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Technological and nutritional properties of amaranth-fortified yellow cassava pasta

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Abstract

Yellow cassava is an affordable starting material to design a healthy food, having high β-carotene content. White and yellow cassava functional pasta were fortified with 50 g/kg (w/w) amaranth dry leaf powder and analyzed to evaluate the impact of cultivar difference, processing, and addition of amaranth leaf powder on the physicochemical, functional, pasting, antioxidant, and cooking properties of the white and yellow cassava pasta samples. Significant differences were observed among the cassava pasta samples. Leaf powder addition significantly enhanced the dietary fiber (7.6–9.1 g/100 g) and protein (1.41–4.69 g/100 g) contents of formulated cassava pasta. Yellow cassava-amaranth pasta had higher β-carotene (2.07 μg/g), iron (59 mg/kg), and zinc (9 mg/kg) contents than the white cassava-amaranth pasta. The addition of amaranth leaf powder also enhanced the antioxidant capacities of pasta products. Cooking time and gruel solid loss were reduced upon the addition of amaranth leaf powder, which is beneficial to the consumers. Data showed the potential of amaranth-fortified yellow cassava pasta in contributing to a healthy diet in low- and middle-income countries by combining a biofortified crop with leafy vegetables via food-to-food fortification.

KEYWORDS
Yellow cassava, amaranth, pasta, micronutrient deficiencies, fortification

Practical Application: This work demonstrates the feasibility of a cassava-based pasta fortified with amaranth vegetables as an affordable and nutritious food to benefit micronutrient deficient consumers in countries with high cassava consumption but low vegetable intake. The inclusion of amaranth leaf powder enhanced the developed pasta's nutritional and technological properties, thus presenting a healthy food choice with the potentials for scaling up commercially.

1 | INTRODUCTION

Consumption of a nutritious diet contributes to good health and the prevention of diseases (WHO, 2013). Accordingly, micronutrient-rich diets can prevent vitamin A, iron, and zinc deficiencies, which are public health challenges, especially in low-and middle-income countries. The nutritional potential of biofortified cassava with provitamin A carotenoids (also known as yellow cassava) as a sustainable food strategy to ease micronutrient deficiency is therefore of interest. Yellow cassava contains up to 15 μg/g carotenoids on a fresh weight basis and is low in cyanogenic glucosides (HCN <10 mg/kg WHO recommended level). Yellow cassava potentially meets about 25% of the daily recommended intake of vitamin A. However, carotenoids degradation during various processing (Ilona et al., 2017), and the full impact of food processing and storage are still largely unknown (Alamu et al., 2017).

In sub-Saharan Africa, cassava is popular for its versatility and affordability. It is the principal staple food of over 500 million people with an average cassava consumption of up to 940 g per adult per day on a fresh weight basis (De-Moura et al., 2015; FAO, 2019). Cassava can be processed into many commonly consumed calorie-rich food products, as both flour and starch have wide food applications. Previous studies examined the production of traditional foods such as *gari, fufu*, and *chikwangue* with provitamin A enriched yellow cassava (Bechoff et al., 2018; Taleon et al., 2019) as vehicles for increased intake of vitamin A, as well as snacks such as cookies and cakes (Maziya-Dixon et al., 2015). These studies revealed that the micronutrient content of these traditional food products are usually inadequate to meet recommended levels of nutrient intake needed to maintain a healthy diet, as processing degraded the micronutrients in yellow cassava (Eyinla et al., 2019; Maziya-Dixon et al., 2016). This is not surprising as β-carotene, the most abundant provitamin A in yellow cassava, is susceptible to degradation due to heat, light, and oxygen (Lawal et al., 2020; Taleon et al., 2019). These researchers reported provitamin A carotenoid losses of up to 75% in food products such as *fufu, chikwangue*, and *lafun*. The direct consequence of this loss during food processing is that the vitamin A content of yellow cassava is insufficient to meet the daily recommended daily intake allowance (RDI) for vitamin A, which has been estimated at 600 μg for adults per day (Wolfe, 2001). Therefore, vitamin A contents of yellow cassava food products need to be enhanced with other food sources. This can be achieved by food to food fortification using readily available materials such as leafy vegetables to enhance the profile of proteins, vitamins, and minerals.

Leafy vegetables contain substantial amounts of carotenoids, minerals, and vitamins, and are abundant, affordable, and accessible to the populace (Lawal et al., 2018; Moyo et al., 2020). A popular leafy vegetable in Nigeria is amaranth, which is liked for its taste and ease of cultivation (Achigan-Dako et al., 2014). Amaranth leaves are rich in protein (17.9 g/kg DW), calcium (44.2 mg/100 g DW), iron (13.6 mg/100 g DW), zinc (3.8 mg/100 g DW), vitamin A (3.3 mg/100 g DW), and vitamin C (25.4 mg/100 g DW; Lawal et al., 2018). They are also high in antioxidant activity because of the presence of carotenoids, flavonoids, and polyphenols (Achigan-Dako et al., 2014).

According to Staatz and Hollinger (2016), changes in consumer preference and taste witnessed in Africa have led to increasing consumption of processed cassava foods and a higher demand for healthy convenience (easy-to-prepare) food products. A typical example of such an easy-to-prepare food is pasta, which is the basis of a large number of diverse, affordable, convenient meals and it has a long shelf life (Nilusha et al., 2019). In Nigeria, about 2 billion servings of noodles were recorded in 2019, according to the World Instant Noodles Association (WINA, 2019). Bustos et al. (2013) reported that among the convenient foods, pasta is an ideal vehicle for the intake of nutrients for its low cost and high worldwide consumption. The development of wheat pasta enriched with vegetables is a well-studied strategy for boosting the intake of vegetables (Nilusha et al., 2019; Oliviero & Fogliano, 2016). The World Health Organization (WHO) and the Food and Drug Administration (FDA) consider pasta as appropriate food for incorporating nutrition supplements. To make the convenient choice also the healthy choice, pasta products are now increasingly fortified with ingredients such as vegetable powders as the large volume of pasta consumption enhances its suitability as a carrier of bioactive substances (Michalak-Majewska et al., 2020). In an earlier study, the authors, Lawal et al. (2021) evaluated the sensory properties and consumer acceptability of pasta made from yellow cassava and leafy vegetables and reported an appreciable acceptance for yellow cassava pasta among the consumers. Thus, as a follow-up, this study evaluated the nutritional and technological properties of the newly developed cassava-amaranth pasta to provide a better understanding of the nutritional value and functional properties.

2 | MATERIALS AND METHODS

2.1 | Materials

2.1.1 | Chemicals

Butylated hydroxytoluene (BHT), 2,6 di tert butyl 4 methyl phenol, 2 dichloroethane, hexane, ethanol, methanol, and 2,2 diphenyl 1 picrylhydrazyl (DPPH) were bought from Sigma Co. (St Louis, MO, USA). Folin Ciocalteu s reagent was purchased from Merck (Kenilworth, NJ, USA). All solvents and chemicals were of analytical grade.

2.1.2 | Sample collection

The International Institute for Tropical Agriculture (IITA) in Ibadan, Nigeria, provided yellow cassava roots and flour (variety TMS07/0593). Conventional white cassava root tubers were bought from Zamzam store, Wageningen, and processed into flour. The white cassava roots were peeled with a knife, washed and grated with the excess water removed by using a muslin cloth for easy handling and to enhance the drying of the wet mash. The wet cake was air-dried for 4 h to a moisture content below 12% and dry milled with the cryo-miller. The flour was stored at −20°C until needed for analysis.

Amaranth was grown in the Unifarm greenhouse of Wageningen University and Research, The Netherlands, at 25°C day and 16°C night under 12–18 h of natural daylight for 1 month. After harvest, the vegetable was de-stalked, washed, freeze-dried, and milled under liquid nitrogen to get leaf powder, which was stored at −20°C until further use.

2.2 | Experimental design

The influence of cassava variety and the addition of amaranth leaf powder (both independent variables) on the quality of cassava pasta (dependent variable) were assessed through a full-factorial central composite design (CCD). Table 1 presents the samples analyzed in this study.

2.3 | Preparation of cassava pasta samples

Boiling water (100 ml) was gradually added to the yellow/white cassava flour (95 g) and amaranth leaf powder (5 g) to make a dough. Initially, water was added under constant stirring, after which the dough was shaped. A stainless-steel manual pasta machine (Gusta RVS, Italy) was used to make the pasta strands, followed by drying in an incubator at 65°C for 12 h. Pictures of developed pasta samples are presented in Figure 1.

TABLE 1 Overview of samples used in the study

Ingredient-based samples	1	White cassava flour (WF)
	2	Yellow cassava flour (YF)
	3	White cassava flour + 5% amaranth (WFA)
	4	Yellow cassava flour + 5% amaranth (YFA)
	5	Amaranth (A)
Pasta-based samples	6	White cassava pasta (flour-based) (WFP)
	7	Yellow cassava pasta (flour-based) (YFP)
	8	White cassava pasta with 5% amaranth (WFAP)
	9	Yellow cassava pasta with 5% amaranth (YFAP)

2.4 | Chemical analysis

2.4.1 | Chemical properties

The moisture, ash, protein, and fat of flour and pasta were determined using standard methods of the Association of Official Analytical Chemists (AOAC, 2019). Specifically, the protein content was measured according to the Dumas method, whereas fat content was determined by the Soxhlet extraction method using petroleum ether. The total dietary fiber content was analyzed using the Official Method 991.43 (AOAC 2005). The amount of total carbohydrate was determined by difference. The sugar content was determined using AOAC (2019) method by weighing about 0.2 g of samples into a centrifuge tube with 1 ml of ethanol (0.789 g/ml), 2 ml of distilled water and 10 ml of hot ethanol. The mixture was vortexed and centrifuged at 2,500 rpm for 10 min after which the supernatant was decanted into another centrifuge tube and used for sugar determination. Atwater factors were used to calculate the total energy content per 100 g of sample (FAO, 2019). All analyses were done in triplicates.

2.4.2 | Mineral analysis

Iron and zinc contents were determined by AOAC (2019) method 999.10 and measured by Inductively Coupled

FIGURE 1 White cassava pasta (upper left), yellow cassava pasta (upper right), white cassava pasta with 5% amaranth leaf powder (lower left), and yellow cassava pasta with 5% amaranth leaf powder

Plasma Atomic Emission Spectrometry (Thermo iCAP-6500 DV; Thermo Fisher Scientific, Waltham, MA, USA) following the validated protocol of the Chemisch Biologisch Laboratorium Bodem (CBLB), Wageningen, the Netherlands.

2.5 | Functional properties

Water solubility and swelling power were determined at 60 and 90°C using the method by Chinma (2013), with slight modifications. The method of Abbey and Ibeh (1988) was used to determine the water-holding (WHC) and oil absorption capacity (OAC). Gelation capacity was determined according to the method of Coffman and Garcia (1977). Suspensions of 2–18 g sample per 100 ml in distilled water were prepared. Ten milliliters each of dispersion was transferred into a test tube and heated in a boiling water bath for 1 h, followed by rapid cooling in a cold-water bath. The tubes were further cooled at 4°C for 2 h. The least gelation concentration (LGC) was determined as the concentration at which the sample from the inverted test tube did not slip or fall. The gravimetric method, as described by Amandikwa et al. (2015), was used to determine bulk densities (loose and packed) of samples. The particle size distribution of cassava starch and flour samples was determined in a particle size analyzer (Mastersizer 3000; Malvern Panalytics, Malvern, UK) by laser scattering following the description of Han et al. (2019).

2.6 | Pasting and thermal properties

The pasting properties were determined according to Chinma et al. (2013), using a Rapid-Visco Analyzer (RVA : Perten Co., Glen Waverley, Melbourne, Australia). The viscosity curve and corresponding parameters, namely pasting temperature, peak viscosity (PV), trough viscosity (TV), final viscosity (FV), breakdown (BD), and setback (SB), were plotted. The unit of viscosity was expressed as mPas. Powder samples were tested for thermal properties following the method by Huerta Abrego et al. (2010), using differential scanning calorimetry (DSC; Perkin Elmer DSC 8000, USA) to determine the onset temperature (T_o), peak temperature (T_P), and the cease temperature (T_C) using Pyrus Software.

2.7 | Cooking properties of pasta

The method described by Rathod and Annapure (2017) was used at intervals of 30 s to determine the optimum cooking time by compressing the cooked product between two glass slides until the central white axis disappeared. Five grams of pasta strands were cooked following the ideal cooking time (20 min) and the cooked strands were weighed to determine the cooking gain. The pasta was put in a preweighed dish and placed in the incubator for 12 h at 110°C. The residual pasta was then weighed to determine the gruel solid loss.

2.8 | Extraction and determination of total phenolics, flavonoids, and antioxidant activity

Extraction of phenolics and flavonoids was performed using the method of Li et al. (20) with slight modifications. Two grams of finely ground pasta samples were extracted with 80% acidified (0.1%) methanol by refluxing for 2 h twice in a shaking Water Bath SW 23 JULABO: Seelbach, Germany at 40°C and centrifuged at 2,000 × *g* for 10 min in a centrifuge (Thermo Scientific Multifuge X3R Refrigerated Centrifuge; Marshall Scientific, Hampton, NH, USA). The methanolic extract was stored at 4°C until needed for further analysis. DPPH radical scavenging activity was determined using the method by Brand-Williams et al. (1995). Reaction mixtures containing 0.1 ml of sample and 3.9 ml of 50 μM DPPH (prepared in methanol) were incubated in a water bath at 37°C for 30 min. After incubation, an aliquot of the sample was placed into a cuvette, and absorbance was measured at 515 nm using the Varian Cary 50 UV-Vis Spectrophotometer. The percentage inhibition was calculated against the control, compared to an ascorbic acid standard curve (0–1,000 μm) and expressed as Trolox equivalent (mmol/kg). The total phenolic content (TPC) was determined by the Folin–Ciocalteu spectrophotometric method (Sharma & Gujral, 2010). Absorbance at 525 nm was read and TPC was expressed as milligrams of gallic acid equivalents (GAE) per g dry weight (mg GAE/g DW).

2.9 | Determination of β-carotene

β-Carotene extraction and analysis were performed by HPLC according to Bechoff et al. (2015), with some modifications. About 2 g of sample was added to a 15 ml centrifuge tube with 10 ml of hexane, vortexed for 10 min, and centrifuged 5 min at 3,000 revolutions per min (rpm). Next, the supernatant was discarded in a 50-ml centrifuge tube and the procedure was repeated twice with tetrahydrofuran (THF) until the sample became colorless. Water confined within the collected supernatant was eliminated by freezing at −20°C. The upper colored part (hexane, THF, and extracted carotenes) was collected in a new tube and the extract was evaporated using a Büchi vacuum evaporator at 40°C and 270 mbar vacuum. Dry extracts were reconstituted in sample buffer (1:1 methanol and THF + 0.01% BHT), after which 1.5 ml was filtered into amber vials for analysis. β-Carotene was analyzed using a YMC C30 column, 3 μm, 150 mm × 4.6 mm column (YMC Europe GMBH, Dinslaken, Germany) in an Alliance 2695 HPLC system (Waters, Milford, MA, USA).

2.10 | Statistical analysis

The study was conducted using a completely randomized design with three replications of the experiments and the analysis done in triplicate. Data were analyzed using an SPSS statistical package (SPSS, version 12.0; Chicago, IL, USA). To determine the difference in significance in means, analysis of variance and Duncan's multiple range tests were performed at 95% significance level.

3 | RESULTS AND DISCUSSION

3.1 | Physicochemical properties of cassava-amaranth flour and pasta

The chemical composition of yellow and white cassava flour and pasta, with and without amaranth leaf powder is presented in Table 2. Low moisture content (<12%) was observed in all the samples, indicating a proper shelf life when stored in dry conditions and in line with *Codex Alimentarius* standards. Energy contents of all samples ranged from 303 to 484 kcal/kg. Protein, fat, and ash contents were significantly higher in samples with amaranth leaf powder while the carbohydrate content remained above 80 g/100 g DW in all pasta samples. The characteristic low protein profile of cassava (1–3 g/100 g DW) was improved, as higher protein contents were recorded with the addition of amaranth leaf powder in both the white and yellow cassava-based samples. The total dietary fiber content of the white and yellow cassava flour products was also improved up to 19% higher levels with amaranth leaf powder addition. This shows the beneficial effect of amaranth as a plant protein source with the leaf powder having protein and fiber contents of 33.5 g/100 g and 17.20 g/100 g (dry weight basis), respectively. Previous studies reported similar appreciable protein and fiber contents of amaranth (Ngugi et al., 2017) whereas the fiber content of the cassava-amaranth flour and pasta was comparable with wheat flour (Nirmala & Joye, 2020). Iron and zinc contents of yellow cassava were higher than for the white cassava samples (9.6 and 6.4 mg/kg, respectively), similar to Maziya-Dixon et al. (2015). Iron is essential for humans, due to its involvement in multiple processes of cell energy metabolism, in which its presence is vital while zinc plays a key role in human metabolic, immunological, and many other biological processes (Allen et al., 2006). Our results confirmed that amaranth leaf powder is a valuable source of mineral and contain a high amount of iron and zinc to meet at least 50% of the daily recommended intake, its addition thus enhanced the nutritional quality of the cassava-amaranth pasta.

TABLE 2 Chemical and mineral composition of amaranth, cassava flour, and pasta

Parameter	White flour	Yellow flour	White flour + Amaranth	Yellow flour + Amaranth	White flour pasta	Yellow flour pasta	White flour + Amaranth pasta	Yellow flour + Amaranth pasta	Amaranth dry powder
Moisture content(g/100 g)	4.18 ± 0.66^{d}	3.42 ± 0.17^{d}	4.24 ± 0.09^{a}	4.20 ± 0.44 ^{cd}	2.15 ± 0.21^{e}	2.71 ± 0.70^{e}	2.85 ± 0.13^{e}	2.57 ± 0.54^{e}	11.97 ± 0.09^{ab}
Protein (g/100 g)	4.23 ± 0.57^{b}	1.41 ± 1.11^{c}	4.69 ± 0.47^{b}	3.30 ± 0.61^{b}	3.48 ± 0.35^{ab}	0.99 ± 0.02^{c}	4.50 ± 0.04^{b}	2.48 ± 0.21^{b}	33.49 ± 1.44^{a}
Fat (g/100 g)	0.24 ± 0.02^{b}	0.20 ± 0.02^{b}	0.34 ± 0.02^{b}	0.32 ± 0.06 ^{b}	0.24 ± 0.02^{b}	0.20 ± 0.02^{b}	0.34 ± 0.02^{b}	0.32 ± 0.06^{b}	2.53 ± 0.18^{a}
Ash (g/100 g)	2.01 ± 0.00^{b}	1.55 ± 0.00^{b}	2.07 ± 0.09^{b}	2.23 ± 0.07^{b}	2.16 ± 0.03^{b}	1.55 ± 0.04^{b}	2.75 ± 0.06^{b}	2.26 ± 0.00^{b}	15.41 ± 0.03^{a}
CHO* (g/100 g)	89.3	93.4	78.7	90	92	94.6	89.6	92.4	36.6
Energy content (kcal/100 g)	376.5	381.1	336.5	375.8	384	384	379.3	382.3	303.1
Dietary fiber	7.6 ±0.01^{d}	9.0 ± 0.03^{bc}	7.8 ± 0.09^{c}	9.1 ± 0.02^{b}	ND	ND	ND	ND	17.20 ± 0.15^{a}
Fe (mg/kg) DW	2.9	7.6	16	69	1	16	6	59	97
Zn (mg/kg) DW	5.6	8.1	3	8	6	4	8	9	49
Fructose (mg/g)	8.15 ± 0.33^{b}	n.d	7.41 ± 0.04^{b}	n.d	8.38 ± 0.12^{b}	0.49 ± 0.01	17.54 ± 1.12^{a}	0.90 ± 0.12	n.d
Glucose (mg/g)	11.13 ± 0.27^{b}	n.d	10.67 ± 0.16^{b}	n.d	11.81 ± 0.06^{b}	0.54 ± 0.09	22.20 ± 1.45^{a}	n.d.	n.d
Sucrose (mg/g)	69.07 ± 0.09^{a}	n.d	62.75 ± 1.14^{a}	n.d	69.21 ± 0.68^{a}	n.d.	47.12 ± 2.59^{a}	n.d.	n.d
Maltose (mg/g)	1.59 ± 0.08^{a}	n.d	2.13 ± 0.04^{a}	n.d	1.21 ± 0.16^{a}	n.d.	1.29 ± 0.12^{a}	n.d.	n.d

Note: Values are means ± standard deviation. Means having different superscripts within the same row differ significantly ($P < 0.05$). n.d., means not detected or quantifiable MC (moisture content) * CHO (carbohydrate) calculated by difference; n.d., means not detected or quantifiable; ND, not determined.

TABLE 3 TPC, TFC, DPPH free radical scavenging activity, and β-carotene contents of cassava products

Sample	DPPH (trolox equivalents (mmol/kg)	TPC {GAE (μg/g)}	TFC {RE (mg/g)}	β-Carotene (μg/g)
White flour	0.17 ± 0.09^{e}	277.9 ± 31.1^{c}	5.56 ± 0.48^{d}	Not detected
White flour + Amaranth	2.50 ± 0.38^{b}	813.6 ± 44.2^{a}	10.95 ± 0.81^{ab}	1.16 ± 0.38^{c}
White flour + Amaranth pasta	2.41 ± 0.42^{ab}	765.6 ± 51.8^{a}	9.21 ± 0.51^{b}	1.03 ± 0.16^{c}
Yellow flour	0.44 ± 0.04^{d}	220.0 ± 31.7^{b}	2.29 ± 0.50^{e}	0.72 ± 0.02^{d}
Yellow flour + Amaranth	2.77 ± 0.29^{a}	674.9 ± 57.4^{ab}	11.76 ± 2.23^{a}	2.34 ± 0.17^{ab}
Yellow flour + Amaranth pasta	0.98 ± 0.12^{c}	450.0 ± 21.2^{b}	5.80 ± 0.07^{c}	2.07 ± 0.13^{b}
Amaranth	16.42 ± 0.37*	8620.2 ± 45.2*	111.46 ± 1.09*	5.48 ± 0.08^{a}

Note: Values are means ± standard deviation. Means having different superscripts within the same column differ significantly ($P < 0.05$). *, Separately analyzed. Abbreviations: TPC, total phenolic content; TFC, total flavonoid content; DPPH, 2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity.

Sucrose was found in the white cassava products, but none was detected in the yellow cassava flour, which agrees with Ayetigbo et al. (2018). Maltose at a range of 1.21–2.13 mg/g was also present in the white cassava flour whereas fructose and glucose were present in similar quantities, with slightly higher values for glucose. The yellow cassava samples had appreciably lower sugar contents than the white cassava samples.

3.2 | TPC and TFC of the pasta

TPC and TFC of cassava samples were significantly enhanced with the addition of amaranth (4-fold increase in TPC and 5-fold increase in TFC). As shown in Table 3, amaranth dry leaf powder samples had the highest phenolic and flavonoid contents among the samples with a TPC of 8,620 μg GAE/g and a TFC of 111.5 mg RE/g, respectively. This result agrees with Obeng et al. (2020), who reported high levels of flavonoids and phenolic acids in amaranth leaves. Cultivar differences influenced the antioxidant activity of the cassava flour as the yellow flour had higher levels than the white. Processing also affected the TPC and TFC as marginal loss in antioxidant activity occurred when the flour was made into pasta (6–50%). Jiménez-Monreal et al. (2009), similarly reported losses in TPC and TFC ranging from 5% to 50% when vegetables were processed using different cooking techniques. Fortification of pasta with vegetables is increasingly being used as a food strategy to enhance the antioxidant activity of pasta products (Oliveiro & Fogliano, 2016), thus the modest loss in the antioxidant activity must be put into consideration when designing vegetable-fortified pasta products.

3.3 | DPPH radical scavenging activity

The addition of amaranth leaf powder significantly impacted the DPPH radical scavenging activity of cassava-amaranth vegetable pasta samples (Table 3). The DPPH free-radical scavenging activity of white and yellow cassava pasta samples was doubled from less than 1.0 Trolox Equivalents (mmol/kg) due to the addition of amaranth vegetable powder. Obeng et al. (2020), reported appreciably high scavenging activities in amaranth vegetables but was lower than other African leafy vegetables in their study. This indicates that leafy vegetables with higher antioxidant capacities could be explored to determine how much they can contribute to the free radical scavenging activity of vegetable-fortified cassava pasta. Retention of phenolics and flavonoids after cooking was however higher in the white (93%) than the yellow cassava pasta (56 %) while DPPH retention after cooking was also higher for the white cassava pasta products (96%).

3.4 | β-Carotene concentration

The addition of amaranth significantly increased the β-carotene content of the cassava-amaranth products (Table 2). β-Carotene was not detected in white cassava but was expectedly present in the white cassava pasta samples with amaranth (1.2–2.4 μg/g DW). La Frano et al. (2014) reported between 3 and 4 μg/g DW trans-β-carotene in gari, a traditional cassava food product, which was higher than in the yellow cassava-amaranth pasta in this study. Taleon et al. (2019) found provitamin A carotenoids in fresh yellow cassava samples between 4.0 and 25.0 μg/g DW. Negi and Roy (2000) also reported β-carotene contents of 9.8 ± 0.5 μg/g DW in fresh amaranth leaf samples. Variations in β-carotene content are also due to varietal differences. However, processing resulted in about 11% loss of the β-carotene contents of the amaranth-cassava pasta (Table 2).

3.5 | Techno-functional properties of cassava flour and pasta

The water holding capacity (WHC) of flour is dependent on its starch fraction having hydrophilic groups and indicates

TABLE 4 Functional properties of amaranth and cassava flour

Functional property	WF	WFA	YF	YFA	Amaranth
Solubility @ 60°C	10.00 ± 0.00 ^{c}	15.00 ± 7.07^{b}	30.00 ± 0.00^{a}	10.00 ± 14.14^{c}	n.a
Solubility @ 90 °C	60.00 ± 14.41^{a}	29.51 ± 14.41^{d}	39.36 ± 0.07^{bc}	34.25 ± 7.15^{c}	n.a
Swelling power @ 60 °C	4.50 ± 1.68^{d}	6.93 ± 0.45^{ab}	6.77 ± 0.09^{b}	5.57 ± 1.36^{c}	n.a
Swelling power @ 90°C	19.18 ± 2.85^{d}	20.92 ± 4.40^{c}	29.45 ± 0.08^{a}	25.43 ± 3.49^{b}	n.a
Water absorption capacity @ 60°C (g water/g sample)	4.05 ± 1.52^{bc}	4.85 ± 0.08^{ab}	5.74 ± 0.07^{a}	4.91 ±0 .45^{ab}	n.a
Water absorption capacity @ 90°C(g water/g sample)	7.88 ± 3.85^{d}	14.43 ±0 .08^{c}	17.86 ± 0.07^{a}	16.59 ± 0.48^{b}	n.a
Oil absorption capacity (g/g oil)	1.91 ± 0.00^{b}	1.96 ± 0.12^{b}	2.42 ± 0.0^{a}	1.79 ± 0.01^{c}	n.a
Least gelation capacity (%)	0.70	1.20	0.80	0.80	n.a
Loose bulk density (g/mL)	0.53 ± 0.00 ^{a}	0.53 ± 0.00 ^{a}	0.52 ± 0.01^{a}	0.51 ± 0.01^{a}	0.21
Packed bulk density (g/mL)	0.80 ± 0.00 ^{a}	0.76 ± 0.01^{a}	0.59 ± 0.01^{bc}	0.58 ± 0.01^{c}	0.34
Total surface area	11.15 ± 0.0	–	82.35 ± 0.64	–	88.75
Volume distribution	228.50 ± 0.00	–	313.50 ± 2.12	–	451
Result range (0.1–0.2 μm)	0.24 ± 0.00	–	0.00 ± 0.00	–	0
Result above (0.2 μm)	99.76 ± 0.00	–	100.00 ± 0.00	–	100

Note: Values are means ± standard deviation. Means having different superscripts within the same row differ significantly ($P < 0.05$).
Abbreviations: WF, white cassava flour; WFA, white cassava flour with 5% amaranth; YF, yellow cassava flour; YFA, yellow cassava flour with 5% amaranth.

the ability of the flour to bind and hold water thus forming a gel at elevated temperatures. WHC is important in pasta production as it provides volume, bulk, and good texture to the final product (Sharma et al., 2021). The WHC of the yellow and white cassava samples differed significantly ($P \leq 0.05$) at two temperatures, 60°C and 90°C, ranging from 3.0 to 5.7 g/g at 60°C and increased from 7.0 to 17.9 g/g at 90°C. The addition of amaranth resulted in a lower WHC for the yellow variety but an increase in the white due mainly to the varietal difference (Table 4). The solubility of the cassava samples ranged from 10% to 45% at 60°C and from 10% to 60% at 90°C, while the swelling power of the cassava flours and starches increased significantly (3.4–29.5 g/g) with the addition of amaranth leaf powder for both the yellow and white cassava ingredients. The swelling power of cassava products indicates the absorption of water as a result of starch gelatinization and is functionally beneficial in the food industry (Ayetigbo et al., 2018). Awoyale et al. (2015) reported lower swelling power values for yellow cassava (7.5 g/g at a solubility of 1.7% at 60°C). The yellow cassava pasta also had higher swelling power than the white cassava pasta, but the amaranth addition resulted in a slight decrease of swelling power in yellow cassava pasta, whereas white cassava pasta remained unchanged (Table 3). The swelling power of the yellow cassava pasta was comparable to commercial wheat pasta (2.4 g/g; Odey & Lee, 2020).

Least gelation capacity, which is the smallest amount of starch required to form a stable gel, is important for the food industry as a better gelling activity is achieved with a lower least gelation capacity and is also preferred for energy efficiency. The ability of the cassava flour to form a gel as measured by the least gelation capacity was found to be at appreciable levels in this study and may have a favorable economic impact on use since this implies that less material is required to make food gels. The gelation capacity is an important quality factor considered for flours used in pasta production. The least gelation capacity of the cassava samples was similar to those reported by Awoyale et al. (2015) for gel formation in three biofortified yellow cassava starches, and an LGC of 4.01–4.06 was recorded. The yellow and white cassava samples were similar in LGC and could be interchangeably utilized for gel formation purposes. The yellow cassava samples also had lower bulk density than white cassava because of the difference in particle size. A low bulk density in food is beneficial for packaging purposes, as fewer materials are used in low bulk density foods. The bulk density of the cassava flours was also lower than those of wheat (0.76) and rice flours (0.91). The packed bulk density (PBD) has also been shown to be positively related to peak time for pasting of the starches and this report is similar to the findings of Agunbiade and Ighodaro (2010).

3.6 | Pasting properties of cassava flour and pasta

Pasting properties are critical to the activities of cassava starch or flour suspension during regulated heating, holding, and cooling temperature regimes. Some pasting properties of cassava can differ significantly depending on the variety, location, and cultivation

TABLE 5 Pasting properties of cassava pasta products

	Peak viscosity (RVU)	Holding viscosity (RVU)	Final viscosity (RVU)	Set back (RVU)	Gel forming	Hardness (N)
WF	2119.5 ± 37.48^{b}	1089.5 ± 13.44^{e}	1671.0 ± 25.46^{c}	581.5 ± 12.02^{d}	Good	0.20 ± 0.03^{d}
WFA	1956.0 ± 80.61^{c}	926.0 ± 16.97^{e}	1328.5 ± 30.41^{e}	402.5 ± 13.44^{e}	No gel	0.56 ± 0.69^{d}
WFP	2265.0 ± 130.11^{b}	1052.0 ± 35.36^{c}	1617.5 ± 57.28^{cd}	565.5 ± 21.92^{d}	–	12.70 ± 3.54^{bc}
WFPA	2123.5 ± 198.70^{b}	1159.5 ± 77.08^{d}	1726.0 ± 114.55^{b}	566.5 ± 37.48^{d}	–	14.74 ± 0.00^{a}
YF	2913.0 ± 86.27^{b}	1707.5 ± 30.41^{a}	2539.5 ± 27.58^{a}	832.0 ± 2.83^{a}	Good	0.14 ± 0.05^{d}
YFA	2789.5 ± 207.18^{b}	1571.0 ± 65.05^{ab}	2340.0 ± 84.85^{a}	769.0 ± 19.80^{b}	Partial gel	0.17 ± 0.09^{d}
YFP	2208.5 ± 152.03^{b}	1550.0 ± 80.61^{ab}	2209.0 ± 103.24^{a}	659.0 ± 22.63^{cd}	–	13.34 ± 2.42^{a}
YFPA	2335.0 ± 189.51^{ab}	1672.5 ± 91.22^{a}	2233.5 ± 105.36^{a}	561.0 ± 14.14^{d}	–	14.74 ± 0.00^{a}

Note: Values are means ± standard deviation. Means having different superscripts within the same column differ significantly ($P < 0.05$).
Abbreviations: WF, white cassava flour; WFA, white cassava flour with 5% amaranth; YF, yellow cassava flour; YFA, yellow cassava flour with 5% amaranth.

conditions. The peak viscosity shows the ability of starch to freely expand before their physical breakdown, thus a high peak viscosity is desirable as it enhances the texture of the paste (Alamu et al., 2017). The white and yellow cassava flours in this study had significantly high peak viscosities and as depicted in Table 5, peak viscosities reduced slightly with the addition of amaranth. The holding viscosity also reduced with the addition of amaranth but increased with processing into pasta. Yellow cassava also had a significantly higher holding viscosity than white. The final viscosity varied from 1,329 to 2,010 RVU and 1,409 to 2,540 RVU for the white and yellow cassava samples, respectively. Ayetigbo et al. (2018), reported a higher final viscosity in yellow compared to white cassava starch, which contrasts with the result in this study which may be due to varietal differences. According to Mandge et al. (2014), final viscosity is the thickness after cooling of cooked starch to at least 50°C and reveals the ability of starch to form a viscous gel or paste following cooking and cooling. The setback results ranged from 402 to 832 RVU with the addition of amaranth, resulting in a decrease in the setback viscosity of the samples. Varietal differences had an impact on the cassava pasting properties, as the yellow varieties had higher peaks than the white. This could be a result of the different alignment of amylose molecules. This is corroborated by the findings of Ayetigbo et al. (2018). Longer peak times may cause extra production costs for the food industry, but are functionally beneficial, as starches resistant to rapid peak time can be valuable in maintaining the structural integrity of foods (Cheng et al., 2020).

3.7 | Particle size distribution (PSD) of the ingredients

Particle size categorization of powder materials is a requirement for food product design and specification purposes. PSD may have a significant effect on the final product performance in terms of content uniformity, dissolution, and stability. The yellow cassava flour had a significantly higher surface area and volume distribution than the white, but no significant difference was observed with the addition of amaranth (Figure 2). Volume distribution was 225.5 for white flour and 313.5 for yellow flour. Overall, almost all results were in a range above 0.2 μm with yellow cassava flour having the highest percentage in the range above 0.2 μm. The average sizes of the flours used in this study are similar to those mentioned in the report of Ayetigbo et al. (2018).

3.8 | Thermal properties of cassava-amaranth pasta

The application of heat to starch in the presence of water results in an irreversible endothermic reaction known as gelatinization. Thermal properties are essential factors in food design as lower thermal properties and gelatinization temperatures of flours, as observed among the samples in this study, may be advantageous, requiring less energy for gelatinization, thus reducing energy costs (Ayetigbo et al., 2018). The effect of processing on thermal properties of cassava flour and pasta samples are shown in Table 6 with yellow cassava having a lower onset temperature (T_o), peak temperature (T_p), and cease temperature (T_c) than the white probably as a result of the larger particle size distribution. Enthalpy ranged from 10.5 to 16.4 J/kg. The pasting temperatures were lower than wheat's in agreement with similar studies of Ubwa et al. (2012).

3.9 | Cooking properties

Cassava cannot be eaten raw but must undergo some form of processing, usually cooking, to enhance

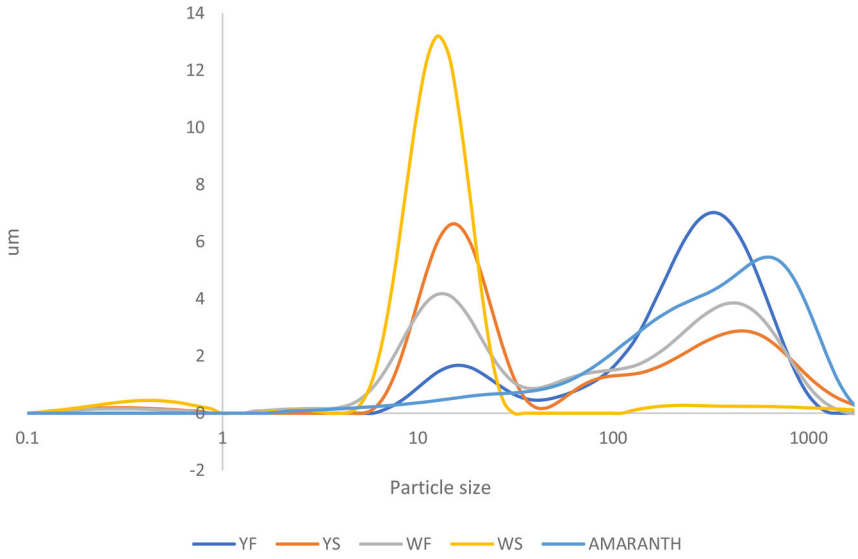

FIGURE 2 Particle size distribution of all ingredient samples (YF, yellow flour; YS, yellow starch; WF, white flour; WS, white starch)

TABLE 6 Thermal properties of cassava flour and pasta

	Onset temp (°C)	Peak temp (°C)	Cease temp (°C)	Enthalpy (j/g)
White cassava flour	68.70 ± 0.04^{a}	78.40 ± 0.08^{a}	91.34 ± 0.03^{b}	12.66 ± 0.02^{ab}
White flour pasta	61.66 ± 0.11^{b}	77.89 ± 0.02^{a}	91.34 ± 0.09^{b}	12.66 ± 0.01^{ab}
White flour amaranth pasta	62.43 ± 0.07^{b}	78.49 ± 0.05^{a}	93.06 ± 0.12^{a}	13.88 ± 0.11^{a}
Yellow cassava flour	63.76 ± 0.05^{ab}	75.44 ± 0.05^{ab}	90.96 ± 0.08^{b}	13.86 ± 0.05^{ab}
Yellow flour pasta	62.56 ± 0.03^{b}	75.85 ± 0.13^{ab}	91.26 ± 0.03^{ab}	10.52 ± 0.00^{b}
Yellow flour amaranth pasta	62.41 ± 0.01^{b}	77.04 ± 0.04^{a}	92.60 ± 0.07^{ab}	12.14 ± 0.01^{ab}

Note: Values are means ± standard deviation, means having the same superscripts within the same column are not significantly different from one another ($P < 0.05$).

palatability and reduce cyanogenic glucosides. In this study, the cassava pasta samples became firmer and stronger internally when cooked. The cooking properties are reported in Table 7. Cooking time ranged from 14 to 22 min, which was longer than for commercial wheat pasta (8–10 min; Reddy et al., 2019). The longer cooking time is probably due to the differences in starch structure. The addition of amaranth leaf powder however significantly decreased the cooking time. The cooking weight gain ranged from 6.27% to 9.11%, whereas the gruel solid loss ranged between 1.38% and 2.5%, which was lower than the values reported by Brennan et al. (2004), who found a cooking loss of 7.93% for commercial wheat pasta. Pasta firmness relates to the hydration of the starch granules during the cooking process and the subsequent embedding of gelatinizing starch granules in a matrix of partially denatured protein (Pellegrini, Vittadini, & Fogliano, 2020). The observed decrease in firmness and swelling index may be associated with a reduction in starch gelatinization in the pasta as cooking time increases with a decrease in the starch content.

4 | CONCLUSION

This study provides the first in-depth evaluation of the nutritional and technological profile of vegetable-fortified pasta made from yellow and white cassava and amaranth leaf powder. The observed higher protein, dietary fiber, iron, zinc, total phenolics, flavonoids, and β-carotene contents in pasta formulated with the addition of amaranth leafy vegetables can improve the nutritional profile of the novel cassava pasta. This is important for addressing the global health issue of vitamin A, iron, and zinc deficiencies, especially in low- and middle-income countries of sub-Saharan Africa where cassava is widely consumed.

The technological properties evaluated also gave positive indications of the feasibility of vegetable inclusion in a cassava pasta product and its applicability for the food industry and as a more affordable, gluten-free alternative to wheat. Cooking, pasting, and thermal properties were considerably improved with the addition of amaranth into the cassava pasta formulation. The yellow cassava also showed significantly higher nutritional value than the

TABLE 7 Functional and cooking properties of yellow and white cassava pasta products

	Solubility (%)	Swelling capacity (%)	Water absorption (g^{-1} sample)	Oil absorption (ml/g)	Cooking time (min)	Weight gain (%)	Gruel solid loss (%)
WFP	20.87 ± 2.00^{a}	3.10 ± 0.06^{c}	2.45 ± 0.00^{b}	1.96 ± 0.04^{a}	22.00 ± 0.00^{a}	8.37 ± 0.12^{b}	1.74 ± 0.25^{a}
WFPA	19.55 ± 0.16^{a}	3.21 ± 0.06^{c}	2.58 ± 0.04^{b}	2.19 ± 0.04^{a}	14.00 ± 0.00^{c}	6.27 ± 1.44^{d}	2.50 ± 0.37^{a}
YFP	3.97 ± 1.31^{c}	4.09 ± 0.07^{a}	3.93 ± 0.03^{a}	1.79 ± 0.04^{b}	22.00 ± 3.71^{a}	6.79 ± 0.60^{c}	1.58 ± 0.01^{a}
YFAP	6.16 ± 0.08^{b}	3.53 ± 0.04^{b}	3.32 ± 0.04^{a}	1.89 ± 0.04^{b}	15.50 ± 0.00^{b}	9.11 ± 0.17^{a}	1.38 ± 0.35^{b}

Note: Values are means ± standard deviation. Means having different superscripts within the same column differ significantly ($P < 0.05$). Abbreviations: WFP, white cassava pasta; WFAP, white cassava with 5% amaranth pasta; YF, yellow cassava pasta; YFAP, yellow cassava flour with 5% amaranth pasta.

white cassava. However, the DPPH free radical scavenging activity of the developed amaranth-cassava vegetable pasta was lower than reported in previous studies for other vegetables. There is thus a need to explore the use of other vegetables as well as the factors that may hinder the digestibility. Further studies are required to determine the bioaccessibility of the nutrients of the developed pasta.

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AUTHOR CONTRIBUTIONS

Nienke Boon: Investigation. Olugbenga Awolu: Writing—review & editing. Vincenzo Fogliano: Project administration; Supervision; Writing—review & editing

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest with the manuscript.

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