chen & Hoseney, 1995; Dhaliwal & MacRitchie, 1990). The increased mixing tolerance was readily observed when the insoluble protein fraction of chickpea flour was added to wheat flour. This indicates the majority of the compounds responsible for the increased mixing tolerance are part of the insoluble protein fraction. It is possible that the high molecular proteins in the insoluble protein fraction are responsible for the improved mixing tolerance. Vanhamel et al. (1993) showed that the high molecular rye pentosans increased the peak height as well as the curve area.

3.2 | Dough strength and extensibility

3.2.1 | Extension properties for the 20 flours and blends

As shown in Supporting Information: Table S6 and Figure 3, the dough strength increased significantly when chickpea flour was added at 7.5% (w/w) into each wheat flour. The exception was observed for the W-20 flour which 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. For most of the samples, the extensibility distance decreased as chickpea flour was incorporated, except for a few flours (W-6, -7, -10, -19, and -20) where no significant decrease was observed.

3.2.2 | Extension properties of the weak flour (W-11) containing different ratios, particle-size, and type of chickpea flour

The dough extensibility results for flour W-11 and its various treatments are shown in Supporting Information: Figure S6 and Tables S7 and S8. The data indicate that the addition of chickpea flour at different ratios up to 15% relatively increased the dough strength; the doughs with very high levels of incorporation (30%) were too weak to reach the threshold for dough strength (5 g) measurements hence recorded as 0 reading. The dough extensibility distance was recorded as 0 since the highest energy of the dough was at the contact time (0 s) making the distance to dough extension be recorded as 0. For both the W-11 and the 15 or 30% incorporation level, there was an extensibility distance, but the instrument couldn't quantify it due to extremely low dough strength.

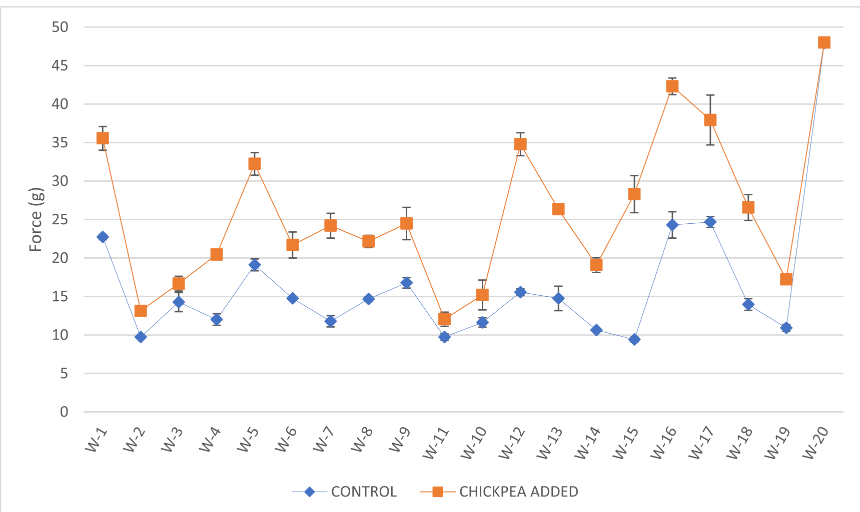

FIGURE 3 Dough strength changes as chickpea flour was added to each flour at 7.5%. [Color figure can be viewed at wileyonlinelibrary.com]

Other ratios (1%, 3.75%, and 7.5%) and desi-type chickpea flour increased both the dough strength and extensibility.

Among different fractions of chickpea added, the soluble protein fraction reduced the dough strength significantly. The soluble fraction made the dough too weak to trigger the initial force of 5 g for dough extensibility measurement. Other fractions increased both the strength and extensibility distance. The insoluble fraction led to a much higher increase in the dough strength. Starch and soluble protein fractions did not affect the extensibility distance compared to the unfractionated chickpea as shown in Supporting Information: Table S8 and Figure S7.

Even for a very weak dough, adding chickpea showed a significant increase in dough strength. Among the fractions, the insoluble protein fractions had an improving influence on the strength of the dough. These results support the mixograph data, which showed that chickpea increased the mixing stability.

3.2.3 | Extension properties of the strong flour (W-17) containing different ratios, particle-size, and type of chickpea flour

As shown in Supporting Information: Table S9, the addition of chickpea flour at a level of 7.5% significantly increased the dough strength, while incorporation at 30% significantly decreased the dough strength. Chickpea flour of different types (desi or kabuli) incorporated at 7.5% greatly increased the strength of the dough. For all ratios 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 detrimental to dough strength.

Different chickpea flour fractions had a distinctive effect on the strong dough extensibility properties as shown in Supporting Information: Table S10, and Figures 4 and Supporting Information: S7. While the soluble protein fraction sharply reduced the strength of the dough, the insoluble protein fraction increased the dough strength significantly. The starch fraction did not have a significant impact, and the defatted chickpea fraction had a similar increase in the dough strength as it was for chickpea flour alone. All the fractions did not exhibit a significant difference in dough extensibility distance. The insoluble protein fraction consistently improved the dough strength of the wheat flour compared to other fractions.

The current data clearly shows that chickpea flour can improve the strength of wheat dough when incorporated at an appropriate level. Simsek and Martinez (2016) showed that the addition of salt increased the dough strength with the increasing concentration while the extensibility distance was mainly reduced with salt. We observed the same phenomenon when chickpea was incorporated at 7.5% (w/w), as the dough strength increased, and the extensibility distance reduced. Chen et al. (2018) observed an increase in dough strength as well when adding potassium salt in wheat flour. Referring to those publications, chickpea flour can be an alternative for salts (sodium or potassium) regarding 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 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

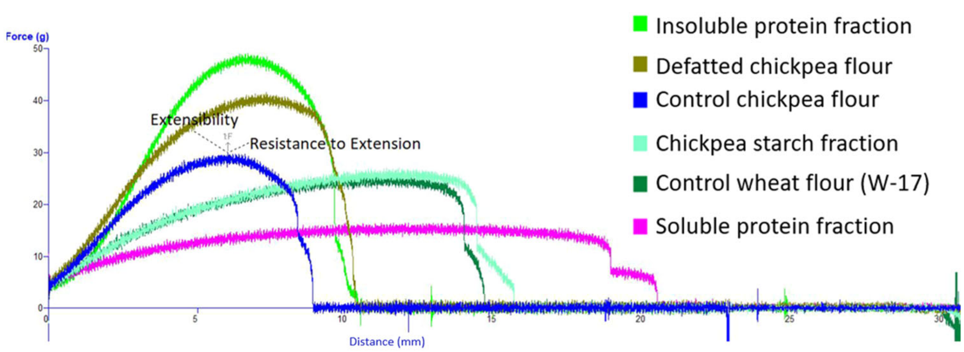

FIGURE 4 Extension graph of the dough when different chickpea flour fractions were added to the strong flour (W-17) at a level of 7.5%. [Color figure can be viewed at wileyonlinelibrary.com]

sulfhydryl groups for further crosslinking that increased dough strength and mixing tolerance.

3.3 | Bread properties of wheat/chickpea composite flour

The results of baking test showed that the incorporation of chickpea flour at a level of 3.75% resulted in a slightly larger (4.48 cm^3/g) bread compared to the control (4.25 cm^3/g) and other levels of incorporation (Table 1 and Supporting Information: Figure S8). Adding 7.5% chickpea resulted in bread with similar volume as the control. When chickpea was incorporated at level of 30%, the resultant bread became significantly smaller (3.23 cm^3/g) in size. Overmixing significantly reduced the bread volume as expected. However, the incorporation of chickpea at 7.5% prevented overmixing much better than the control flour as shown by its bread specific volume (4.17 vs. 3.77 cm^3/g). During dough mixing, optimal gluten development is achieved at the peak time and the dough is strong. Increased mixing after the peak time disrupts the gluten network and degrades the dough, causing it to weaken as mixing is continued. If excessively mixed, the dough becomes too sticky and weak to make good bread. This phenomenon has been a challenge to bakers who must be cautious not to overmix a dough, as it is irreversible (Lancelot et al., 2021; Sadot et al., 2017; Schiraldi & Fessas, 2012). The finding of this study is that addition of chickpea flour increases resistance to dough breakdown and significantly buffered loss of loaf volume. This has promising practical applications for bakers, since they can have some flexibility in case of overmixing the dough.

C-cell analysis showed a difference in a number of cell when chickpea was incorporated at 30%, or when the control flour was overmixed (Table 1). The breads from 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 the different treatments. The bread physical characteristics show that the incorporation of chickpea does not affect the quality of the bread.

The effect of chickpea on the crust color was more noticeable when addition above 7.5% were applied (Supporting Information: Table S11). The L^* value, which represents the lightness decreased (darkened) significantly when chickpea flour was incorporated at a level of 30% into wheat flour. This was due to the chickpea pigments and the Maillard reaction, which increased due to increased protein addition and/or sugars. Overmixing the dough had the opposite effect on the crust color. The overmixed control bread showed a significantly lighter crust color (L^* of 57) compared with normal mixing control bread (L^* of 52). This phenomenon may be a result of extensive protein degradation during overmixing, which inhibited the formation of color compounds. The 30% chickpea incorporation showed an increase in green and blue pigmentation (smaller *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 darken compared with other treatments. The crumb color parameter a showed an increase when chickpea flour was incorporated at 30% and when chickpea at 7.5 was overmixed, which means they were slightly more reddish in color compared to other crumbs. The *b* value was increased significantly when 30% chickpea was added depicting that the crumb was more yellow compared to other treatment while the 1.75% incorporation had significantly lower *b*-value (more bluesish). Other treatments were not significantly different among them.

TABLE 1 Composite bread physical characteristics.

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

Note: Means in the same column with a different superscript letter are significantly different ($p < .05$).

Abbreviations: OM, overmixed dough; xx-CP, level of kabuli medium chickpea incorporation in refined wheat flour.

TABLE 2 Average responses on appearance, aroma, taste, and acceptability determined by sensory evaluation of wheat-chickpea composite bread slices.

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

Note: Panelists mean responses in the same column with a different superscript letter are significantly different ($p < .05$).
Abbreviation: xx-CP, level of medium kabuli chickpea incorporation in refined wheat flour.

The texture profile analysis showed that the texture was mostly affected only when chickpea was incorporated at a level of 30% (Supporting Information: Table S12). The 30% inclusion level increased the hardness of the bread almost twofold. Adhesives and springiness were the only texture profiles not to be affected by 30% incorporation compared to the control. The resilience and cohesion of the bread were reduced significantly, while the gumminess and chewiness increased. These texture changes are attributed to the 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 conducted on the breads up to the incorporation level of 7.5%, as this was the level at which the beneficial properties of chickpea on the dough were optimum. The results of this sensory evaluation showed that no significant difference could be identified by the consumers when chickpea flour is incorporated up to 7.5% (Table 2). All the bread slices were deemed acceptable, with ratings above 5. In a previous study by Atudorei et al. (2022), germinated chickpea flour was incorporated in white flour at levels between 5% and 20%, and the sensory evaluation showed that the inclusion of 20% was much less appreciated by the jury. Other chickpea flour incorporation from 5% to 15% produced acceptable bread qualities according to the jury. In another study performed by Guardado-Félix 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 finding is consistent with the previous studies. The above results clearly indicate that chickpea flour can be incorporated into refined wheat flour at appropriate levels and produce similar quality bread while improving the mixing properties of the dough, which is beneficial to both the baker and the end consumer.

4 | CONCLUSIONS

This research has shown that adding chickpea flour can improve the mixing tolerance of wheat flour, particularly for weak/normal flour, meaning that the quality of the dough can be preserved during overmixing when chickpea flour is incorporated. Dough strength was improved significantly by the incorporation of chickpea flour. Chickpea flour may be used to replace some other industrial dough additives or improvers. The sensory study conducted showed that chickpea flour incorporation at levels up to 7.5% did not affect bread quality. When overmixed, the dough with chickpea incorporation resisted to bread quality loss compared to that with wheat flour alone. However, extensive addition of chickpea flour into wheat flour is not recommended in regard to improving the dough mixing properties. Further research should be conducted to identify the molecule compounds in the insoluble protein fraction that are responsible for improving the mixing tolerance and dough strength.

AUTHOR CONTRIBUTIONS

Eric Nkurikiye: Conceptualization; data curation; formal analysis; investigation; methodology; validation; writing—original draft; writing—review and editing. **Gengjun Chen**: Formal analysis; writing—review and editing. **Michael Tilley**: Resources; writing—review and editing. **Xiaorong Wu**: Resources; writing—review and editing. **Guorong Zhang**: Resources; writing—review and editing. **Allan Fritz**: Resources; writing—review and editing. **Yonghui Li**: Conceptualization; funding acquisition; methodology; project supervision; resources; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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