International Journal of Food Science + Technology

International Journal of Food Science and Technology 2021

Original article

Technological functionality of composite flours from sorghum, tapioca and cowpea

Mia Marchini,[1] Alessandra Marti,[2] Maria Grazia Tuccio,[1] Elena Bocchi[1] & Eleonora Carini[1]*

1 Department of Food and Drug, University of Parma, Parco Area delle Scienze, 47/A, Parma (PR) 43124, Italy

2 Department of Food, Environmental, and Nutritional Sciences (DeFENS), University of Milan, Via Mangiagalli 25, Milan (MI) 20133, Italy

(Received 29 July 2021; Accepted in revised form 14 November 2021)

Summary Composite flours from accessible raw materials may interest developing countries, cutting wheat import costs, bolstering domestic agriculture and boosting nutrition. Technological functionality (WHC and OHC, pasting, swelling and thermal properties) of composite tapioca, sprouted sorghum, cowpea and wheat flours (at 50%, 33% and 25% (w/w) flour basis) was evaluated. PCA revealed that, in a 50% w/w blend, sprouted sorghum and tapioca were technologically similar to wheat, and thus of interest when gluten's viscoelastic properties are not required (e.g. flatbread). Since cowpea flour can enhance nutrients, a flour from sprouted sorghum, tapioca and cowpea is preferable nutritionally and technologically, and potentially sustainable, its raw materials being available locally. Furthermore, PCA showed that composites of sprouted sorghum, tapioca, cowpea and wheat flours at 25% w/w offer a good compromise between technological and nutritional qualities, while reducing wheat imports and cassava post-harvest losses. These results may herald technologically satisfactory, nutritional, sustainable bakery products.

Keywords Cowpea flour, germination, pasting properties, sprouted sorghum flour, starch functionality, tapioca flour, thermal properties.

Introduction

For most developing countries, fighting hunger while cutting imported foods is priority. Scientific innovations should promote country-specific food crops, encourage agri-food development, reduce imports and provide income for smallholder farmers (Abass *et al.*, 2018). Consequently, composite flours are seen as advantageous, encouraging domestic agriculture while boosting human nutrition (Hugo *et al.*, 2000).

Sorghum (*Sorghum bicolor* [L.] Moench) represents a staple for over 500 million developing-world populations, especially in Africa, and is therefore viable for composite flours (Hugo *et al.*, 2000; Xu, 2019). Sprouting of sorghum – along with post-sprouting drying, is a sustainable way to improve nutritional profiles and functionality. Sprouting increases bioactive compounds and bioavailability, as well as the flour's solubility, water and oil holding, foaming and emulsifying capacities, although impairing pasting (Afify *et al.*, 2011; Marengo *et al.*, 2015; Marchini *et al.*, 2021).

Thus, sprouted sorghum with other staples could realise sustainable, tasty and nutritional bread.

*Correspondent: E-mail: eleonora.carini@unipr.it

Cassava (*Manihot esculenta* Crantz) is a starchy tuber and calorie source for around two-fifths of all Africans (Zhu, 2015). Its drought and climate tolerance, high yield in poor soil and around-the-year availability make it dependable for food security (Zhu, 2015). Additionally, its flour (tapioca) is suitable for various food products and can partially replace wheat in baking, reducing wheat imports and post-harvest losses (Falade & Akingbala, 2010; Abass *et al.*, 2018).

Cowpea (*Vigna unguiculata L. Walpers*) is a vital legume for food security and environmental protection for millions of developing-country farmers (Da Silva *et al.*, 2018). Around 83% of cowpea production is African, over 80% from West Africa (Kebede & Bekeko, 2020). Cowpea is a cheap source of protein, amino acid lysine, carbohydrate, fibre and bioactive compounds (Jayathilake *et al.*, 2018; Oyeyinka *et al.*, 2020). Nonetheless, its use has mainly been traditional (Oyeyinka *et al.*, 2020). To encourage higher consumption, it is now used in composite flours to improve technological and nutritional profiles and protein and starch functionality (Phebean *et al.*, 2017; Ngoma, *et al.*, 2018).

This work studied the technological/functional features of potentially sustainable composite flours of

doi:10.1111/ijfs.15471

sprouted sorghum, tapioca and cowpea to hopefully develop highly nutritional bakery products, primarily for African countries.

Materials and methods

Blend preparation

Sprouted sorghum flour was obtained as described previously (Marchini *et al.*, 2021). Briefly, kernels sprouted at 25 °C for 72 h and dried at 40 °C for 12 h, milled using a laboratory-scale mill (Labormill, BONA, Monza, Italy) to produce refined flour, middlings and bran, and were reconstituted to wholemeal sorghum flour (SS) with the following particle mass distribution: ≈23% particle size >300 μm; ≈30% particle size between 300 and 200 μm; ≈27% between 200 and 100 μm and ≈20% particle size <100 μm.

Seven composite flours (SM1) blended SS with wheat flour (W) (alveographic parameters: W = 240 J 10^{-4}, P/L = 0.55, Molino Grassi S.p.A., Fraore, PR, Italy), tapioca flour (T) and cowpea flour (C) (Molino Bongiovanni S.r.l., Villanova Mondovì, CN, Italy) flours in different proportions: 50:50 w/w flour basis (f.b.; SS_T; SS_W; SS_C); 33:33:33 w/w f.b. (SS_W_T; SS_W_C; SS_C_T) and 25:25:25:25 w/w f.b. (SS_C_W_T). Flours were mixed for 15 min at medium speed using a flat beater and then manually for a further 5 min. The proximate raw flour composition was measured as described by Marchini *et al.* (2021). Protein, lipid, ash and moisture contents were measured in triplicate by AACC standard methods (46–12.01, 30–25.01, 08–01.01, 44–15.02, respectively; AACC, 2001), while carbohydrates were determined by difference and the results were expressed as % (g per 100 g) on dry basis (d.b.). The flour blends' composition was calculated based on the raw flour composition and percentages of addition (Table S2).

Functional, thermal and pasting properties

The flours' water holding capacity (WHC), oil holding capacity (OHC), swelling power (S_P, measured at 60, 70, 80 and 90 °C), thermal and pasting properties were determined as described previously (Marchini *et al.*, 2020). Concerning thermal properties, the enthalpy (ΔH, J g^{-1}), onset (T_{on}, °C), peak (T_p) and offset (T_{off}, °C) temperatures of the observed transitions were extrapolated by heat flow curves using Universal Analysis Software, Version 4.5A (TA Instruments, New Castle, DE, USA). The parameters calculated from the pasting curves were the following: pasting temperature (°C), peak viscosity (BU), peak temperature (temperature at which peak viscosity occurs, °C), final viscosity (BU), breakdown (BD, BU) and setback (SB, BU).

Proximate composition and technological behaviour of SS sample were provided previously (Marchini *et al.*, 2021).

Statistical analysis

All analyses were performed in triplicate, and data expressed as mean ± standard deviation (SD). ANOVA, followed by Duncan's *post hoc* test at 0.05 significance level, was performed to assess significant differences between samples.

Data were processed with SIMCA® Software using multivariate statistics. Unsupervised PCA was performed with mean centring and unit variance (UV) scaling as data pre-treatment. The dataset consisted of values obtained from the flours' proximate composition (carbohydrates, protein, fat, moisture content and ash) and functional (WHC, OHC and S_p measured at different temperature - S_p_60, S_p_70, S_p_80, S_p_90), thermal (T_{on}_gel, T_p_gel, T_{off}_gel, ΔH_gel, T_{on}_ ALC, T_p_ ALC, T_{off}_ ALC, ΔH_ ALC) and pasting (pasting temperature, peak viscosity, peak temperature, final viscosity, BD and SB) properties.

Results

Proximate composition

Among the wheat-free composite flours, SS_T had the most carbohydrates and the least protein, fat and ash, reflecting tapioca's chemical composition (Table S2). In contrast, SS_C flour had the fewest carbohydrates and the most protein, fat and ash, reflecting C's proximate composition. As expected, the SS_C_T sample showed an intermediate composition similar to W.

The addition of W acted dissimilarly on the blends' proximate composition. Mixing W with SS at 50% w/w produced flour with more protein and ash but fewer carbohydrates and fats than SS alone. Similarly, the SS_T_W blend presented more protein, fat and ash but fewer carbohydrates than SS_T, with the opposite when comparing SS_C_W and SS_C. Differences between SS_C_T_W and SS_C_T were few.

Functional properties

In wheat-free blends, SS_C showed the highest WHC, understandably, since composed of flours with the highest WHC, followed by SS_C_T and SS_T (Table 1). In all C blends, the addition of W, with a decrease in C and SS percentages, reduced WHC. A worse WHC when W was combined with SS was also observed, due to the low WHC of the former.

As for OHC, in comparing wheat-free composite flours, SS_C_T showed the highest OHC, followed by SS_C and SS_T, understandably given cowpea flour's

Table 1 Water holding capacity (WHC), oil holding capacity (OHC) and swelling power (S_p) of flours and their blends

	WHC (g g^{-1}) 25 °C	OHC (g g^{-1}) 25 °C	S_p (g g^{-1}) 60 °C	70 °C	80 °C	90 °C
SS[†]	1.68 ± 0.05d	1.05 ± 0.00de	5.39 ± 0.24bC	5.35 ± 0.23deC	6.86 ± 0.24dB	7.63 ± 0.13deA
T	0.84 ± 0.02g	0.86 ± 0.01f	5.35 ± 0.14bD	10.11 ± 0.59aB	17.58 ± 0.15aA	9.39 ± 0.33bcC
W	0.98 ± 0.1fg	0.82 ± 0.03f	6.27 ± 0.18aC	7.67 ± 0.24bB	9.98 ± 0.60bA	9.93 ± 0.10bcA
C	2.55 ± 0.13a	1.16 ± 0.09c	4.85 ± 0.15cC	5.05 ± 0.52efC	6.75 ± 0.50dB	9.17 ± 0.28bcA
SS_T	1.02 ± 0.03f	0.73 ± 0.04g	5.18 ± 0.16bB	4.48 ± 0.07fB	5.08 ± 0.30eB	6.93 ± 0.67eA
SS_W	1.29 ± 0.04e	1.11 ± 0.02 cd	4.44 ± 0.00dC	4.61 ± 0.20fC	6.15 ± 0.88deB	9.07 ± 0.63cA
SS_C	2.30 ± 0.16b	1.03 ± 0.03e	4.84 ± 0.12cD	5.37 ± 0.10deC	8.50 ± 0.29cA	8.03 ± 0.23dB
SS_T_W	1.00 ± 0.01f	0.84 ± 0.04f	2.86 ± 0.07fD	4.46 ± 0.23fC	5.38 ± 0.08eB	9.24 ± 0.50bcA
SS_C_W	1.63 ± 0.09d	1.32 ± 0.02a	4.84 ± 0.18cC	4.78 ± 0.15efC	8.63 ± 0.37bcB	10.52 ± 0.87bA
SS_C_T	2.05 ± 0.01c	1.24 ± 0.06b	4.09 ± 0.20eB	5.74 ± 0.16cdB	8.66 ± 2.13bcA	9.13 ± 0.26cA
SS_C_T_W	1.61 ± 0.13d	0.83 ± 0.05f	4.10 ± 0.28eC	5.95 ± 0.53cB	5.22 ± 0.38eB	11.38 ± 0.74aA

Values are expressed as mean ± SD (n = 3). For S_p, values followed by different lowercase letters in each column are significantly different ($P \leq 0.05$). Values followed by different capital letter in each row are significantly different ($P \leq 0.05$).
C, cowpea flour; SS, sprouted sorghum flour; SS_C, sprouted sorghum and cowpea flour blend; SS_C_T, sprouted sorghum, cowpea and tapioca flour blend; SS_C_W, sprouted sorghum, cowpea and wheat flour blend; SS_C_W_T, sprouted sorghum, cowpea, wheat and tapioca flour blend; SS_T, sprouted sorghum and tapioca flour blend; SS_W, sprouted sorghum and wheat flour blend; SS_W_T, sprouted sorghum, wheat and tapioca flour blend; T, tapioca; W, wheat flour.
[†]SS data on functional properties were published in a previous work (Marchini *et al.*, 2021).

superior OHC compared with wheat and tapioca (Table 1), confirming previous findings (Melini *et al.*, 2017). Despite the lower OHC of W compared with SS and C, its addition to 50:50 w/w blends and SS alone increased OHC, unlike the addition to SS_C_T.

S_p of flours and their blends increased with rising temperature, unsurprisingly (Table 1). Almost all blends showed higher S_p with a rise in temperature than SS. In comparing wheat-free composite flours, SS_C_T showed the highest increase in S_p with temperature, followed by SS_C and SS_T. When considering S_p at each temperature for wheat-free blends, SS_T was highest at 60 °C, while SS_C_T was highest at 70, 80 and 90 °C. Intermediate behaviour was seen in SS_C. Generally, flours containing W did not show better S_p values than wheat-free blends in the 60–80 °C range. Only at 90 °C, the S_p of blends increases by adding W.

Thermal properties

Except for T, with a unique thermal transition at 56-102 °C related to starch gelatinisation, two endothermic peaks were evident in the other samples: the first at ~52-96 °C and the second at ~90-109 °C (Table 2). Among the three wheat-free blends, SS_C_T recorded the lowest T_{on}, followed by SS_T and SS_C. Gelatinisation for W began at a lower temperature than in all other samples. W addition to SS_C and SS_T blends favoured gelatinisation, decreasing T_{on}, while its presence in the SS_C_T_W blend induced no substantial difference in gelatinisation onset.

As for gelatinisation enthalpies, SS_T showed the highest ΔH among wheat-free blends due to the T and its high percentage (50% w/w), followed by SS_C_T and SS_C. The addition of W to SS_C and SS_C_T and the concomitant reduction in percentages of other flours did not change ΔH. Only SS_T_W was a strong increase in ΔH seen compared with SS_T, while the opposite was true in the SS sample, since its ΔH decreased significantly after W addition.

Analysing wheat-free blend parameters, SS_C and SS_C_T flours showed higher T_{on} but lower ΔH than those of SS_T, explicable by the C delaying transition start and reducing enthalpy.

Generally, the addition of W to the blends produced slight changes in thermal transition parameters. Specifically, the second peak's characteristic temperatures and enthalpies did not vary uniformly.

Pasting properties

The pasting properties of SS, T, C and W samples are shown in Fig. S1 and Table 3. Pasting temperature identifies the temperature at which an initial viscosity increase occurs: the lower the pasting temperature, the lower the energy to trigger the gelatinisation and advantageous in baking (Zi *et al.*, 2019). Among the wheat-free blends, SS_C showed the highest T, compatible with the higher T_{on} in DSC (Table 2). In contrast, SS_T showed the lowest pasting temperature, similar to W. The addition of W caused heterogeneous effects on T.

Peak viscosity represents the highest viscosity value reached during the heating cycle. Unsurprisingly, the T

Table 2 Thermal properties of flours and their blends

	First endothermic peak				Second endothermic peak			
	T_{on} (°C)	T_p (°C)	T_{off} (°C)	ΔH (J g^{-1})	T_{on} (°C)	T_p (°C)	T_{off} (°C)	ΔH (J g^{-1})
SS[†]	68.2 ± 0.2c	77.0 ± 0.2ab	86.1 ± 1.0cde	1.63 ± 0.31d	93.7 ± 1.3bc	98.7 ± 4.7bc	107.5 ± 0.9ab	0.33 ± 0.01a
T	56.5 ± 0.3d	71.6 ± 0.3d	102.4 ± 1.4a	9.30 ± 0.04a	n.a.	n.a.	n.a.	n.a.
W	53.7 ± 2.4e	67.2 ± 0.2e	74.5 ± 1.1f	3.34 ± 0.28c	90.7 ± 2.8de	97.9 ± 0.2bc	104.7 ± 0.8 cd	0.34 ± 0.04a
C	72.8 ± 1.0ab	n.a.	95.6 ± 0.3b	1.53 ± 0.14d	96.9 ± 0.1a	102.5 ± 3.3a	105.7 ± 0.4c	0.06 ± 0.00e
SS_T	66.5 ± 0.5c	75.3 ± 0.4bc	85.1 ± 0.1e	3.12 ± 0.15c	92.6 ± 0.1 cd	98.3 ± 0.4bc	104.0 ± 0.1d	0.22 ± 0.03bc
SS_W	74.3 ± 0.3a	79.1 ± 0.2a	85.5 ± 1.7de	0.42 ± 0.07e	91.0 ± 1.8de	97.6 ± 0.2c	104.8 ± 1.5 cd	0.26 ± 0.05b
SS_C	71.7 ± 0.4b	78.3 ± 0.3a	96.3 ± 0.8b	1.69 ± 0.16d	96.9 ± 0.7a	100.9 ± 0.0abc	105.9 ± 0.7c	0.14 ± 0.00d
SS_T_W	52.0 ± 3.1e	73.0 ± 4.6 cd	85.9 ± 0.4cde	5.72 ± 0.53b	90.2 ± 0.8e	98.0 ± 0.2bc	106.0 ± 0.9c	0.24 ± 0.08b
SS_C_W	57.6 ± 0.5d	n.a.	88.1 ± 0.7c	1.47 ± 0.06d	96.4 ± 0.6a	100.9 ± 0.2abc	106.2 ± 0.5bc	0.12 ± 0.01de
SS_C_T	58.1 ± 0.2d	73.6 ± 0.3 cd	87.6 ± 0.9 cd	2.12 ± 0.09d	96.6 ± 0.2a	101.1 ± 0.1ab	106.2 ± 0.6bc	0.11 ± 0.01de
SS_C_T_W	57.3 ± 0.1d	72.6 ± 0.1 cd	84.6 ± 0.1e	2.11 ± 0.11d	95.4 ± 0.1ab	101.2 ± 0.3ab	108.9 ± 0.7a	0.17 ± 0.01 cd

Values are expressed as mean ± SD (n = 3). Values followed by different lowercase letters in each column are significantly different ($P \leq 0.05$).
C, cowpea flour; nd; n.a., not available data; SS, sprouted sorghum flour; SS_C, sprouted sorghum and cowpea flour blend; SS_C_T, sprouted sorghum, cowpea and tapioca flour blend; SS_C_W, *s*prouted sorghum, cowpea and wheat flour blend; SS_C_W_T, sprouted sorghum, cowpea, wheat and tapioca flour blend; SS_T, sprouted sorghum and tapioca flour blend; SS_W, sprouted sorghum and wheat flour blend; SS_W_T, sprouted sorghum, wheat and tapioca flour blend; T, tapioca; T_{off}, offset temperature; T_{on}, onset temperature; T_p, peak temperature; W, wheat flour; ΔH, peak enthalpy.
[†]SS data on thermal properties were published in a previous work (Marchini *et al.*, 2021).

Table 3 Pasting properties of flours and their blends

	Pasting temperature (°C)	Peak viscosity (BU)	Peak temperature (°C)	Final viscosity (BU)	Breakdown (BU)	Setback (BU)
SS[†]	76.5 ± 0.1c	92.5 ± 7.8f	89.9 ± 2.7d	105.0 ± 15.6g	47.5 ± 9.2f	59.0 ± 24.0h
T	64.2 ± 0.2f	1219.5 ± 16.3a	71.8 ± 0.6f	2186.0 ± 15.6a	719.0 ± 12.7a	1849.5 ± 33.2a
W	59.9 ± 1.8g	341.5 ± 17.5c	90.4 ± 0.1d	610.5 ± 32.5b	97.5 ± 1.5e	368.5 ± 9.5b
C	81.3 ± 0.1b	153.5 ± 0.5f	95.0 ± 0.0ab	241.0 ± 1.0f	10.5 ± 0.5h	98.0 ± 1.0g
SS_T	66.5 ± 0.6e	347.0 ± 23.6c	87.5 ± 0.9e	511.3 ± 48.3c	192.0 ± 17.7c	369.0 ± 34.8b
SS_W	85.5 ± 0.6a	177.0 ± 2.0e	95.2 ± 0.2ab	411.3 ± 4.0d	31.0 ± 1.7g	264.7 ± 8.5d
SS_C	85.1 ± 0.7a	166.7 ± 1.2ef	95.7 ± 0.1a	211.0 ± 4.4f	47.0 ± 1.7f	91.3 ± 3.1g
SS_T_W	66.4 ± 0.4e	277.5 ± 3.5d	89.5 ± 0.3d	397.5 ± 26.2d	102.0 ± 14.1e	209.0 ± 24.0e
SS_C_W	81.7 ± 0.3b	182.0 ± 1.0e	94.1 ± 0.6bc	301.7 ± 2.1e	58.3 ± 1.2f	181.3 ± 3.2f
SS_C_T	70.9 ± 2.3d	399.5 ± 9.5b	94.2 ± 0.8bc	522.0 ± 40.0c	207.0 ± 7.0b	329.5 ± 1.5c
SS_C_T_W	71.3 ± 0.5d	355.7 ± 0.6c	93.4 ± 0.6c	527.7 ± 3.5c	160.0 ± 1.7d	332.0 ± 4.4c

Values are expressed as mean ± SD (n = 3). Values followed by different lowercase letters in each column are significantly different ($P \leq 0.05$).
Pasting temperature, temperature at which an initial increase in viscosity occurs; peak viscosity, maximum viscosity achieved during the heating cycle; peak temperature, temperature at the maximum viscosity; final viscosity, viscosity at the end of the test; breakdown, viscosity difference between peak and after holding at 95 °C; setback, difference between the final viscosity at 30 °C and the viscosity after the holding period at 95 °C.
C, cowpea flour; SS, sprouted sorghum flour; SS_C, sprouted sorghum and cowpea flour blend; SS_C_T, sprouted sorghum, cowpea and tapioca flour blend; SS_C_W, *s*prouted sorghum, cowpea and wheat flour blend; SS_C_W_T, sprouted sorghum, cowpea, wheat and tapioca flour blend; SS_T, sprouted sorghum and tapioca flour blend; SS_W, sprouted sorghum and wheat flour blend; SS_W_T, sprouted sorghum, wheat and tapioca flour blend; T, tapioca; W, wheat flour.
[†]SS data on pasting properties were published in a previous work (Marchini *et al.*, 2021).

sample showed the highest value (Table 3 and Fig. S1). Thus, considering only non-W flours, the two blends including T showed the highest viscosities, similar to W. For both samples, the addition of W to the blend with a decrease in the other ingredients determined a decrease in maximum viscosity, thus worsening the technological performance.

Peak temperature measures the temperature recorded at maximum viscosity. In SS_T, the high amount of T, characterised by the lowest peak temperature, resulted in maximum viscosity at a lower temperature than the other samples. The addition of W to the blend increased this parameter, comparable to W flour.

For all other blends, the presence of C delayed peak viscosity. Here too, the addition of W to the blends caused slight variations in the parameter.

Furthermore, the BD value describes the heat stability of the starch paste. In W-free blends, the highest BDs were recorded when T was included, while SS_C was the most heat stable. The addition of W increased heat stability of SS and T-based composite flours.

As for W-free samples, SS_C_T and SS_T showed a final viscosity around 500 BU, lower than wheat but higher than all other wheat-free blends. The SB value indicates the retrogradation tendency of amylose in starch paste. Among samples without W, SS_C recorded the lowest SB value, unsurprisingly, given the high presence of cowpea (being SB values of SS and C the lowest). Low SB values indicated low starch retrogradation and syneresis rates, which would help maintain softness during bread storage (Marti *et al.*, 2017). Furthermore, the data showed that the use of W changed SB in different way.

Principal component analysis (PCA)

The first two components (PCs) explained 66% of total variance (52% and 14% for PC1 and PC2, respectively; Fig. 1). PC1 was explained by T_{on}_ALC, T_p_ALC, peak temperature, ash, protein and carbohydrates, whereas PC2 was explained by T_{off}_gel, WHC, OHC, Sp_80, peak viscosity, breakdown, setback and final viscosity. The plot of the first two principal components (t1/t2; Fig. 1a) highlighting PC1 clearly discriminated the T sample (left quadrant) from all other flours in the centre. All composite flours were distributed along PC2 based on their greater or lesser similarity to W and C flours which lay in the negative and positive quadrants of PC2 at the extremes of the grouping, demonstrating their opposite properties. Instead, SS lay in the negative PC2 quadrant, along with the composite flours and showing intermediate behaviour compared with the extremes, C and W, albeit more akin to the latter. In addition to SS, in the negative quadrant identified by PC2, from sample W towards the centre, we see SS_T, SSD_T_W, SS_W and SSD_C_T_W, showing intermediate behaviour between W and C. Meanwhile, in the upper quadrant, from the end of group (C) towards the centre, we find the C-based blends: SS_C, SSD_C_T and SS_C_W, with technological behaviour increasingly different from C, and intermediate between C and W.

Discussion

This study assessed the technological properties of composite flours to develop bakery products primarily for African countries (e.g. flatbread). Sorghum, cowpea and tapioca were chosen since these are regional staples. Sprouting is a traditional method in most sorghum-producing countries to enhance the final product, hence the sprouted sorghum flour in this study. Both wheat-free and wheat-based blends were assessed.

Considering the chemical composition of the blends (Table S2), specific nutritional goals were attained by combining the various ingredients. SS_T being best for carbohydrates (Abass *et al.*, 2018), SS_C or SS_C_W for protein, (Boye *et al.*, 2010), fat and ash.

After nutritional value, functionality was assessed. WHC, the water/gram of protein, is important in breadmaking, since high WHC means better bread. The composites' WHC mirrored that of the raw materials (Table 1), C having the highest value. Consequently, SS_C showed the highest value, underlining the importance of water for successful breadmaking. A blend with WHC similar to W was SS_T (perhaps also SS_T_W).

In baking, OHC is important for flavour, palatability and shelf-life (Adebowale & Lawal, 2004). Overall, the best OHC was in SS_C_W (Table 1); however, SS_C_T flour is also recommended, its OHC exceptional despite being wheat-free. SS_T_W and SS_C_T_W blends had OHC similar to wheat. Generally, the proteins in C showed excellent WHC and OHC: an ideal breadmaking raw material.

S_p, pasting and thermal properties were also investigated to study flour behaviour during processing.

S_p measures the water absorbed and entrapped during heating and stirring (Li *et al.*, 2014) and is influenced by several factors. At low temperature, thermal energy swells starch without disrupting granules; a temperature rise induces crystalline structure breakdown with increased S_p (Li *et al.*, 2014). Overall, SS_C_T showed the best swelling capacity, and its S_p with temperature increase resembled W (Table 1). A greater swelling capacity was expected for SS_T given the greater amount of tapioca. Processing affects this parameter; the low S_p of SS was previously related to the effects of sprouting on starch structure and the accumulation of dextrins, oligosaccharides and fermentable sugars, stopping the formation of a compact gel (Marchini *et al.*, 2021). In SS_T, the starch–protein–fibre interactions on S_p are interesting and deserve further investigation.

Thermal properties mostly depend on starch's characteristics, granule size and relative crystallinity (Ai & Jane, 2015). For all samples (except T), two endothermic peaks were evident: The first (~52–96 °C) represented starch gelatinisation, and the second (~90–109 °C) represented the dissociation and/or melting of crystalline amylose–lipid complexes (ALCs), typical of cereal starches (Ai & Jane, 2015). As for gelatinisation transition, its onset temperatures indicated a stable crystalline starch structure with heating (Dhital *et al.*,

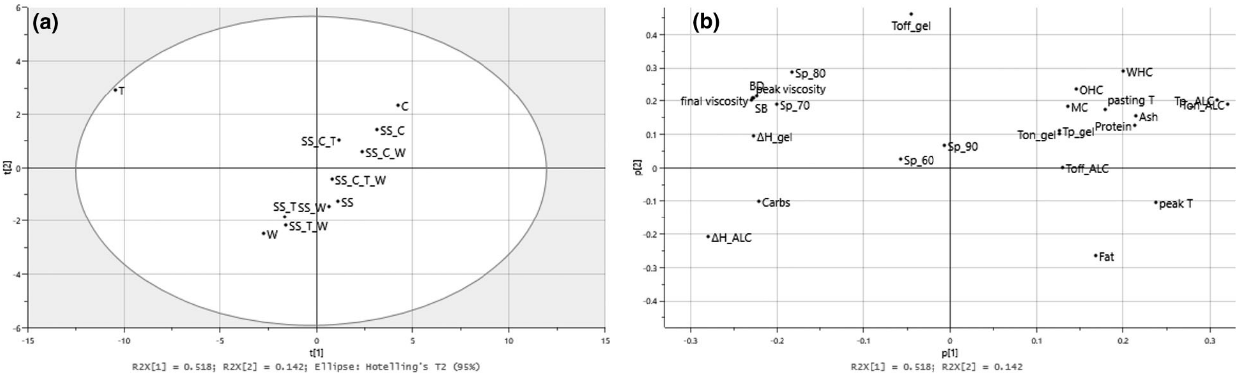

Figure 1 Plots of the PCA model: (a) score plot (t1/t2) and (b) loading plot (p1/p2) of the first two principal components

2011). Higher transition temperatures mean higher crystallinity, structural stability and granules resistant to gelatinisation.

The higher gelatinisation temperature in SS_C may be due to the greater amount of C (50% w/w), with higher energy needed to initiate gelatinisation.

Overall, where gelatinisation temperatures similar to those of W are required, the SS_T_W blend is suggested. Where other flours are in the blend, higher gelatinisation temperatures are required.

Pearson correlation analysis highlighted a relationship between fat content and ΔH of ALC melting peaks: Higher fat content matched higher ΔH of the ALC melting transition ($r = 0.52$; $P < 0.05$). By decreasing starch digestibility, ALCs are considered dietary fibre (Panyoo & Emmambux, 2017). Accordingly, blends with ALC melting at low temperature and low ΔH values are recommended for undernourished who require a readily available energy source. With all blends showing significantly lower enthalpies than wheat, SS_T first, and then SS_W and SS_T_W, should be preferred.

Finally, the effect of temperature on starch properties was examined. Generally, composite flours showed better pasting profiles than individual flours (Zi *et al.*, 2019). SS and C showed poorer pasting properties than W. The lower pasting properties of C compared with W are due to its botanical origin (Ai & Jane, 2015). For its excellent gelatinisation, the addition of T is recommended to improve composite flours' pasting properties.

Finally, PCA was performed to understand the effect of individual flours on technological profile and how they differ from one another. Overall, PCA data were poor (66% of the total variance explained by PC1 and PC2), the different flours affecting the technological parameters. However, SS_T seems the only wheat-free composite with technological behaviour like wheat. Hence, it can be considered likely comparable to W when used for bakery products not requiring gluten's viscoelasticity. However, C is recommended to provide protein and microelements. If the SS_C_T blend in the positive quadrant suggests properties closer to C, SS_C_T_W is dead centre, showing intermediate behaviour, a valid compromise between technological and nutritional qualities.

Conclusions

This work evaluated the technological properties of composite flours for potentially sustainable, nutritionally enhanced bakery products (e.g. flatbread), primarily for African countries.

Sprouted sorghum flour is a widespread raw material in Africa and sprouting is a sustainable way to improve nutritional profile, although it reduces the starch technological functionality In contrast, tapioca exhibits excellent starch functionality, hence indicated to improve the technological properties of sprouted sorghum flour. PCA revealed that, in a 50% w/w blend (SS_T), this composite exhibited technological properties analogous to wheat. However, cowpea flour in breadmaking is recommended to provide protein and micronutrients (e.g. amino acid lysine) and thus improve the nutritional profile of everyday foods. If a sprouted sorghum, cowpea and tapioca blend (SS_C_T) flour may represent an ideal composite for nutrition and sustainability, PCA confirmed a sprouted sorghum, tapioca, cowpea and wheat flour composite at 25% w/w (SS_C_T_W) as a sound compromise between technological and nutritional qualities, reducing wheat flour imports and post-harvest losses of cassava, which starts deteriorating soon after gathering, becoming worthless for consumption or industrial applications unless processed to lengthen shelf-life. Further studies could investigate SS_C_T_W in breadmaking by evaluating technological, nutritional and sensory properties of finished products, as well as modifications of the formulation for satisfactory potentially sustainable flatbread.

Conflict of interest

The authors declared that there is no conflict of interest.

Author contributions

Mia Marchini: Conceptualization (equal); Data curation (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Writing – original draft (equal). **Alessandra Marti:** Conceptualization (equal); Formal analysis (equal); Investigation (equal); Resources (equal); Writing – review & editing (equal). **Maria Grazia Tuccio:** Data curation (equal); Formal analysis (equal); Investigation (equal). **Elena Bocchi:** Investigation (equal). **Eleonora Carini:** Conceptualization (equal); Funding acquisition (equal); Methodology (equal); Project administration (equal); Resources (equal); Supervision (equal); Writing – review & editing (equal).

Ethical approval

Ethical approval was not required for this research.

Funding information

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Peer review

The peer review history for this article is available at https://publons.com/publon/10.1111/ijfs.15471.

Data availability statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on request.

References

This review highlights areas that require further research in order to achieve sustainable development in the processing of raw cassava root into cassava flour for bread production.
This work studied the functional characteristics of flours derived from jack bean, mucuna bean and bambarra groundnut.
In this work it was investigated the effects of temperature on swelling power and established relationships between swelling power, thermal and rheological properties of starches.
This review summarizes the present knowledge on the isolation, composition, physicochemical properties and modification methods of cowpea starch.
AACC. (2001). *Methods of Analysis*, 11th edn. St. Paul, MN: Cereals & Grains Association.
Abass, A.B., Awoyale, W., Alenkhe, B. *et al*. (2018). Can food technology innovation change the status of a food security crop? A review of cassava transformation into "bread" in Africa. *Food Reviews International*, **34**, 87–102.
Adebowale, K.O. & Lawal, O.S. (2004). Comparative study of the functional properties of Bambara groundnut (Voandzeia subterranean), jack bean (*Canavalia ensiformis*) and mucuna bean (*Mucuna pruriens*) flours. *Food Research International*, **37**, 355–365.
Afify, A.E.M.M., El-Beltagi, H.S., Abd El-Salam, S.M. & Omran, A.A. (2011). Bioavailability of iron, zinc, phytate and phytase activity during soaking and germination of white sorghum varieties. *PLoS One*, **6**, e25512.
Ai, Y. & Jane, J.L. (2015). Gelatinization and rheological properties of starch. *Starch-Stärke*, **67**, 213–224.
Boye, J., Zare, F. & Pletch, A. (2010). Pulse proteins: Processing, characterization, functional properties and applications in food and feed. *Food Research International*, **43**, 414–431.
Da Silva, A.C., da Costa Santos, D., Junior, D.L.T., da Silva, P.B., dos Santos, R.C. & Siviero, A. (2018). Cowpea: A strategic legume species for food security and health. In: *Legume seed Nutraceutical Research* (edited by J.C. Jimenez-Lopez & A. Clemente). Pp. 47–50. London, UK: IntechOpen. https://doi.org/10.5772/intechopen.79006
Dhital, S., Shrestha, A.K., Hasjim, J. & Gidley, M.J. (2011). Physicochemical and structural properties of maize and potato starches as a function of granule size. *Journal of Agricultural and Food Chemistry*, **59**, 10151–10161.
Falade, K.O. & Akingbala, J.O. (2010). Utilization of cassava for food. *Food Reviews International*, **27**, 51–83.
Hugo, L.F., Rooney, L.W. & Taylor, J.R.N. (2000). Malted sorghum as a functional ingredient in composite bread. *Cereal Chemistry*, **77**, 428–432.
Jayathilake, C., Visvanathan, R., Deen, A. *et al*. (2018). Cowpea: An overview on its nutritional facts and health benefits. *Journal of the Science of Food and Agriculture*, **98**, 4793–4806.
Kebede, E. & Bekeko, Z. (2020). Expounding the production and importance of cowpea (*Vigna unguiculata* (L.) Walp.) in Ethiopia. *Cogent Food & Agriculture*, **6**, 1769805.
Li, W., Xiao, X., Guo, S. *et al*. (2014). Proximate composition of triangular pea, white pea, spotted colored pea, and small white kidney bean and their starch properties. *Food and Bioprocess Technology*, **7**, 1078–1087.
Marchini, M., Carini, E., Cataldi, N. *et al*. (2020). The use of red lentil flour in bakery products: How do particle size and substitution level affect rheological properties of wheat bread dough? *LWT – Food Science and Technology*, **136**, 110299.
Marchini, M., Marti, A., Folli, C. *et al*. (2021). Sprouting of sorghum (*Sorghum bicolor* [L.] Moench): Effect of drying treatment on protein and starch features. *Foods*, **10**, 407.
Marengo, M., Bonomi, F., Marti, A., Pagani, M.A., Abd Elmoneim, O.E. & Iametti, S. (2015). Molecular features of fermented and sprouted sorghum flours relate to their suitability as components of enriched gluten-free pasta. *LWT-Food Science and Technology*, **63**, 511–518.
Marti, A., Cardone, G., Nicolodi, A., Quaglia, L. & Pagani, M.A. (2017). Sprouted wheat as an alternative to conventional flour improvers in bread-making. *LWT - Food Science and Technology*, **80**, 230–236.
Melini, F., Melini, V., Luziatelli, F. & Ruzzi, M. (2017). Current and forward-looking approaches to technological and nutritional improvements of gluten-free bread with legume flours: a critical review. *Comprehensive Reviews in Food Science and Food Safety*, **16**, 1101–1122.
Ngoma, T.N., Chimimba, U.K., Mwangwela, A.M. *et al*. (2018). Effect of cowpea flour processing on the chemical properties and acceptability of a novel cowpea blended maize porridge. *PLoS One*, **13**, e0200418.
Oyeyinka, S.A., Kayitesi, E., Adebo, O.A. *et al*. (2020). A review on the physicochemical properties and potential food applications of cowpea (*Vigna unguiculata*) starch. *International Journal of Food Science & Technology*, **56**, 52–60. https://doi.org/10.1111/ijfs.14604

Panyoo, A.E. & Emmambux, M.N. (2017). Amylose–lipid complex production and potential health benefits: a mini-review. *Starch-Stärke*, **69**, 1600203.
Phebean, I.O., Akinyele, O., Toyin, A., Folasade, O., Olabisi, A. & Nnenna, E. (2017). Development and quality evaluation of carrot powder and cowpea flour enriched biscuits. *International Journal of Food Science and Biotechnology*, **2**, 67–72.
Xu, T.(2019). Sorghum. In: *Bioactive Factors and Processing Technology for Cereal Foods* (edited by J. Wang, B. Sun & R. Tsao) Pp. 103–135. Singapore: Springer.
Zhu, F. (2015). Composition, structure, physicochemical properties, and modifications of cassava starch. *Carbohydrate Polymers*, **122**, 456–480.
Zi, Y., Shen, H., Dai, S. *et al.* (2019). Comparison of starch physicochemical properties of wheat cultivars differing in bread-and noodle-making quality. *Food Hydrocolloids*, **93**, 78–86.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Proportions of different flours in the seven composite flours blends expressed as percentage (%).

Table S2. Proximate composition of analyzed flour blends.

Figure S1. Pasting properties of SS (sprouted sorghum flour), C (cowpea flour), W (wheat flour) and T (tapioca) samples measured by means of a Micro-Visco Amylograph.