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Dough rheology and loaf quality of wheat-cassava bread using different cassava varieties and wheat substitution levels

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ABSTRACT

Cassava flours obtained from 6 cassava varieties grown in Zambia were incorporated into wheat flour for bread making. The effect of cassava variety (CV) and cassava flour substitution level (CFSL) (wheat:cassava, 90:10, 80:20, 70:30) on dough rheology and bread quality were investigated. Dough rheology and bread baking were determined using the Brabender Farinograph and the straight-dough method, respectively, while chemical composition was done using AOAC and AACC standard methods**.** There was a positive correlation ($r = 0.60$, $p < 0.05$) between gluten content (7–13%) and water absorption capacity (WAC) (60–62%). Dough development time and stability time of the composite doughs ranged from 1.5-11 min and 6.3–12 min, respectively. Dough consistency (476–512 FU) positively correlated ($r = 0.54$) with gluten content. Bread specific volume (1.5–2.5 g/cm^3) varied significantly ($p < 0.05$) with CV and CFSL, and correlated positively ($r = 0.76$, $p < 0.05$) with gluten content. Flour particle size negatively correlated with WAC ($r = -0.26$, 0.001), bread specific volume ($r = -0.72$, $p < 0.05$) and bread volume ($r = -0.68$, $p < 0.05$). The flour particle size, WAC, and gluten content are significant flour properties influencing dough rheology and bread quality. The results showed that wheat can be substituted with cassava flour from cassava varieties *Mweru*, *Kariba* and *Katobamputa* in bread making up to a level of 10%, without negatively affecting bread quality. Cassava inclusion generally led to reduced bread weight loss. Further work, however, needs to be done to explore use of higher levels of cassava in composite bread.

1. Introduction

Wheat is widely consumed in many African countries and ranks third after maize and cassava for daily caloric supply (Chapoto, 2010). However, continuous increases in the price of wheat in international markets, due to inflation and changes in exchange rate, is raising serious concern about the economic sustainability of wheat importation by some African countries, including Zambia. Thus, there is a growing interest to promote the use of locally produced staples for partial substitution of wheat flour in baking (Abass et al., 2016). Cassava flour has been identified for partial replacement of wheat flour (Eriksson, Koch, Tortoe, Akonor, & Oduro-Yeboah, 2014).

The gluten proteins (glutenins and gliadins) in wheat are responsible for the unique viscoelastic dough that is suitable for leavened baked products (Ribeiro et al., 2018). During dough making, the hydration of glutenins and gliadins results in the development of the gluten structure, a viscoelastic network held together by covalent bonds and to some extent non-covalent bonds (Chen et al., 2018; Jekle & Becker, 2015).

Gluten is not present in cassava flours. However, cassava flour has some attractive properties such as a low tendency for starch retrogradation, good stability, high water binding capacity and good adhesive strength (Jyothi, Sasikiran, Nambisan, & Balagopalan, 2005; Shittu, Alimi, Wahab, Sanni, & Abass, 2016; Sriroth et al., 1999), which could complement dough mixing properties and subsequent bread quality. Thus, it might be beneficial to determine the influence of partial substitution of wheat flour with cassava flour on dough rheology and consequently bread quality. Currently, there has been limited research on the effect of partially substituting wheat flour with cassava flour on dough rheology and bread quality, particularly on cassava varieties grown in Zambia.

Previous studies have observed that genotypes of both cassava and

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wheat significantly influenced the physical, chemical and functional characteristics of cassava-wheat composite flours and that bread quality varied with cassava genotype and substitution levels (Eriksson et al., 2014). Product physical characteristics were not only due to processing conditions but also varied with genotype (Ngobese & Workneh, 2018). The amylose content was reported to vary with genotype (Mejía-Agüero et al., 2012), and variations in starch types, proteins, lipids and fibre were found with different genotypes along with subtle influences of growing conditions (Halford, Curtis, Chen, & Huang, 2014; Zhu, 2015). However, the previous studies did not determine the chemical components of cassava flour that influenced dough rheology and bread quality. Differences in particle size distribution can affect water absorption capacity of flours, which subsequently influences dough rheological properties, and bread quality (Liu et al., 2015). Sakhare, Inamdar, Soumya, Indrani, and Rao (2014) reported that when wheat flour was fractionated using sieving, the finer (< 75 and 75–118 μm) fractions produced high-quality bread than the coarser fractions (118–150 and > 150 μm).

The cassava root is perishable due to physiological deterioration of the root immediately after harvest (Zainuddin et al., 2018). Thus, processing of cassava into flour for bread making is one strategy to reduce postharvest loss and could lead to greater diversification of cassava root use. In Zambia, cassava is important for food security and the most important staple crop after maize (Haggblade et al., 2012). The Zambian Government has prioritized improvement of cassava through breeding. One of the national agricultural strategies is to develop a viable cassava industry. As a result, a number of cassava varieties have been developed and released into the Zambian market. Nonetheless, there is no cassava variety that was developed for a specific culinary and/or food processing purpose, e.g., bread making. Therefore, there is a need to evaluate these cassava varieties for their potential suitability for partial replacement of wheat flour in bread making. Positive evaluation of some of the cassava varieties for bread making would enhance their market value, thereby encouraging their cultivation. Thus, in this study, the effects of cassava variety and substitution level on dough rheology and bread quality were measured.

2. Materials and methods

2.1. Source of materials

White bread wheat flour (Golden Cloud *since*1940™, Tiger Consumer Brands Ltd., Johannesburg, South Africa) was obtained from the local market of Pietermaritzburg, South Africa. Six cassava varieties (*Bangweulu, Katobamputa, Mweru, Kariba, Kampolombo* and *Chila)* were planted at the Mansa Root and Tuber Research Station, a branch of the Zambian Agriculture Research Station (ZARI), Mansa District, Luapula Province, Zambia, in a completely randomized block design in triplicates on plots of 5 m with plant spacing of 1 m in January 2016, and were harvested 18 months after planting (June 2017). The roots were collected from 5 cassava plants randomly selected from each block.

2.2. Processing of cassava flour and blending

2.2.1. Cassava flour

Cassava roots were processed into flour as described by Eriksson et al. (2014). The fresh cassava roots were cleaned to remove soil and debris. The cleaned roots were peeled and chopped into small pieces by hand with a knife, and washed 2x in potable water. The chopped cassava was grated using a motorized grating machine (2 t/h, 10 Hp electric motor) with an inbuilt spiked stainless steel sheet mounted on the wooden roller. The grating roller rotates against the clearance space of the adjustable wooden board at the bottom of the hopper, and can be adjusted according to the desired fineness of cassava pulp (locally fabricated, National Institute for Scientific and Industrial Research, Lusaka, Zambia). The fine grated cassava pulp was then put into clean polypropylene woven sacks (Sack & Twine Ltd., Lusaka, Zambia) and dewatered to remove excess water by pressing using a manually operated vertical screw press (locally fabricated, National Institute for Scientific and Industrial Research). The dewatered pulp was then granulated by crumbling by hand into small particles (grits) and spread on mats (polyethylene plastic sheet) placed on raised platforms. The grits were then sun-dried for 8 h before drying using a hot air circulation oven drier at 35 °C for 12 h. The dried grits were milled using a centrifugal mill (Retsch ZM200, Haan, Germany) at a peripheral tip speed of 93 m/s.

2.2.2. Flour particle size

The particle size distribution at 90% (D90) finer particles of cassava flours was determined as described by Patwa, Malcolm, Wilson, and Ambrose (2014) by sieving 250 g of sample for 5 min using 7 sieves with opening dimensions of 425, 300, 180, 150, 106, 90 and 38 μm. The sieves were serially stacked in descending order with the receiver pan at the base on a single shaker using a vibratory mechanical shaker (DuraTap, Model DT168, Advantech Mfg. Co., New Berlin, Germany).

2.2.3. Blending of wheat and cassava flour

Three levels of wheat:cassava (90:10, 80:20, 70:30) composite flours were prepared as described in Aboaba and Obakpolor (2010). The cassava flour sample (25 g) was mixed with 225 g of wheat flour to obtain the ratio of 90:10 (wheat:cassava). Wheat flour (100%) was used as the control.

2.3. Chemical analysis

2.3.1. Proximate composition

Crude protein content was determined as described in Nuwamanya, Baguma, and Rubaihayo (2010) using the Dumas combustion method of nitrogen content analysis (Leco Truspec Model FP-528, St Joseph MI, USA) by taking about 0.3 g of sample. Crude protein was estimated as % N x 6.25 for cassava flour while crude protein in white wheat flour was estimated as %N x 5.7. The moisture, lipid and fibre contents were determined as described in AOAC (2012) Methods 925.10, 920.39 and 962.09, respectively.

2.3.2. Amylose contents

The amylose content in cassava and wheat flour samples was determined using a Megazyme amylose/amylopectin assay kit (K-AMYL 12/16; Megazyme International Co., Bray, Wicklow, Ireland). A flour sample (20 mg) was dispersed using dimethyl sulfoxide (Sisco Research Laboratories, Maharashtra, India) and precipitated in 95% (v/v) ethanol solution (Sisco Research Laboratories) using a centrifuge (Avanti® J-26XPI, Beckman Coulter, Inc., Indianapolis, IN, USA) at 2000 g for 5 min. The precipitated starch sample in 1 mL 2 mM sodium acetate buffer and 0.5 mL lectin concanavalin A (Con A) were precipitated to remove amylopectin using a mini centrifuge (Microfuge® 16, Beckman Coulter, Inc., Krefeld, Germany) at 14,000 *g* for 10 min. The amylose in the supernatant was enzymatically hydrolysed to glucose using a amyloglucosidase:α-amylase (2:3) enzyme system. The absorbance was measured at 510 nm using a UV–Vis spectrophotometer (UV–1800PC, Shimadzu Corp., Kyoto, Japan). The concentration of amylose in the starch sample was then estimated as the ratio of absorbance of the supernatant at 510 nm of the Con A precipitated sample to that of the total starch sample.

2.3.3. Gluten content

The gluten content was determined using the hand washing method using 2% sodium chloride solution (Sisco Research Laboratories) by taking an ~10 g flour sample as described in AACC (2011) Method 38–10.2.8.

2.4. Rheological properties

The water absorption capacity (WAC), dough development time (DDT), dough stability time (DST), mixing tolerance index (MTI), and consistency of composite flours were determined with a Brabender Farinograph (Model 820603, Brabender OHG, Duisberg, Germany) at 30 ± 0.2 °C using a 300 g mixing bowl operated at 63 rpm according to AACC (2011) Method 54–21.

2.5. Preparation of bread

Bread was baked according to the straight-dough bread-making method (AACCI Method 10–09) (AACCI, 2000). The flour (250 g), 25 g sugar, 3 g salt, 5 g baking fat (Margarine, Spar Group Ltd., Pietermaritzburg, South Africa) and 2.5 g baker's yeast (Gold Star, Anchor Yeast Ltd., Johannesburg, South Africa) were weighed into a mixing bowl. About 150 mL water was added and the mixture was kneaded by hand and proofed for 45 min in the SelfCookingCentre® (Rational AG, Landsberg am Lech, Germany) at 30 °C and 100% humidity. After proofing, the dough was re-kneaded and divided into 70 g portions (three portions for each blend), moulded and placed in separate margarine greased baking pans. The baking took place in the SelfCookingCentre® in the temperature range of 178–193 °C for 16 min. The quality characteristics of the bread were determined after cooling at room temperature (20–22 °C) overnight.

2.6. Bread quality characteristics

2.6.1. Crumb and crust colour

The breadcrumb and crust colour; L* (degree of lightness), a* (redness to greenness) and b* (yellowness to blueness) were measured using a HunterLab ColorFlex instrument (Hunter Associate Laboratories Inc., Reston, VA, USA). The crumb samples were prepared by slicing a ~4 mm thick cross section of the bread and slicing off the crust area. The crust samples were obtained by thin sectioning (1–2 mm) of the bread crust using a razor blade. The samples were placed directly on the sample holder and covered with a black cup (HunterLab Cup). The whiteness index of crumb and brownness index of crust were calculated as described by Zhu, Sakulnak, and Wang (2016) using the equations:

$$\text{Whiteness index (WI)} = \sqrt{[(100-L)^2 + a^2 + b^2]} \quad (1)$$

$$\text{Brownness Index (BI)} = \frac{100 \text{ x } (\chi - 0.31)}{0.17} \quad (2)$$

where

$$\chi = \frac{a+1.75L}{5.645\text{ L}+ \text{a}- 3.01\text{b}} \quad (3)$$

2.6.2. Bread specific volume and density

Bread mass (W) was measured using a digital balance (Kern & Sohn, GmbH, Balingen, Germany). Bread volume (BV) was determined using a modification of the AACC Method 10–05 rapeseed replacement method using maize grit (~1.0 mm mesh using sieving) instead of rapeseeds (Eriksson et al., 2014). The bread was placed in a container of known volume (VC) and the basin filled to the brim with grits, bread was removed and the volume of the grits (VG) was measured using a measuring cylinder.

$$\text{Loaf volume, BV (cm}^3) = \text{VC} - \text{VG} \quad (4)$$

$$\text{Bread Density, BD (g/cm}^3) = \frac{W}{BV} \quad (5)$$

$$\text{Specific volume, SV (cm}^3\text{/g)} = \frac{BV}{W} \quad (6)$$

2.6.3. Weight loss

The weight loss of the bread in percent was determined as described in Bakare, Osundahunsi, and Olusanya (2016).

$$\text{Weight loss, WL (\%)} = \frac{A - B}{A} \text{ x } 100 \quad (7)$$

where A = weight of dough; B = weight of baked bread.

2.6.4. Breadcrumb pore size characteristics

The bread morphology and pore size of the crumb were studied using a scanning electron microscope (SEM) as described in Hayta and Ertop (2018) with modifications. The bread crumb samples of ~5 × 5 × 3 mm were prepared and mounted on the SEM sample stubs with double adhesive tape. Freeze-drying and gold sputtering were skipped to obtain actual crumb pores (gas cells). The crumb pores were evaluated using the variable pressure mode (VPM), which allows viewing of fresh samples (uncoated specimens) using an environmental SEM (ESEM) (EVO LS15, Carl Zeiss Microscopy, Jena, Germany). The SEM images were subjected to image analysis for pore size (cross section area in mm^2) estimation using the Soft Imaging System (Olympus Soft Imaging Solutions, Munster, Germany). The porosity was expressed as total pore area to the total surface area of the image.

2.7. Experimental design and statistical analysis

A completely randomized design with two factors: Cassava variety and blend ratio (cassava concentration) was used. Triplicate data were evaluated using two-way ANOVA. Pearson's correlation and multivariate principal component analysis (PCA) were done using GenStat (18th Edition software, VSN International Ltd., Hemel, Hempstead, UK) and mean differences were determined using Fisher's Least Significance Difference (LSD) test at a 5% significant level ($p < 0.05$). Although $p < 0.05$ was generally used, $p < 0.01$ and $p < 0.001$ were used for some of the data to indicate greater significant differences.

3. Results and discussion

3.1. Proximate composition of cassava and wheat flours

The moisture content of the cassava flours was significantly less than in the wheat flour (Table 1). The protein content of the cassava

Table 1
Moisture, crude protein, lipid, and amylose contents, and particle size of cassava flours from six cassava varieties grown in Zambia.

Variety	Moisture (%)	Crude protein (%)	Lipid (%)	Fibre (%)	Amylose (%)	Size (µm)
Bangweulu	11 ± 1^{ab}	1.9 ± 0.8^{b}	0.4 ± 0.04^{bc}	0.6 ± 0.5^{b}	22 ± 3^{ab}	312^{a}
Katobamputa	11 ± 1^{ab}	1.5 ± 0.03^{ab}	0.4 ± 0.1^{bc}	0.2 ± 0.1^{a}	27 ± 2^{b}	283 ± 0.02^{c}
Mweru	12 ± 2^{b}	1.8 ± 0.3^{ab}	0.6 ± 0.2^{cd}	0.1 ± 0.1^{a}	18 ± 8^{a}	250 ± 0.03^{b}
Kariba	11 ± 1^{ab}	1.4 ± 0.4^{ab}	0.6 ± 0.1^{d}	0.04 ± 0.02^{a}	16 ± 1^{a}	333 ± 0.02^{e}
Kampolombo	11 ± 1^{a}	1.6 ± 0.2^{ab}	0.3 ± 0.2^{ab}	0.03 ± 0.02^{a}	18 ± 7^{a}	334 ± 0.01^{e}
Chila	10 ± 0.4^{a}	1.2 ± 0.1^{a}	0.2 ± 0.04^{a}	0.2 ± 0.1^{a}	16 ± 4^{a}	278^{c}
Wheat (control)	13 ± 0.2^{d}	11 ± 0.3^{c}	1.7 ± 0.2^{c}	2.9 ± 0.1^{c}	21 ± 0.5^{ab}	210 ± 10^{a}

Values are presented as mean ± standard deviation (n = 3). Within the same column, the values with different letters are significantly different at $p < 0.05$.

flours was very low compared to that of wheat flour. Wheat flour protein contain about 85% gluten proteins (glutenins and gliadins) (Avramenko, Tyler, Scanlon, Hucl, & Nickerson, 2018; Ribeiro et al., 2018), while cassava flour protein is gluten-free (Chakrabarti, Poonia, & Chauhan, 2017). The lipid contents in all cassava flour varieties were significantly lower than in wheat flour. The lipids reinforce gluten structure through lipid-protein interactions (Avramenko et al., 2018). The fibre content of the cassava flour was significantly lower than that of the wheat flour. Leavened aerated bread cannot be made without wheat flour because of viscoelastic dough making properties of wheat gluten proteins.

3.2. Amylose content

The amylose content was not significantly different among cassava varieties except *Katobamputa*. There was no significant difference between the amylose content of the wheat flour and that of any of the cassava varieties. The amylose content of cassava were reported previously, 19–20% (Morante et al., 2016), 23% (dos Santos et al., 2018), and 17–26% (Liu et al., 2019). The amylose content is the basis of classifying starches into waxy, semi-waxy, normal/regular and high-amylose types when amylose content is 0–2, 3–15, 16–35, and > 35% of the total starch, respectively (Botticella et al., 2018; Morante et al., 2016; Tester, Karkalas, & Qi, 2004). The results showed that all the cassava flour varieties along with wheat flour were generally classified as normal/regular starches. High amylose content can reduce starch granules swelling and significantly increase the level of resistant starches (Hallström, Sestili, Lafiandra, Björck, & Östman, 2011).

3.3. Particle size of cassava varieties and wheat flours

The flour particle size varied among the cassava varieties (Table 1). The average particle size of the wheat flour was low compared to the particle size of cassava flours. The particle size of flour is an important factor that can affect the baking properties and end product quality (Vouris, Lazaridou, Mandala, & Biliaderis, 2018). Particle size is influenced by the milling technique and the inherent hardness differences of wheat and cassava flour varieties (Liu et al., 2015). Reduction of flour particle size during milling can result in a high proportion of damaged starch granules leading to high water absorption capacity of the flour and high susceptibility of starches to enzymatic hydrolysis, both of which can affect bread quality (Wang, Hou, & Dubat, 2017).

3.4. WAC

The moisture content of the composite flour blends (Table 2) increased with increased CFSL. The WAC for the flour blends were negatively correlated with CFSL suggesting that higher CFSL resulted in decreasing WAC, in part, due to large the particle size of cassava flour with low WAC. There was a weak positive correlation between WAC and crude protein and fibre. The high crude protein and fibre levels in wheat flours are significant contributors to water absorption. The crude protein contents were generally very low in cassava with no significant differences ($p \geq 0.05$) among the cassava varieties. The fibre contents of the cassava varieties were low compared to wheat flours and hence the contribution of cassava fibre to WAC was probably low. Nevertheless, the difference in fibre content can bring a difference in water absorption of wheat flours. A study by Struck, Straube, Zahn, and Rohm (2018) observed that addition of almond fibre significantly reduced WAC of wheat flour.

In a similar study on potato-wheat flour, higher crude protein contents increased WAC of wheat flour (Sarker et al., 2008). According to Liniņa, Kunkulberga, and Ruža (2014), water absorption of weak flour is < 55%, of medium flour 54–60%, and strong > 58%. The WAC of the flour blends was characteristic of strong flours and showed significant positive correlations with gluten content ($p < 0.05$), an indication that high gluten content resulted in a higher WAC. There was a strong negative correlation ($p < 0.01$) between WAC and flour particle size which indicated that smaller particle size flours had higher water hydration capacity.

3.4.1. Gluten content

The dry gluten content of wheat flour decreased with increased CFSL. The mixing of wheat flour with water transforms gluten proteins into viscoelastic gluten structures that ultimately determine the quality of the final bread product (Sissons & Smit, 2018). The significant negative correlation between protein content and CFSL ($p < 0.05$) suggested that inclusion of cassava flour diluted out the gluten, an effect also observed by Collar and Armero (2018). Thus partial replacement of wheat flour with cassava flour could reduce bread volume because of dilution of wheat gluten functionalities (Šárka et al., 2017). Flour particle size had a significant negative correlation (Table 3) with gluten development implying that smaller particles hydrate faster and thereby promoted migration of excess water to the gluten network.

3.5. Dough rheological properties

3.5.1. DDT

The DDT of composite flours increased with increased CFSL. The DDT of the control (wheat) flour was not significantly different from that of composite flours of *Katobamputa*, *Mweru* and *Kampolombo* at 10%, Kariba at 20%, and *Mweru* at 30%. The DDT showed significant negative correlation with WAC and gluten content ($p < 0.01$), and positive correlation with flour particle size ($p < 0.05$). Reduced WAC inhibited gluten development. Excess water beyond that required for gluten development can cause weakening of the gluten matrix leading to delayed dough development (Jafari, Koocheki, & Milani, 2018). Higher WAC increased hydration of gluten and hence contributed to quicker dough development. Jafari et al. (2018) reported that decreased gluten hydration is the main reason for high DDT. The high DDT observed could be attributed to decreasing gluten content with increasing cassava flour content, which might have disrupted the formation of the gluten network (Zhang, Mu, & Sun, 2018), thus increasing DDT (Eduardo, Svanberg, Oliveira, & Ahrné, 2013). DDT is influenced by crude protein content (Huang, Guo, Wang, Ding, & Cui, 2016). The positive correlation between DDT and flour particle size suggested that large particle size was a significant contributor to the low hydration capacity that might have delayed gluten development resulting in an extended period of dough development.

3.5.2. Consistency

Cassava variety and the main interaction (CV x CFSL) had significant ($p < 0.05$) influence on the consistency of dough. The peak consistency value of the wheat dough was higher than those of the composite doughs, which varied among flour blends, showing a decreasing trend with increasing CFSL. This indicated that inclusion of cassava flour resulted in a decrease in dough consistency. Dough consistency positively correlated with gluten content, which is expected because gluten is largely responsible for dough structure and strength. Dough consistency positively correlated with WAC and protein content indicating that strong, high gluten content dough would be of high dough consistency. The dough consistency correlated negatively with flour particle size implying that doughs with smaller particles had higher consistency than doughs made with flour of larger particle size.

3.5.3. DST

The DST at 10% CFSL decreased when CFSL increased to 20% except for *Bangweulu* and *Kariba*. DST showed a weak negative correlation with CFSL suggesting that high DST were associated with low CFSL. The DST of the composite doughs increased when CFSL was increased to 30%, and DST values were similar ($p \geq 0.05$) to the DST of the control. DST indicates the tolerance of the dough to mixing stress. Flour with a

Table 2
Moisture and gluten contents and Brabender Farinograph dough mixing properties of wheat flour and cassava-wheat flour blends.

Variety	CFSL (%)	Moisture (%)	WAC (%)	Gluten (%)	DDT (min)	Consistency (FU)	DST (min)	MTI (FU)
Bangweulu	10	13 ± 0.3^{ab}	60 ± 2^{abcd}	10 ± 0.04^{de}	1.9 ± 0.3^{bcde}	478 ± 2^{cd}	7.2 ± 0.1^{b}	30 ± 1^{hi}
Katobamputa	10	13 ± 0.1^{bcd}	62 ± 0.1^{e}	11 ± 0.01^{ef}	2.1 ± 0.1^{de}	478 ± 2^{cd}	9.9 ± 0.05^{ef}	25 ± 1^{efg}
Mweru	10	13 ± 0.2^{ab}	62 ± 0.2^{e}	10 ± 0.02^{de}	2 ± 0.1^{cde}	501^{h}	11 ± 0.1^{gh}	29 ± 4^{hi}
Kariba	10	13 ± 0.1^{abc}	61 ± 1^{cde}	11 ± 0.01^{ef}	1.7 ± 0.1^{ab}	516 ± 1^{i}	7.2 ± 0.3^{b}	35 ± 1^{jk}
Kampolombo	10	13 ± 0.1^{ab}	62 ± 0.5^{e}	11 ± 0.01^{ef}	2.1 ± 0.1^{de}	476 ± 0.5^{c}	9.4 ± 0.5^{de}	35 ± 1^{jk}
Chila	10	13 ± 0.1^{ab}	62 ± 0.3^{e}	11 ± 0.01^{ef}	2.2 ± 0.1^{e}	490^{fg}	7.1 ± 0.1^{b}	35 ± 1^{jk}
Bangweulu	20	13 ± 0.2^{a}	61 ± 1^{bcde}	9.6 ± 0.02^{cd}	1.8 ± 0.2^{abcd}	510 ± 1^{i}	8.2 ± 0.1^{c}	18 ± 1^{bc}
Katobamputa	20	14 ± 0.1^{ef}	61 ± 0.2^{cde}	8.6 ± 0.8^{bc}	1.8 ± 0.1^{abcd}	511 ± 1^{i}	6.3 ± 0.1^{a}	32 ± 1^{ij}
Mweru	20	13 ± 0.2^{ab}	61 ± 1^{bcde}	8.7 ± 1^{bc}	1.5 ± 0.1^{a}	501 ± 1^{h}	6.7 ± 1.1^{ab}	40 ± 10^{k}
Kariba	20	14 ± 0.1^{cde}	62 ± 0.5^{e}	7.8 ± 1^{ab}	2.1 ± 0.1^{de}	480 ± 20^{def}	10 ± 0.3^{fg}	22 ± 1^{k}
Kampolombo	20	13 ± 0.2^{av}	62 ± 0.2^{de}	12 ± 0.03^{fg}	7.8 ± 0.2^{h}	492 ± 2^{g}	6.6 ± 0.2^{ab}	28 ± 5^{a}
Chila	20	13 ± 0.2^{abc}	61 ± 1^{cde}	10 ± 0.02^{de}	1.7 ± 0.1^{abc}	482 ± 1^{cde}	6.9 ± 0.1^{ab}	28 ± 1^{gh}
Bangweulu	30	13 ± 0.2^{abcd}	60 ± 0.5^{a}	8.7 ± 0.02^{bc}	7.2 ± 0.1^{g}	493^{g}	9.1 ± 0.1^{d}	40 ± 1^{l}
Katobamputa	30	14 ± 1^{cde}	60 ± 0.1^{a}	8.1 ± 1^{bc}	4.0^{f}	488 ± 1^{i}	9.5 ± 0.1^{de}	11 ± 1^{a}
Mweru	30	13 ± 0.2^{ab}	60 ± 0.4^{a}	6.9 ± 1^{a}	2.1 ± 0.1^{de}	453 ± 0.5^{h}	11 ± 1^{hi}	15 ± 4^{b}
Kariba	30	14 ± 0.1^{f}	60 ± 0.2^{ab}	6.9 ± 1^{a}	9.4 ± 0.6^{j}	481 ± 1^{def}	12 ± 0.1^{k}	24 ± 1^{de}
Kampolombo	30	13 ± 0.2^{abcd}	60 ± 1^{abc}	9.2 ± 0.5^{c}	11 ± 0.5^{k}	462^{g}	11 ± 0.3^{ij}	24 ± 1^{def}
Chila	30	14 ± 0.1^{def}	60 ± 1^{ab}	10 ± 0.01^{de}	8.7 ± 0.1^{i}	467 ± 1^{cde}	12 ± 0.1^{jk}	27 ± 1^{fgh}
Wheat	0	13 ± 0.2^{abc}	62 ± 1^{e}	13 ± 1^{g}	2.1 ± 0.1^{de}	512 ± 0.5^{i}	12 ± 0.2^{k}	24 ± 1^{fgh}

Values are presented as mean ± standard deviation (n = 3). Within the same column, the values with different letters are significantly different at $p < 0.05$. .

DST > 10 min is resistant to mechanical stress (Edun, Olatunde, Shittu, & Adeogun, 2018), and is classified as flour of excellent quality, and flour of poor quality has a stability time of < 3 min (Liniņa et al., 2014). DST had a negative correlation with particle size implying that DST increased with reduced particle size, presumably because smaller particle size favour uniform and high water absorption that in turn improves gluten development. Wang et al. (2017) reported that reducing the particle size strengthened the gluten network, and resulted in shorter development time and longer mixing stability of the dough. DST showed significant correlation with crude protein and fibre. Increased fibre along with starch content might have contributed to an increase in the water absorption required for the development of gluten structure (Hrušková; Švec, 2018). The increased starch-protein interaction may have contributed to increased hydrogen bonding in the starch-gluten interaction and thus contributed to the stability of the gluten network. A similar, observation was made by Zhang et al. (2018) on tapioca starch-wheat composite flours.

3.5.4. MTI

The MTI did not vary with CFSL. The MTI for the control was not significantly different from *Katobamputa* at 10%, *Kariba* at 20%, and *Kariba* and *Kampolombo* at 30% CFSL. MTI indicates the degree of dough softening over a period of mixing (Srikanlaya, Therdthai, Ritthiruangdej, & Zhou, 2018). The lower the MTI value the better quality. According to Liniņa et al. (2014), dough mixing quality is considered satisfactory if MTI is < 70 FU. Doughs with MTI values > 110 FU are considered weak and are characterised as having difficulties in mechanical handling during dough making. Depending on its quantity and composition (Gómez, Ronda, Blanco, Caballero, & Apesteguía, 2003), dietary fibre can have a dilution effect on gluten proteins (Ho & Aziah, 2013). All the composite flour samples, irrespective of variety and CFSL had satisfactory MTI which indicated good dough mixing quality. Values obtained were in the range considered satisfactory for good dough mixing quality. However, the MTI showed poor correlation with other mixing properties. Similar results were reported by Isah (2017) in the study of African locust bean pulp flour incorporated into wheat flour at different ratios. It seems likely that high levels of cassava flour contributed a large amount of starches which may have weakened the gluten structure.

3.6. Bread quality

3.6.1. BV and SV

Table 4 shows the BV, SV and BD of bread made from cassava-wheat flour blends. The BV of the control decreased with increased CFSL. BV correlated strongly and positively with gluten content, crude protein, WAC, dough consistency, and negatively with DDT. This showed that dough with high gluten content had good mixing properties, along with good consistency, short mixing time and resistance to stress and yielded quality bread with respect to BV. Further, the BV showed a negative correlation with particle size (Table 4), indicating flours of small particle size produced bread of large volume. Similarly, Jacobs et al. (2018) reported that flours of smaller particle size produced large volume bread. This suggested that flours of small particle size have high WAC, which promoted good gluten development.

The SV of wheat bread decreased with increase in CFSL. The SV correlated positively with WAC, gluten content, DST, and negatively with DDT. The SV obtained at 10% CFSL of *Katobamputa*, *Mweru* and *Kariba* were not significantly different ($p \geq 0.05$) from that of wheat bread. These results are similar to those of Eriksson et al. (2014), who observed insignificant variation with cassava variety on SV. The decrease in SV with an increasing amount of cassava flours has been reported by several authors (Aboaba & Obakpolor, 2010; Eggleston, Omoaka, & Arowshegbe, 1993; Eriksson et al., 2014). The SV values obtained in the previous studies were higher than the current values, which was probably influenced by additional ingredients. Ingredients such as concentrated milk have an enhanced emulsifying effect (Julianti, Rusmarilin, & Yusraini, 2017), which promotes emulsification of the shortening, which improves bread quality. The negative correlation between flour particle size and SV indicated that smaller flour particle size were associated with large BV likely due to the high WAC of the flour.

3.6.2. BD

The BD of wheat bread (control) was the lowest and increased with increased CFSL. Increased CFSL favoured starch-starch/starch-protein

Table 3
Correlation coefficients of dough mixing properties, bread quality, amylose and proximate contents.

	CFSL	M	WAC	DDT	DST	MTI	DC	Amy	Prt	Lip	Fib	BV	WB	BD	SV	WL	PA	P	D90	G
CFSL	1																			
M	0.37	1																		
WAC	−0.65	−0.30	1																	
DDT	0.62	0.32	−0.44	1																
DST	−0.27	0.19	0.00	0.19	1															
MTI	−0.06	−0.19	0.16	0.00	−0.48	1														
DC	−0.65	−0.19	0.45	−0.45	0.03	0.12	1													
Amy	−0.10	0.12	−0.12	−0.16	0.00	−0.21	0.18	1												
Prot	−0.77	−0.14	0.34	−0.28	0.64	−0.25	0.60	0.15	1											
Lip	−0.74	−0.08	0.36	−0.31	0.65	−0.27	0.61	0.14	0.96	1										
Fib	−0.76	−0.15	0.36	−0.29	0.61	−0.23	0.60	0.16	0.98	0.93	1									
BV	−0.87	−0.21	0.66	−0.51	0.36	−0.06	0.60	0.16	0.77	0.78	0.74	1								
WB	0.04	0.13	0.08	0.21	−0.27	0.25	−0.02	0.06	−0.23	−0.32	−0.20	−0.13	1							
BD	0.85	0.24	−0.65	0.58	−0.30	0.05	−0.57	−0.13	−0.71	−0.73	−0.66	−0.98	0.24	1						
SV	−0.86	−0.22	0.63	−0.52	0.39	−0.09	0.59	0.14	0.79	0.81	0.75	0.99	−0.25	−0.98	1					
WL	−0.04	−0.13	−0.08	−0.21	0.27	−0.25	0.02	−0.06	0.23	0.32	0.20	0.13	−1.0	−0.24	0.25	1				
PA	0.19	0.00	−0.05	0.12	−0.23	0.40	−0.20	0.26	−0.29	−0.36	−0.24	−0.16	0.38	0.20	−0.20	−0.38	1			
P	−0.71	−0.23	0.35	−0.30	0.43	−0.09	0.41	0.40	0.75	0.68	0.78	0.66	−0.0	−0.58	0.64	0.01	0.18	1		
D90	0.64	0.13	−0.26	0.45	−0.51	0.24	−0.48	−0.16	−0.83	−0.79	−0.81	−0.68	0.50	0.67	−0.72	−0.50	0.29	−0.57	1	
G	−0.84	−0.44	0.60	−0.28	0.25	0.10	0.54	0.08	0.70	0.62	0.70	0.78	0.07	−0.72	0.76	−0.07	−0.08	0.64	−0.53	1

WAC = Water Absorption Capacity, DDT = Dough Development Time, DST = Dough Stability Time, MTI = Mixing Tolerance Index, DC = Dough Consistency, VB = Volume of Bread, WB = Weight of Bread, BD = Bread Density, SV = Specific Volume, WL = Weight loss, P = Porosity, PA = Pore area of bread crumb, D90 = Particle Size Distribution at 90% finer particles pass, G = Gluten.

systems more than protein-protein interactions, which can weaken the gluten structure. During baking, starch granules lose birefringence properties through swelling and leaching of amylose and result in an increase in viscosity and migration of plasticising water from gluten to starch (Verbauwhede et al., 2018). Higher absorption capacities due to the damaged starch of cassava flour (Nindjin, Amani, & Sindic, 2011) can deplete water to a level lower than is required for gluten structure, which can lead to inhibition of expansion of gas cells and hence a dense (less foam) crumb structure at the end of oven spring. The BD positively correlated with flour particle size indicating that flours of larger particle size had low expansion capacity when processed into dough and then bread. BD had significant negative correlations with gluten content and WAC ($p < 0.05$) but was positively correlated with DDT. This suggested that high BD values were associated with flours of low gluten content, low WAC and high DDT.

3.6.3. WL

The WL of wheat bread was similar to the WL of the bread containing *Bangweulu* at 20%, *Chila* at 20% and *Bangweulu* at 30% CFSL. The WL did not show a consistent pattern of change with CFSL. Vouris et al. (2018) reported WL of wheat bread in the range of 16–18%, values somewhat higher than those obtained in this study. WL occurring during the baking stage of bread processing may be due to evaporation of water as well as volatilization of low molecular weight compounds including ethanol produced during fermentation (Bakare et al., 2016; Shittu, Raji, & Sanni, 2007b; Verbauwhede et al., 2018).

3.7. Bread crumb colour and crust colour

The bread crumb L* for flour blends did not vary with CFSL (Table 5). The L* value of the control was similar ($p \geq 0.05$) to the L* values of bread samples at 20% CFSL for *Mweru*, 30% CFSL for *Kampolombo* and 30% for *Chila*. These results indicated that cassava flour of different cassava varieties can be incorporated at different substitution levels to obtain bread with L* similar to that of the wheat bread. The bread crumb a* ranged between −0.4 (green) and 0.7 (red), and varied significantly ($p < 0.05$) across blend ratios. However, their values were too low to significantly reduce L*. These traces of weak red and green could be attributed to carotenoid pigments in wheat flour (Zhai et al., 2018) and residual pigment due to the reddish peels of cassava. The b* varied significantly ($p < 0.05$) across the blend ratios. Crumb b* could be attributed, in part, to the non-enzymatic reaction between reducing sugar and proteins to develop a yellow-brown colour. Flour b* was most probably a result of the accumulation of carotenoids in the wheat flour (Zhai et al., 2018). A combination of lower a* and b*, and higher L* values increased the WI (see Table 5).

The WI did not vary with CFSL. The WI of the control was similar ($p \geq 0.05$) to the whiteness of *Bangweulu, Kariba, Katobamputa,* and *Chila* at 30% CFSL. The WI of the crumb significantly correlated positively with L*, implying that increased L* produced a high level of whiteness. Nevertheless, WI is affected by the b* of the crumb. The increased crumb b* reduced L* resulting in decreased WI. Crumb colour affects consumer preference of bread because it is perceived as a measure of quality. Crumb colour is influenced by the colour of flours and other ingredients (Shittu, Raji, & Sanni, 2007a), as well as non-enzymatic reactions, which can contribute to yellowness or brownness. The desired colour of wheat flours for industrial applications is a high value for L* and low value for chroma (Sankhon et al., 2014; Vasconcelos, Brito, Carmo, Oliveira, & Oliveira, 2017). The chroma varied significantly ($p < 0.05$) with CFSL. However, there was no consistent trend in the variations across the flour blend ratios. Chroma is influenced by a* and b*. Chroma positively correlated with a* and b*, suggesting that higher levels of crumb a* and b* increased the chroma.

The bread crust L* of the control was similar to the bread processed with the inclusion of cassava flour at 30% for *Mweru* and at both 10% and 20% CFSL for *Kampolombo*. Crumb colour was lighter than crust

Table 4
Volume, specific volume and density of bread baked from cassava-wheat flours blends.

Variety	CFSL (%)	BV (cm^3)	SV (cm^3/g)	BD (g/cm^3)	WL (%)
Bangweulu	10	100 ± 10^{abcd}	1.7 ± 0.1^{abc}	0.6 ± 0.03^{fghi}	12 ± 0.3^{bcde}
Katobamputa	10	140 ± 5^{gh}	2.3 ± 0.1^{ij}	0.4 ± 0.01^{ab}	12 ± 1^{bcde}
Mweru	10	120 ± 10^{ef}	2.1 ± 0.1^{hi}	0.5 ± 0.03^{bc}	17 ± 1^{gh}
Kariba	10	130 ± 10^{fg}	2.1 ± 0.1^{ghi}	0.5 ± 0.02^{bc}	12 ± 1^{abcd}
Kampolombo	10	122 ± 3^{ef}	1.9 ± 0.1^{efgh}	0.5 ± 0.01^{cd}	10 ± 1^{a}
Chila	10	120 ± 10^{ef}	1.9 ± 0.1^{defg}	0.5 ± 0.03^{cde}	10.9 ± 0.4^{ab}
Bangweulu	20	100 ± 10^{abcd}	1.7 ± 0.1^{abcd}	0.6 ± 0.03^{fgh}	13 ± 0.4^{def}
Katobamputa	20	120 ± 10^{ef}	1.9 ± 0.1^{efgh}	0.5^{def}	11 ± 1^{abc}
Mweru	20	115 ± 5^{de}	2 ± 0.1^{fgh}	0.5 ± 0.03^{def}	16 ± 2^{g}
Kariba	20	110 ± 10^{cde}	1.8 ± 0.1^{cdef}	0.6 ± 0.03^{def}	12 ± 0.5^{cde}
Kampolombo	20	110 ± 10^{cde}	1.8 ± 0.1^{cdef}	0.6 ± 0.02^{def}	12 ± 1^{bcde}
Chila	20	112 ± 3^{cde}	1.8 ± 0.1^{cdef}	0.6 ± 0.01^{def}	13 ± 1^{def}
Bangweulu	30	93 ± 10^{ab}	1.5 ± 0.1^{ab}	0.7 ± 0.04^{ij}	13 ± 0.3^{ef}
Katobamputa	30	100 ± 10^{abc}	1.6 ± 0.2^{abc}	0.6 ± 0.1^{ghij}	12 ± 1^{de}
Mweru	30	100 ± 10^{abcd}	1.8 ± 0.2^{cdef}	0.6 ± 0.1^{def}	18 ± 1^{h}
Kariba	30	95 ± 10^{ab}	1.5 ± 0.1^{ab}	0.7 ± 0.1^{hij}	12 ± 0.4^{bcde}
Kampolombo	30	105^{bcd}	1.7 ± 0.1^{bcde}	0.5^{efg}	13 ± 0.5^{def}
Chila	30	92 ± 3^{a}	1.5 ± 0.01^{a}	0.7 ± 0.02^{j}	12 ± 0.5^{bcde}
Wheat flour	0	150 ± 10^{h}	2.5 ± 0.2^{j}	0.4 ± 0.03^{a}	14 ± 1^{f}

Values are presented as mean ± standard deviation (n = 3). Within the same column, the values with different letters are significantly different at $p < 0.05$.

colour. The acceptable range of L* value for bread crust is 54–62 (Fu et al., 2018) which was achieved by most bread samples except for *Mweru* at 10 and 20% CFSL. Crust a* significantly varied with CFSL without a consistent trend. Crust b* values significantly varied across CFSL. The colour shift from crumb to crust was characterised by increased a* and b* values. It is generally acceptable to have darker crust than crumb, therefore, the relative colour of the crust and crumb of the bread samples were acceptable.

The BI of the wheat bread was similar with bread samples containing flours of *Bangweulu* and *Katobamputa* at 20% CFSL, and *Chila* at 30% CFSL. The reduced L* and increased chroma resulted in an increased BI (Table 6). The BI correlated negatively with WL and B, and positively with the weight of the bread (Table 7). In addition, the weight of the bread showed a strong negative correlation with WL. The high BI of the bread was typical of reduced BV and WL with increased bread weight. Browning can be ascribed to the products of the Maillard and caramelisation reactions that occur during dry heating as in baking (Shen, Chen, & Li, 2018). The BI showed a weak negative correlation with crude protein content. The flour blends with higher CFSL had lower crude protein content and higher BI. Increased starch contents in the flour blends may possibly lead to higher levels of reducing sugars available for the Maillard reaction that resulted in a high BI of the bread

Table 5
Colour parameters of the crumb of the bread baked from six cassava varieties-wheat flour blends.

Variety	CFSL (%)	L*	a*	b*	WI	Chroma
Bangweulu	10	74 ± 0.1^{fg}	0 ± 0.1^{c}	21 ± 0.1^{cd}	67 ± 0.2^{efg}	21 ± 0.1^{cd}
Katobamputa	10	73 ± 0.3^{cd}	0.1 ± 0.1^{ef}	21 ± 0.1^{fgh}	65 ± 0.1^{bc}	21 ± 0.1^{fgh}
Mweru	10	73 ± 0.1^{def}	0.6 ± 0.04^{l}	22 ± 0.1^{j}	65 ± 0.1^{ab}	22 ± 0.1^{j}
Kariba	10	73 ± 0.3^{fg}	0.04 ± 0.03^{cd}	21 ± 0.3^{cde}	66 ± 0.4^{ef}	21 ± 0.3^{cde}
Kampolombo	10	73 ± 0.3^{ef}	-0.4 ± 0.1^{a}	20 ± 0.4^{a}	67 ± 0.5^{ghi}	20 ± 0.4^{a}
Chila	10	75 ± 0.1^{j}	0.3 ± 0.1^{gh}	21 ± 0.2^{gh}	67 ± 0.4^{j}	21 ± 0.2^{gh}
Bangweulu	20	72 ± 1^{cd}	-0.3 ± 0.1^{ab}	20 ± 0.1^{c}	66 ± 0.4^{cd}	20 ± 0.1^{c}
Katobamputa	20	73 ± 0.3^{cd}	-0.3 ± 0.1^{b}	19 ± 0.5^{a}	66 ± 0.04^{bc}	19 ± 0.5^{a}
Mweru	20	75 ± 0.5^{hi}	0.7 ± 0.03^{jk}	22 ± 0.1^{j}	66 ± 0.3^{de}	23 ± 0.1^{j}
Kariba	20	71 ± 1^{a}	0.2 ± 0.03^{fg}	21 ± 0.2^{cd}	65 ± 1^{a}	21 ± 0.2^{cd}
Kampolombo	20	73 ± 0.2^{cde}	0.4 ± 0.01^{ijk}	21 ± 0.1^{ef}	66 ± 0.4^{cd}	21 ± 0.1^{ef}
Chila	20	73 ± 0.3^{cde}	0.1 ± 0.02^{de}	21 ± 0.1^{fg}	66 ± 0.3^{bcd}	21 ± 0.1^{fg}
Bangweulu	30	72 ± 1^{ab}	0.1 ± 0.1^{cde}	20 ± 0.6^{b}	65 ± 0.4^{fgh}	20 ± 1^{b}
Katobamputa	30	75 ± 0.01^{ij}	0.5 ± 0.02^{k}	21 ± 0.04^{def}	68 ± 0.03^{j}	21 ± 0.04^{def}
Mweru	30	75.6 ± 0.5^{j}	0.4 ± 0.1^{jk}	22 ± 0.1^{i}	67 ± 0.4^{ij}	22 ± 0.1^{i}
Kariba	30	74 ± 0.01^{fg}	0.3 ± 0.1^{hi}	21 ± 0.1^{c}	67 ± 0.03^{fg}	21 ± 0.1^{c}
Kampolombo	30	74 ± 0.5^{h}	0.6 ± 0.1^{lm}	21 ± 0.1^{cd}	67 ± 0.4^{hij}	21 ± 0.1^{cd}
Chila	30	74 ± 1^{gh}	0.7 ± 0.1^{m}	21 ± 0.3^{fg}	66 ± 0.4^{efg}	21 ± 0.3^{fgh}
Wheat	0	74 ± 0.02^{h}	0.4 ± 0.02^{ij}	22 ± 0.03^{hi}	67 ± 0.01^{fgh}	22 ± 0.03^{hi}

Values are presented as mean ± standard deviation (n = 3). Within the same column, the values with different letters are significantly different at $p < 0.05$.

Table 6
Colour parameters of the crust of the bread baked with six cassava-wheat flour blends.

Variety	CFSL (%)	L*	a*	b*	BI	Chroma
Bangweulu	10	53 ± 0.4^{b}	17 ± 0.2^{k}	38 ± 0.1^{fgh}	137 ± 1^{j}	41 ± 0.01^{ij}
Katobamputa	10	58 ± 2^{d}	14 ± 1^{def}	37 ± 0.2^{def}	120 ± 10^{e}	40 ± 0.5^{cde}
Mweru	10	51 ± 1^{a}	15 ± 0.1^{gh}	34 ± 1^{a}	122 ± 0.4^{f}	37 ± 1^{a}
Kariba	10	58 ± 0.01^{d}	15 ± 0.04^{efg}	37 ± 0.1^{de}	115 ± 0.3^{e}	40 ± 0.1^{cd}
Kampolombo	10	60 ± 0.01^{efg}	15 ± 0.03^{fg}	39 ± 0.04^{i}	116 ± 0.1^{e}	42 ± 0.03^{j}
Chila	10	64 ± 0.01^{j}	12 ± 0.02^{a}	38 ± 0.1^{gh}	100 ± 0.4^{b}	40 ± 0.1^{cd}
Bangweulu	20	62 ± 0.5^{h}	13 ± 0.05^{b}	38 ± 0.04^{h}	106 ± 1^{cd}	40 ± 0.03^{def}
Katobamputa	20	61 ± 0.4^{g}	14 ± 0.4^{cd}	37 ± 1^{def}	108 ± 4^{cd}	40 ± 1^{cd}
Mweru	20	51 ± 0.1^{a}	15 ± 0.2^{gh}	35 ± 0.4^{b}	128 ± 2^{cd}	38 ± 0.40^{b}
Kariba	20	53 ± 0.04^{b}	16 ± 0.1^{j}	38 ± 0.1^{gh}	134 ± 0.4^{ij}	41 ± 0.1^{hij}
Kampolombo	20	60 ± 0.4^{fg}	14 ± 0.2^{c}	378 ± 0.1^{efgh}	109 ± 1^{d}	40 ± 0.1^{cd}
Chila	20	53 ± 1^{b}	16 ± 0.2^{jk}	37 ± 0.4^{de}	132 ± 3^{hi}	41 ± 0.3^{efg}
Bangweulu	30	54 ± 0.3^{c}	15 ± 1^{hi}	38 ± 0.5^{fgh}	128 ± 3^{gh}	41 ± 1^{fghi}
Katobamputa	30	64 ± 1^{j}	12 ± 0.5^{a}	36 ± 0.5^{c}	95 ± 3^{a}	38 ± 1^{b}
Mweru	30	59 ± 0.1^{e}	14 ± 0.1^{de}	38 ± 0.1^{gh}	113 ± 0.5^{e}	40 ± 0.2^{defg}
Kariba	30	63 ± 1^{ij}	13 ± 0.5^{b}	39 ± 0.4^{i}	105 ± 4^{c}	41 ± 0.5^{fghi}
Kampolombo	30	55 ± 1^{c}	16 ± 1^{i}	38 ± 0.3^{fgh}	127 ± 5^{g}	41 ± 0.5^{ghij}
Chila	30	62 ± 1^{hi}	13 ± 0.2^{b}	39 ± 0.4^{i}	105 ± 1^{cd}	41 ± 0.5^{efgh}
Wheat	0	59 ± 0.2^{ef}	14 ± 0.2^{def}	37 ± 0.3^{cd}	109 ± 2^{cd}	39 ± 0.4^{c}

Values are presented as mean ± standard deviation (n = 3). Within the same column, the values with different letters are significantly different at $p < 0.05$.

Table 7
Correlation coefficients of colour parameters of crumb and crust of bread baked from flour blends of wheat and cassava flour.

Parameter	Crumb CFSL	L*	a*	b*	WI	Chroma	Crust CFSL	L*	a*	b*	BI
CFSL	1						1				
L*	−0.20	1					0.01	1			
a*	0.08	0.51	1				−0.12	−0.87	1		
b*	−0.32	0.52	0.74	1			0.32	0.46	−0.12	1	
BI	–	–	–	–	–	–	0.32	0.46	−0.12	1.00	1
WI	−0.05	0.85	0.15	−0.01	1		–	–	–	–	–
Chroma	−0.31	0.52	0.74	1.00	0.00	1	–	–	–	–	–
BV	−0.87	0.23	0.04	0.35	0.06	0.35	−0.87	0.05	0.06	−0.35	−0.35
WB	0.04	−0.31	−0.48	−0.67	0.06	−0.67	0.04	0.37	−0.15	0.59	0.59
BD	0.85	−0.24	−0.07	−0.42	−0.03	−0.42	0.85	0.05	−0.12	0.43	0.43
SV	−0.86	0.27	0.11	0.43	0.05	0.43	−0.86	0.00	0.08	−0.42	−0.42
WL	−0.04	0.31	0.48	0.67	−0.06	0.67	−0.04	−0.37	0.15	−0.59	−0.59
Pore Area	0.19	−0.33	−0.37	−0.50	−0.09	−0.50	0.19	0.02	0.06	0.33	0.33

Hyphen (−) = not determined.

(Buckman, Oduro, Plahar, & Tortoe, 2018). Crust chroma of the bread samples varied across CFSL, without a consistent pattern. Compared to the crumb, the crust colour had higher a* and b* values.

3.8. Bread crumb pore area

The average crumb pore area of bread increased with increased CFSL (Fig. 1). The porosity of the control (Fig. 2) differed significantly from the porosities of composite bread, which decreased with increasing CFSL. Crumb porosity was negatively correlated with flour particle size. This indicated that flours with smaller particles produced bread of higher porosity. Crumb porosity correlated positively with SV and gluten content. The breads with larger volume were associated with higher gluten content, which promotes appreciable pore formation and better gas retention during proofing. Fig. 3 shows photos of typical crust and crumb structures. Espinosa-Ramírez, Garzon, Serna-Saldivar, and Rosell (2018) reported that high BV is related to better retention of carbon dioxide during proofing. Increasing CFSL led to increased BD and a decrease in crumb porosity. The microstructures of the bread crumb which had low porosity, showed a continuous dense mass (Fig. 4). The increased levels of cassava flour seem to have weakened the gluten network by disrupting the intermolecular disulphide bonds in the glutenin and gliadins molecules, thereby limiting protein-protein interaction. The fat and protein contents at higher CFSL possibly increased hydrophobicity (Muoki, Kinnear, Emmambux, & de Kock, 2015; Uthumporn, Nadiah, Izzuddin, Cheng, & Aida, 2017), thereby limiting available water for gluten development. Hydration is primarily responsible for the development of the gluten network (Chen et al., 2018). Hence any other flour component with strong WAC is likely to limit gluten development by reducing the hydration of the gluten proteins and consequently affect bread quality negatively.

4. Multivariate analysis

PCA was used to provide in-depth analysis of the differences among the cassava varieties. The scree plot (Fig. 5A) showed that the cassava flour properties had low percentage variations resulting in no significant differences among the cassava varieties ($p \geq 0.05$). This implies that the cassava flour properties did not show distinct separation among the cassava varieties. The scree plot (Fig. 5B) showed that partial replacement of wheat with cassava flour yielded high percentage variations resulting in distinct separation among cassava varieties.

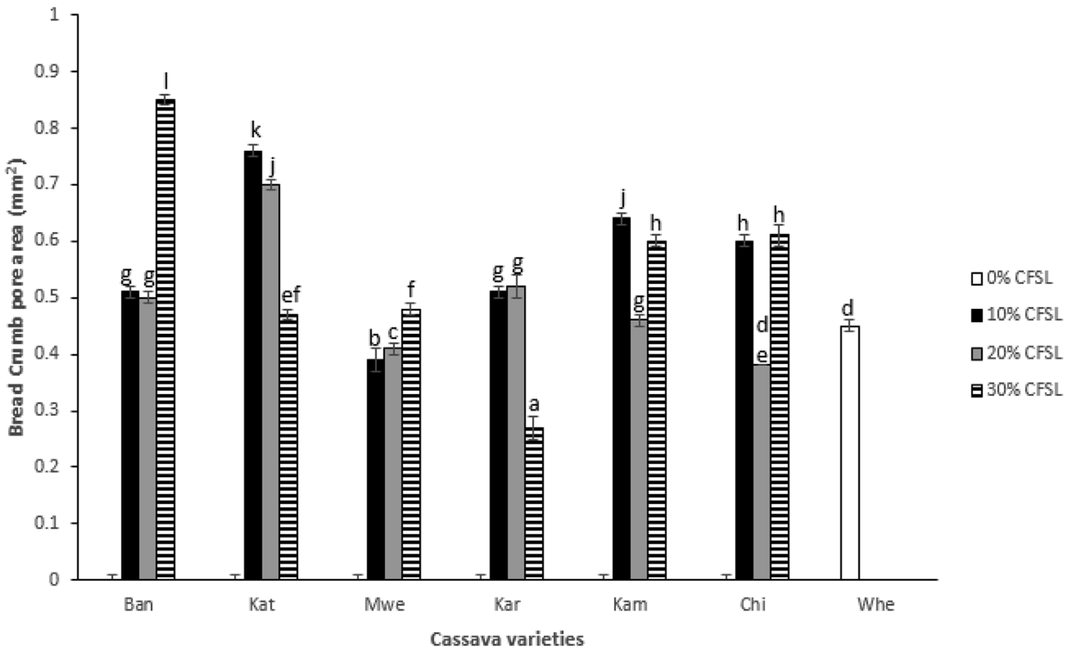

Fig. 1. Bread Crumb pore cross surface area (mm^2)/cassava flour substitution level (CFSL). Ban = Bangweulu, Kat = Katobamputa, Mwe = Mweru, Kar = Kariba, Kam = Kampolombo, Chi = Chila, Whe = Wheat (control). Values are presented as mean ± standard deviation (n = 3). Error bars represent standard deviations based on 3 replicates. Bars marked with different letters within the same CFSL indicated significant difference ($p < 0.05$) among cassava varieties.

This suggests that wheat flour properties were significant contributors to differences among cassava varieties across the blend ratios. The dough mixing properties (Fig. 5C) showed wheat clustered separately from cassava varieties. All cassava varieties at zero (0%) CFSL overlapped with the actual coordinates of 100% wheat flour resulting in over clouding (hence black shading). Based on the coordinates of the plot *Mweru* showed a distinct separation from other varieties and closely associated with *Katobamputa* and *Kariba*. These varieties (*Mweru*, *Katobamputa* and *Kariba*) were near the coordinates of wheat, and did not cluster together with other varieties. The variety *Kampolombo* was separate but strongly overlapped with *Bangweuru* and *Chila*. For the bread quality characteristics (Fig. 5D), bread baked from composite

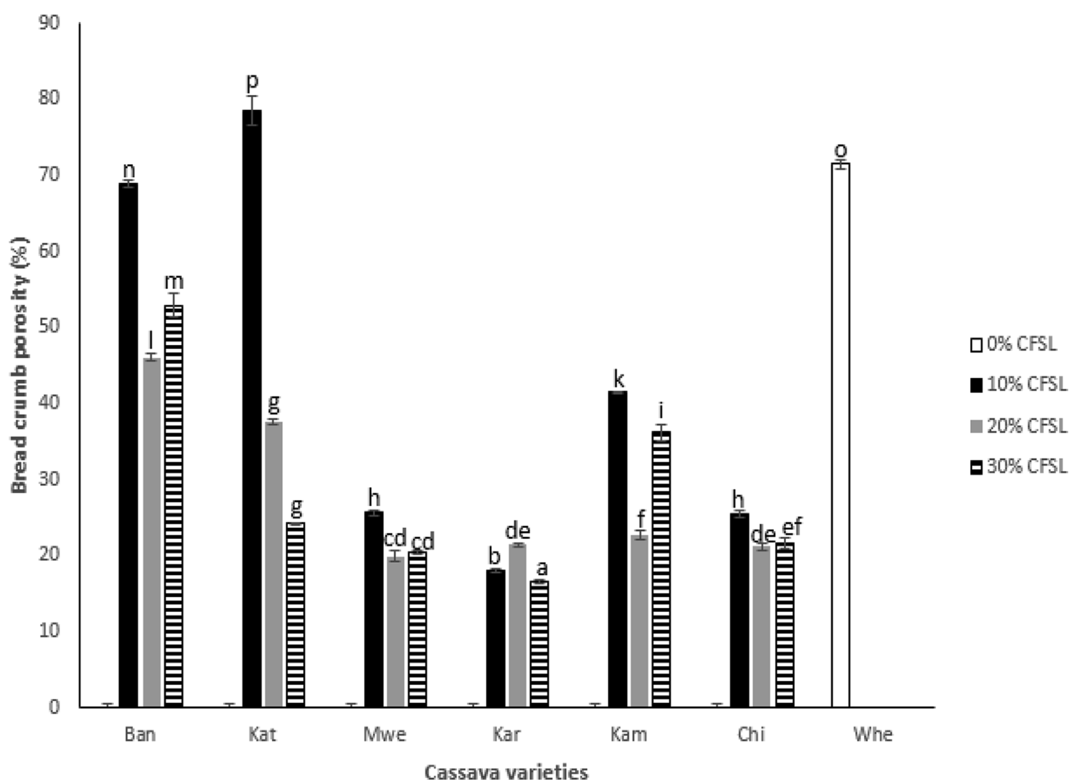

Fig. 2. Bread crumb porosity (%)/CFSL. Ban = Bangweulu, Kat = Katobamputa, Mwe = Mweru, Kar = Kariba, Kam = Kampolombo, Chi = Chila, Whe = Wheat (control). Values are presented as mean ± standard deviation (n = 3). Error bars represent standard deviations based on 3 replicates. Bars marked with different letters within the same CFSL indicated significant difference ($p < 0.05$) among cassava varieties.

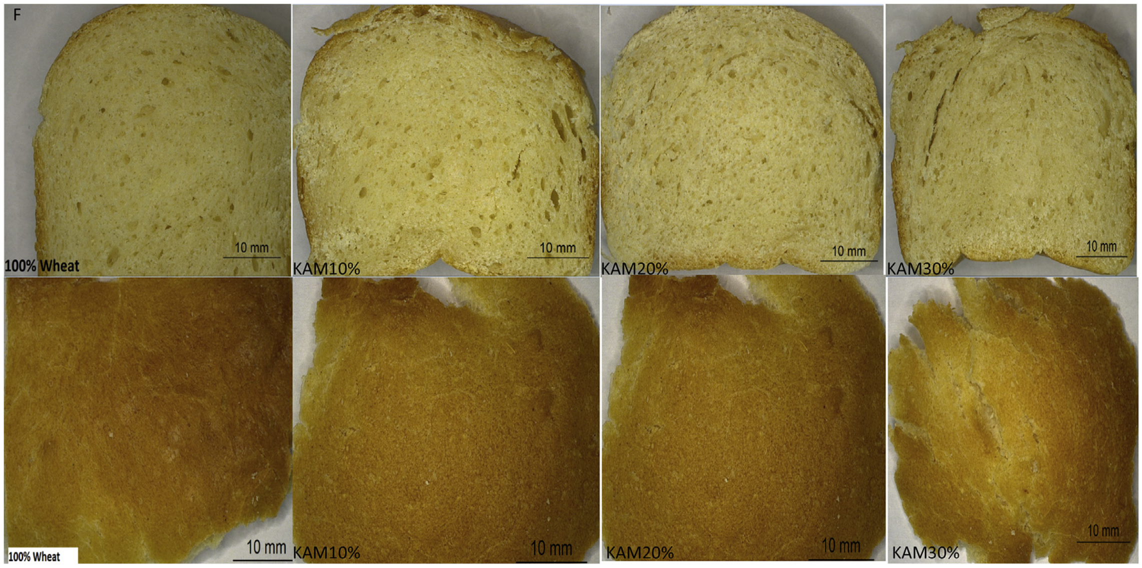

Fig. 3. Bread crumb and crust from flour blend of cassava-wheat in Kampolombo at 10, 20 and 30% CFSL. Photos at scale of 10 mm.

flour of *Mweru* could be distinguished from other varieties and was close to the coordinates of wheat bread without interference from other varieties. Similarly, *Katobamputa* and *Kariba* clustered separately on the same coordinates as those for wheat bread, however with little overlap with the other varieties. The PCA plot (Fig. 5E) described the effect of flour properties on dough mixing characteristics. According to Mtunguja et al. (2016), based on the coordinates of the plot, values close to the origin have smaller impact on the plot pattern, while those further away are significant contributors. The plot showed that the impact of flour properties on dough characteristics varied with CFSL. The control (wheat) dough was distinguished from cassava varieties. The flour proximate properties (crude protein, fibre and lipids) were closely associated (clustered together) on the PCA plot and strongly correlated with the D90-axis but in the opposite direction. This indicated that proximate contents had a similar effect on dough mixing properties (Equations (8) and (9)), and were impacted negatively by D90. Gluten content, flour particle size and water absorption capacity were distinctly separated on the plot, suggesting that these properties impacted dough mixing differently. The DDT is closely associated with WAC but in the opposite direction, indicative of the negative effect of water absorption capacity on dough development time. The mixing dough properties of cassava varieties *Mweru*, *Katobamputa*, *Kampolombo* and *Kariba* (clustered in the bottom left of plot) were strongly influenced by WAC and gluten content. However, all cassava varieties clustered strongly along the D90-axis, indicative of variations due to flour particle size. The PCA plot (Fig. 5F) showed the effect of flour properties on bread quality characteristics. Flour particle size, water absorption capacity and gluten contents showed different correlation coefficients (Equations (10) and (11)) and were distinct on the plot suggesting that they were significant sources of bread quality variation. The proximate contents (crude protein, fibre and lipid) were clustered together in the plot suggesting similar correlations and contributions to the bread quality characteristics. The coordinates of BV and SV were close together, indicative of a similar response to flour properties. The bread made from *Mweru* and *Katobamputa* clustered along the lower axis of WAC and gluten, respectively. This indicated that *Mweru* and *Katobamputa* were strongly influenced by low levels of WAC and gluten content. The bread from all cassava composite varieties showed the

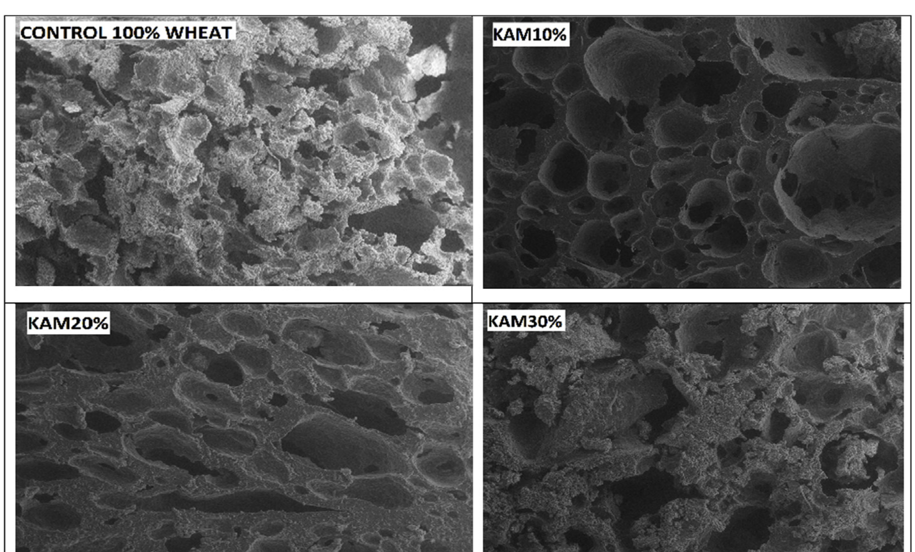

Fig. 4. Scanning electron microscopic images of bread made from cassava-wheat flour blends at 10, 20 and 30% CFSL. Variety: KAM = Kampolombo. Image properties: Mag = 100x.

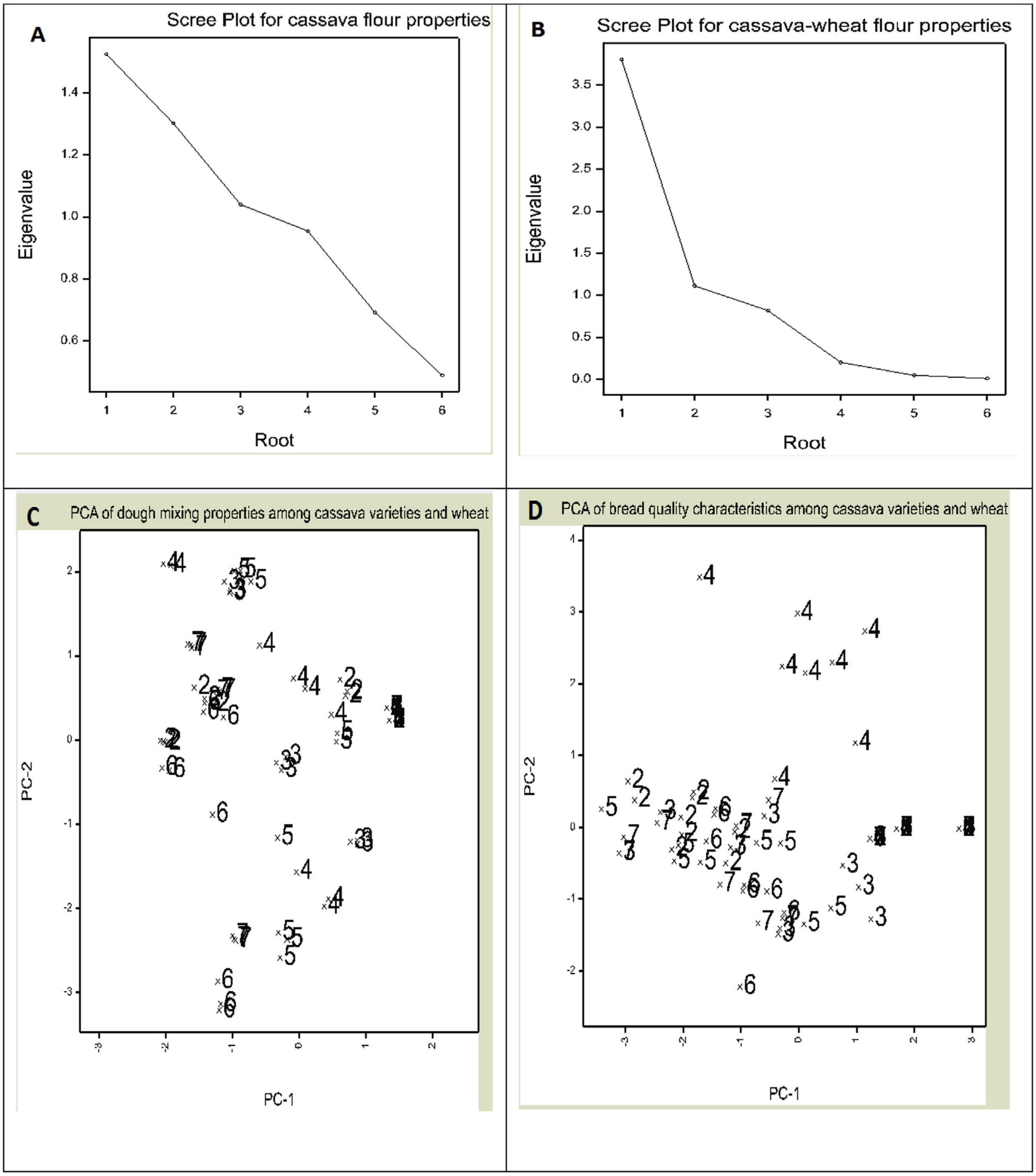

Fig. 5. Principal component analysis (PCA). (A) Scree plot for cassava flour properties, Latent roots PC 1 = 1.5, PC2 = 1.3. Percentage variation PC1 = 25, PC2 = 22. (B) Scree plot for cassava flour with wheat flour, Latent roots PC1 = 3.7, PC2 = 1.1. Percentage variation PC1 = 62, PC2 = 19. (C) PCA of dough mixing properties and (D) PCA of bread quality characteristic among cassava varieties and wheat. Varieties: 1 = Control (wheat shaded black), 2 = Bangweulu, 3 = Katobamputa, 4 = Mweru, 5 = Kariba, 6 = Kampolombo and 7 = Chila.

strong presence along and towards the D90-axis. This suggested that flour particle size distribution was the source of variations among the cassava varieties (see Fig. 6).

The principal component equations for the effect of flour properties on the dough mixing properties are:

$$PC1 = 0.09X_1 - 0.37X_2 + 0.40X_3 + 0.33X_4 + 0.40X_5 + 0.40X_6 + 0.22X_7 + 0.30X_8 - 0.20X_9 + 0.27X_{10} - 0.12X_{11} \quad (8)$$

$$PC2 = 0.10X_1 - 0.07X_2 + 0.08X_3 - 0.21X_4 + 0.09X_5 + 0.09X_6 - 0.43X_7 - 0.30X_8 + 0.38X_9 + 0.47X_{10} - 0.52X_{11} \quad (9)$$

where X_1 = Amylose, X_2 = D90, X_3 = Fibre, X_4 = Gluten, X_5 = Lipids, X_6 = Crude protein, X_7 = WAC, X_8 = Dough consistency, X_9 = DDT, X_{10} = DST, X_{11} = MTI.

The principal component equations for the effect of flour properties on the bread quality characteristics are:

$$PC1 = 0.06X_1 - 0.32X_2 + 0.34X_3 + 0.31X_4 + 0.35X_5 + 0.35X_6 + 0.23X_7 + 0.35X_8 - 0.34X_9 + 0.35X_{10} + 0.11X_{11} \quad (10)$$

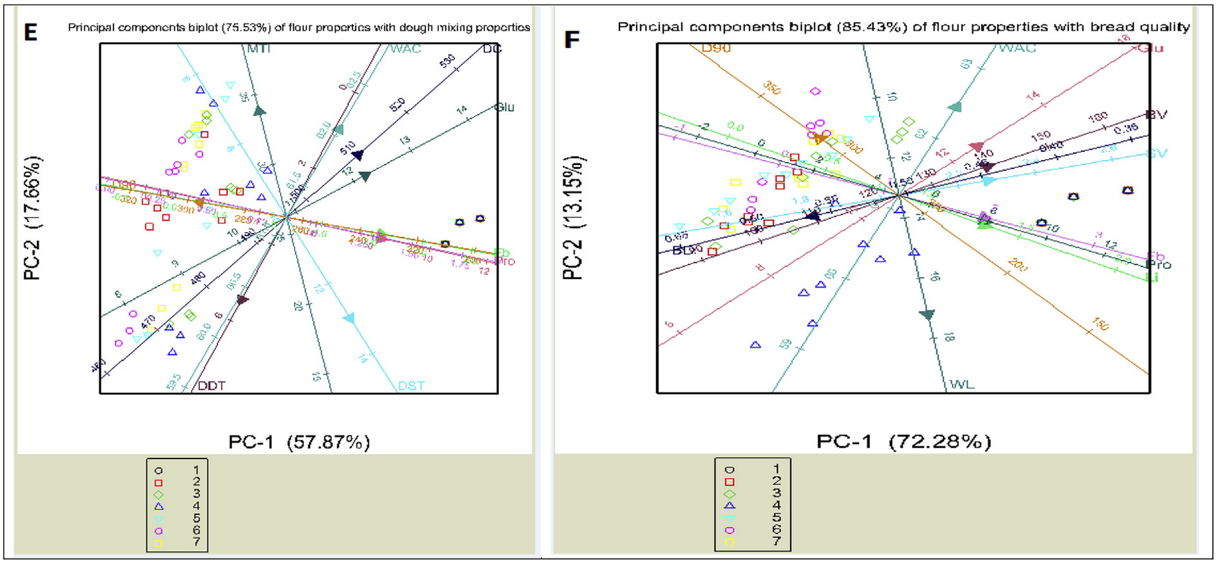

Fig. 6. (E) Principal components biplot of flour properties with dough mixing properties. Latent roots: PC1 = 5.8, PC2 = 1.8. Percentage variations: PC1 = 53, PC2 = 16. (F) Principal components of biplot of flour properties with bread quality characteristics. Latent roots: PC1 = 7.3, PC2 = 1.3. Percentage variations: PC1 = 66, PC2 = 12. Flour properties WAC = water absorption capacity, D90 = flour particle size, Pro = protein, Li = Lipid, Fb = Fibre, Glu = Gluten. Dough properties: DDT = dough development time, DC = dough consistency, DST = dough stability time, MTI = mixing tolerance index. Bread characteristics: BV = bread volume, SV = bread specific volume, BD = bread density, and WL = weight loss. Varieties: 1 = Wheat, 2 = Bangweulu, 3 = Katobamputa, 4 = Mweru, 5 = Kariba, 6 = Kampolombo and 7 = Chila.

$$PC2 = 0.19X_1 - 0.32X_2 + 0.13X_3 - 0.27X_4 + 0.17X_5 + 0.16X_6 - 0.53X_7 - 0.16X_8 + 0.12X_9 - 0.09X_{10} - 0.60X_{11} \quad (11)$$

where X_8 = BV, X_9 = BD, X_{10} = SV, X_{11} = WL.

5. Conclusion

Cassava variety and CFSL had varying effects on dough rheology and bread quality. The differences among cassava varieties were attributed to variation in cassava flour particle size, a parameter that affected the WAC and SV. The bread SV was high, specifically at 10% CFSL of *Mweru*, *Kariba,* and *Katobamputa*. The SV for the bread containing 10% *Katobamputa* cassava flour was insignificantly different from wheat bread. Breads with acceptable quality can be obtained from these varieties at about 10% CFSL. Further studies could target the effect of particle size distribution (fractionated flour) on rheology and bread quality characteristics to ascertain the effective flour size for substitution into wheat flour.

The bread SV is a response function of flour particle size and WAC. Particle size can be a differentiating genetic trait among cassava varieties. Cassava genotypes were cultivated simultaneously on a single plantation and harvested at the same time, with the same milling conditions. Thus, the variation in flour particle size was attributed to genetic differences among the cassava varieties (Vasconcelos et al., 2017). Particle size distribution influences the hydration properties of flours, which in turn, was responsible for gluten development in dough systems and ultimately bread quality. Optimising the flour particle size between the blends of wheat and cassava flours in response to WAC can be the basis for formulating composite flours with improved properties for dough performance and bread quality.

Declaration of competing interest

No competing conflicts of interest were expressed by any author.

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