






# Canned porridges based on African indigenous crops; nutritional content, consistency, and sensory compared to 'home-made' maize porridge, and effect of legume protein concentrates

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## ABSTRACT

A shift in dietary habits toward increased intake of fat- and sugar-rich foods is leading to an emerging trend of obesity in Africa. To reverse this trend, it is necessary to offer convenient and affordable food products which are nutritious and tasty. The objective of this study was to develop food-to-food fortified, convenient porridges for adults on a pilot scale. The porridges were based on blends of flours from African indigenous crops, i.e. orange fleshed sweet potato (OFSP), cowpea (CP), Bambara groundnut (BGN), finger millet, amaranth, and maize. Porridge with OFSP and amaranth each on a 22% dry weight (dw) basis and smaller amounts of CP, maize, and skimmed milk powder (SMP) achieved 20-fold more provitamin A than the reference with only maize and the same SMP content and were also significantly higher in iron, zinc, and vitamin C. The properties of concentrated protein fractions from CP and BGN as porridge ingredients was also studied. Substitution of up to 20% of unmodified flours with protein concentrates resulted in up to 42% increase in the protein content. The inclusion of protein fractions did not adversely affect viscosity compared to when unmodified flours were used or compared to the maize reference. Protein fractions did not influence the sensory profile compared to unmodified flours. However, prototypes based on African indigenous crops were characterized by more intense vegetable and leguminous flavors, and less bitterness, compared to the maize reference.

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## Introduction

Adult malnutrition is multifaceted and one of the causes is energy-dense rather than nutrient-dense foods. This is also characterized as “nutrition transition” that has resulted in substantial increases in the intake of sugar, salt, and saturated fats, at the expense of a reduced consumption of whole grains, pulses, vegetables, and fruits.<sup>[1,2]</sup> African people living in urban environments are nowadays consuming more “Western”-type food that are energy-dense and with limited dietary diversity, rather than their traditional local African foods.<sup>[3,4]</sup> Worldwide, obesity has nearly tripled since 1975, and the trend is emerging in Africa.<sup>[5,6]</sup> The WHO report on Diet, Nutrition and Prevention of Chronic Diseases<sup>[7]</sup> stated that the fundamental cause of obesity and overweight is an energy imbalance between calories consumed and calories expended. Globally, there has been an increased intake of energy-dense foods that are high in fat and sugars and a decrease in physical activity.<sup>[7]</sup> Non-communicable diseases resulting from overweight and obesity can be prevented. By making healthier foods more accessible, available, and affordable, and aided by supportive environments and communities, people’s choices can be shaped to healthier eating habits and thereby preventing overweight and obesity.

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Conversely, though nutritionally balanced and sustainable, indigenous African food diets are generally characterized by long preparation time, more cooking energy, and drudgery in preparation. This is one of the major drivers contributing to the shift toward “Western”-type diets which offer convenience to the African urban consumers constrained by time and work demands. The food industry can play a significant role in reducing the time, drudgery, and energy used in preparation as well as reducing fat, sugar, and salt content of processed foods, thus ensuring that healthy and nutritious food choices are available and affordable to all consumers. The food groups that are recommended to increase consumption include vegetables, fruits, lentils, and legumes.

African crops, such as orange fleshed sweet potato (OFSP), cowpea (CP), Bambara groundnut (BGN), finger millet (FM), maize, and amaranth vary in nutritional composition. OFSP is rich in  $\beta$ -carotene and provitamin A<sup>[8,9]</sup>, FM, maize, and amaranth complement each other in terms of protein, fiber, essential amino acids, mineral nutrients, carotenoids, phenolic compounds, and phytosterols,<sup>[10–13]</sup> whereas CP and BGN are rich in protein and oils<sup>[14,15]</sup>. Moreover, protein-rich legumes like CP and BGN have the potential to substitute animal-based protein and thus improve affordability and hence food security on the African continent and improve human health. Besides, these crops are well-adapted to local soil and climatic conditions, making them more resilient to pests, diseases, and the effects of climate change. They are less demanding in terms of soil nutrients, support biodiversity, and maintain a diverse range of plant species, which can enhance ecosystem health and stability which lowers the environmental footprint. Legumes are a perfect source of protein and have a balanced nutritional profile. They can complement the lysine-deficient cereal flours. However, the commercial application of legume protein isolates is still limited due to insufficient functional properties and food neophobia.<sup>[16]</sup> These crops being both a food and cash crop, they enormously contribute to supporting smallholder farmers by enhancing food and nutrition and increasing economic resilience. Their suitability to diverse agroecological conditions makes them a reliable source of household food and income, especially in places with erratic weather patterns. Through integrating these crops into farming systems, smallholder farmers achieve greater resilience to climate change, diversify their sources of income, and promote sustainable agriculture, which improves rural communities and livelihoods.<sup>[17,18]</sup>

The goal of the present study was to develop nutritious, convenient, and affordable porridges for adults based on indigenous and locally available African crops and assess the effect of legume protein concentrates as protein enrichment and their functional properties as ingredients in canned porridge. Canned porridge prototypes were compared to a traditionally prepared maize meal.

## Materials and Methods

### Raw materials and flour preparation

Flour of OFSP (Bellevue cultivar) was supplied by Langplaas Boerdery (Brits, North West Province, South Africa), CP was procured from Farm Uitvaln Ver-mass in North West province, South Africa, and BGN was purchased from a local farm in Mbombela (Nelspruit), Mpumalanga, South Africa. Maize (cv. Longe 8), FM (cv. Naromill 4), and amaranth grain flours were imported from Kampala, Uganda. The protein rich fractions (PF) of CP flour (PF-CP) and BGN flour (PF-BGN) were prepared as previously described in Palsola<sup>[19]</sup> and Silventoinen-Veijalainen et al.,<sup>[20]</sup> respectively. Briefly, PF-CP was prepared with a 50-ATP classifier (Hosokawa Alpine AG, Augsburg, Germany) with rotor speed of 9000 rpm and 50 m<sup>3</sup> h<sup>-1</sup> airflow. PF-BGN was prepared by first pre-milling BGN grains with a hammer mill. This pre-milled flour was defatted with supercritical CO<sub>2</sub> extraction (445 bar, 50°C) to reduce the amount of lipids. The defatted material was further milled using an impact mill with stainless steel pin disc grinders (Hosokawa Alpine 100-UPZ) at a rotor speed of 17 800 rpm and milling the material twice. This fine milled flour was then air classified (50 ATP air classifier, classifier wheel speed of 6000 rpm, air flow of 50 m<sup>3</sup> h<sup>-1</sup>) to produce a fine fraction (PF-BGN).

**Table 1.** Ingredients in recipes for canned porridges and the reference. OFSP = Orange Fleshed Sweet Potato, CP = Cowpea, PF-CP = the protein fraction of CP, BGN = Bambara groundnut, PF-BGN = the protein fraction of BGN, FM = Finger Millet, SMP = Skimmed Milk Powder, — means not added.

Ingredient	Porridge no.						Reference (Maize)
	#1-BGN+FM	#1-10%PF-BGN	#1-20%PF-BGN	#2-OFSP+CP+Maize+Amaranth	#2-10%PF-CP	#2-20%PF-CP	
OFSP (g)	—	—	—	45	45	45	—
CP (g)	—	—	—	25	—	—	—
PF-CP (g)	—	—	—	—	18	36	—
BGN (g)	25	—	—	—	—	—	—
PF-BGN (g)	—	15	30	—	—	—	—
Maize (g)	—	—	—	30	37	19	110
FM (g)	90	100	85	—	—	—	—
Amaranth (g)	—	—	—	45	45	45	—
SMP (g)	30	30	30	30	30	30	30
Water (g)	900	900	900	900	900	900	900

### Porridge recipes and preparation

After an initial screening of several recipes, two recipes for canned porridges were selected for further analysis based on taste, protein, and energy content (#1-BGN+FM and #2-OFSP+CP+Maize+Amaranth; designated as #1 and #2 from here on; Table 1). In addition, to increase the protein content further, two variants each with protein fractionated BCN and CP, respectively, were made based on #1 and #2, respectively. These were made with two levels of the protein fractionated flours, and the unmodified flours were replaced with PF-BGN or PF-CP to make up 10 or 20% of the dry weight, whereas the amount of FM in #1-10%PF-BGN and #1-20%PF-BGN or maize flour in #2-10%PF-CP and #2-20%PF-CP were adjusted to obtain the same total solids content as in #1 and #2, respectively (Table 1). A reference made from African indigenous maize, and with similar solids content and viscosity as the six experimental porridges was prepared by traditional boiling. Solids content was between 13.5 and 16.3%. All recipes were with skimmed milk powder (SMP; TINE, Norway) and tap water. The SMP was made from low-pasteurized skimmed cow milk by spray drying and had a whey protein index between 1.5 and 6 mg per gram of powder. The powder had a yellow-white color and a sweet smell and taste. The energy content of SMP was 345 Kcal per 100 g and fat, protein, and carbohydrates content 0.8, 36.9, and 47.9 g/100 g, respectively.

The canned porridges were prepared as follows; 700 g of water was cooked to boiling. In a separate container, 200 g of cold water was mixed with the dry ingredients (Table 1). The two liquids were mixed with continuous stirring, brought to boil, and kept at careful boiling for 3 min. The porridges were set aside and allowed to soak for 5 min. The porridges were then transferred to small cans (100 g content). The cans were sealed and sterilized in an autoclave and the cans became shelf stable and could be stored at room temperature. The autoclave program resulting in an  $F_0$ -value of 22 is shown in Supplementary Table S1.

The reference porridge was prepared the same way, except that it was boiled for 7 min instead of three and not autoclaved, to mimic a traditional home-made meal. The reference was prepared fresh before analysis.

### Nutrient analysis

Porridge samples (100 g) were freeze-dried with a Scanvac CoolSafe Touch Superior (LaboGene, Denmark) with an ice condenser temperature of  $-50^{\circ}\text{C}$  and pressure of 0.370 hPa and stored at  $-20^{\circ}\text{C}$  in the dark until analysis. Crude protein, fat, crude fiber, phosphorus, iron, potassium, calcium, sodium, zinc, ascorbic acid, and  $\beta$ -carotene were analyzed as previously detailed in Løvdal et al.<sup>[21]</sup> Proximate composition of the flour raw materials was determined following the methods described by AOAC<sup>[22]</sup> as follows: Moisture (dry matter) content – draft oven method (AOAC Method no. 934.01), crude protein – Kjeldahl method (AOAC Method no. 976.06), crude fat – Soxhlet method (AOAC Method no. 991.36), crude fiber – acid detergent method (962.09), ash – carbolite furnace at  $550^{\circ}\text{C}$ , 6 h method (AOAC Method no. 942.05).

Carbohydrate was calculated by subtraction ( $100 \div$  crude protein  $\div$  crude fiber  $\div$  crude fat), and the energy value of the porridges was calculated as described by FAO/WHO<sup>[23]</sup> Analytical Methods for

Carbohydrates in Foods as  $[(4 \times \text{carbohydrate}) + (4 \times \text{protein}) + (9 \times \text{fat})]$  and energy value expressed in Kcal/100 g. Vitamin A was expressed as retinol equivalents (RE) and estimated by using a conversion factor of 13:1 by weight for  $\beta$ -carotene.<sup>[24,25]</sup> Two parallel samples (two cans per type) were analyzed for protein, fat, fiber, phosphorus, iron, potassium, calcium, sodium, and zinc. Ascorbic acid and  $\beta$ -carotene analyses were performed only in #1-BGN+FM, #2-OFSP+CP+Maize+Amaranth, and the reference, and in duplicate in two cans per porridge type. Flour raw materials were analyzed in triplicate.

### **Rheological properties of porridges**

The flow characteristics of various porridge formulations were analyzed using a hybrid rheometer (Discovery HR-2, TA Instruments, Newcastle, UK) equipped with a parallel plate geometry (diameter: 40 mm, gap distance: 1500  $\mu$ m) as previously described in Løvdal et al.<sup>[21]</sup> Each porridge sample was analyzed in triplicate.

### **Sensory properties of porridge**

#### **Quantitative descriptive analysis (QDA)**

Sensory analysis was performed by a QDA according to ISO 13299:2016 “General Guidance for Establishing a Sensory Profile” by a sensory panel consisting of trained assessors. The assessors were selected based on their abilities to recognize smell and taste that meet the requirements in ISO 8586:2012 “General Guidelines for the Selection, Training and Monitoring of Selected Assessors and Expert sensory Assessors.” The sensory panel was trained, tested, and calibrated regularly. The trained panel consisted of 10 assessors. Twenty-six sensory attributes were evaluated by the sensory panel (Supplementary Table S2) as previously described in Løvdal et al.<sup>[21]</sup> The scale was from 1 to 9, where 1 = no intensity and 9 = strong intensity.

#### **Temporal dominance of sensations (TDS)**

The assessors were selected based on their abilities to recognize smell and taste that meet the requirements in ISO 8586:2012 “General Guidelines for the Selection, Training and Monitoring of Selected Assessors and Expert Sensory Assessors.” The sensory panel was trained, tested, and calibrated regularly. The trained sensory panel consisted of 10 assessors. Ten sensory attributes were evaluated by the sensory panel (Supplementary Table S3) in five of the samples (Reference, #1-BGN+FM, #1-20%PF-BGN, #2-OFSP+CP+Maize+Amaranth, #2-20%PF-CP) as previously described in Løvdal et al.<sup>[21]</sup>

### **Statistical analysis**

Statistical significance for the difference between means was tested by one-way analysis of variance (ANOVA) with Holm-Sidak post-hoc test in the SigmaPlot v14.5 software. The QDA sensory data were analyzed using Principal component analysis, ANOVA with Tukey post-hoc test, and the TDS data were time standardized to remove assessor noise. The interpretation of the curves was assisted by defining a “chance level” and “significance level”, for details on these calculations see Nguyen<sup>[26]</sup>. The confidence level of all analyses was set at 95%.

**Table 2.** Macronutrients composition and energy of the raw material flours used for complementary porridges. OFSP = Orange Fleshed Sweet Potato, CP = Cowpea, PF-CP = the protein fraction of CP, BGN = Bambara groundnut, PF-BGN = the protein fraction of BGN, FM = Finger Millet.

Flour type	Crude protein (%)	Crude fiber (%)	Crude fat (%)	Carbohydrates (%)	Energy (Kcal/100 g)
OFSP	8.1 $\pm$ 0.1	2.6 $\pm$ 0.1 <sup>A</sup>	0.6 $\pm$ 0.3	88.7 $\pm$ 0.5	392.6 $\pm$ 1.1
CP	21.1 $\pm$ 0.3	6.6 $\pm$ 0.3	0.9 $\pm$ 0.1	71.4 $\pm$ 0.6	378.1 $\pm$ 0.7
PF-CP	42.9 $\pm$ 0.9	1.7 $\pm$ 0.2	2.4 $\pm$ 0.1	53.0 $\pm$ 1.2	405.2 $\pm$ 0.3
BGN	17.7 $\pm$ 0.5	5.2 $\pm$ 0.4	6.0 $\pm$ 0.1	71.1 $\pm$ 1.0	409.2 $\pm$ 1.1
PF-BGN	43.5 $\pm$ 0.9	1.2 $\pm$ 0.1	4.6 $\pm$ 0.2	50.7 $\pm$ 1.2	418.2 $\pm$ 0.6
Maize	8.5 $\pm$ 0.9	5.7 $\pm$ 0.2	4.7 $\pm$ 0.1	81.1 $\pm$ 1.2	400.7 $\pm$ 0.3
FM	10.1 $\pm$ 0.1	18.7 $\pm$ 1.1	1.2 $\pm$ 0.1	70.0 $\pm$ 1.3	331.2 $\pm$ 3.9
Amaranth	17.0 $\pm$ 0.2	7.1 $\pm$ 0.4	2.9 $\pm$ 0.4	73.0 $\pm$ 1.0	386.1 $\pm$ 0.4

<sup>A</sup>Crude fiber in OFSP flour adapted from Rodrigues et al.<sup>[27]</sup> All other data analysed in this study.

**Table 3.** Nutrient composition per 100 g dry weight. ND = Not Determined, BGN = Bambara groundnut, FM = Finger millet, PF-BGN = the protein fraction of BGN, OFSP = Orange-fleshed sweet potato, CP = cowpea, PF-CP = the protein fraction of CP. Different letters indicate significant differences ( $p < .05$ ) according to ANOVA with Holm-Sidak post-hoc test.

	Porridge no.							Reference (Maize)
	#1-BGN+FM	#1-10%PF-BGN	#1-20%PF-BGN	#2-OFSP+CP+Maize +Amaranth	#2-10%PF-CP	#2-20%PF-CP		
Protein (g)	15.4 ± 0.0 <sup>A</sup>	18.8 ± 0.2 <sup>B</sup>	21.9 ± 0.2 <sup>C</sup>	17.7 ± 0.0 <sup>D</sup>	18.4 ± 0.2 <sup>B</sup>	22.0 ± 0.2 <sup>C</sup>	11.9 ± 0.6 <sup>E</sup>	
Fat (g)	0.5 ± 0.2 <sup>ABC</sup>	0.2 ± 0.0 <sup>B</sup>	0.3 ± 0.0 <sup>AB</sup>	1.4 ± 0.2 <sup>D</sup>	1.3 ± 0.1 <sup>D</sup>	1.6 ± 0.1 <sup>D</sup>	0.8 ± 0.0 <sup>C</sup>	
Fiber (g)	3.3 ± 0.2 <sup>A</sup>	3.2 ± 0.2 <sup>A</sup>	2.4 ± 0.4 <sup>AB</sup>	3.3 ± 0.0 <sup>A</sup>	1.7 ± 0.3 <sup>BC</sup>	1.3 ± 0.2 <sup>C</sup>	1.2 ± 0.0 <sup>C</sup>	
Carbohydrates (g)	80.9 ± 0.4 <sup>A</sup>	75.4 ± 0.6 <sup>BCE</sup>	76.9 ± 1.3 <sup>BDE</sup>	77.7 ± 0.1 <sup>BCDE</sup>	78.7 ± 0.4 <sup>BD</sup>	75.2 ± 0.2 <sup>E</sup>	86.2 ± 0.6 <sup>F</sup>	
Energy (Kcal)	389.1 ± 0.1 <sup>AB</sup>	388.5 ± 1.1 <sup>A</sup>	391.9 ± 1.9 <sup>AB</sup>	393.8 ± 1.0 <sup>B</sup>	399.8 ± 1.2 <sup>C</sup>	402.9 ± 1.2 <sup>C</sup>	399.4 ± 0.2 <sup>C</sup>	
Phosphorus (mg)	440 ± 0 <sup>A</sup>	457 ± 5 <sup>AB</sup>	480 ± 8 <sup>BC</sup>	455 ± 5 <sup>AD</sup>	480 ± 0 <sup>CD</sup>	517 ± 5 <sup>E</sup>	355 ± 15 <sup>F</sup>	
Iron (mg)	8.0 ± 1.0 <sup>A</sup>	3.9 ± 0.1 <sup>BD</sup>	4.3 ± 0.5 <sup>B</sup>	7.3 ± 0.0 <sup>A</sup>	9.0 ± 0.6 <sup>AC</sup>	9.9 ± 0.1 <sup>C</sup>	2.2 ± 0.1 <sup>D</sup>	
Potassium (mg)	1000 ± 0 <sup>A</sup>	1100 ± 0 <sup>B</sup>	1300 ± 0 <sup>C</sup>	1300 ± 0 <sup>C</sup>	1400 ± 0 <sup>D</sup>	1600 ± 0 <sup>E</sup>	550 ± 20 <sup>F</sup>	
Calcium (mg)	545 ± 5 <sup>A</sup>	540 ± 8 <sup>A</sup>	507 ± 12 <sup>B</sup>	340 ± 0 <sup>C</sup>	333 ± 5 <sup>C</sup>	330 ± 0 <sup>C</sup>	250 ± 10 <sup>D</sup>	
Sodium (mg)	92 ± 0 <sup>A</sup>	100 ± 0 <sup>B</sup>	100 ± 0 <sup>B</sup>	100 ± 0 <sup>B</sup>	110 ± 0 <sup>C</sup>	110 ± 0 <sup>C</sup>	69 ± 4 <sup>D</sup>	
Zinc (mg)	2.8 ± 0.1 <sup>A</sup>	3.3 ± 0.0 <sup>BC</sup>	3.6 ± 0.1 <sup>D</sup>	3.5 ± 0.0 <sup>CD</sup>	3.5 ± 0.0 <sup>CD</sup>	3.8 ± 0.1 <sup>D</sup>	2.6 ± 0.1 <sup>A</sup>	
Vitamin C (mg)	13.3 ± 0.8 <sup>A</sup>	ND	ND	19.9 ± 0.2 <sup>B</sup>	ND	ND	9.5 ± 0.5 <sup>A</sup>	
β-carotene (mg)	1.9 ± 0.9 <sup>A</sup>	ND	ND	9.4 ± 0.6 <sup>B</sup>	ND	ND	0.4 ± 0.2 <sup>A</sup>	
Vitamin A (μg) Retinol Equivalents (RE)	142.6 ± 72.1 <sup>A</sup>	ND	ND	725.8 ± 43.0 <sup>B</sup>	ND	ND	35.0 ± 19.6 <sup>A</sup>	

**Table 4.** Daily diet reference intake (DDR) and % of DDRI contributed by one 250 g serving of the wet porridge. M = Men, W = Women. ND = Not Determined, BGN = Bambara groundnut, FM = Finger millet, PF-BGN = the protein fraction of BGN, OFSP = Orange-fleshed sweet potato, CP = cowpea, PF-CP = the protein fraction of CP.

	% of DDRI contributed by one 250 g serving porridge (w/w)															
	Porridge no.															
	Daily Dietary Reference Intake (DDR) †		#1-BGN+FM		#1-10%PF-BGN		#1-20%PF-BGN		#2-OFSP+CP+Maize +Anaranth		#2-10%PF-CP		#2-20%PF-CP		Reference (Maize)	
M	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W	
Protein	56 g	46 g	9.8	12.0	11.6	14.1	13.4	16.3	12.9	15.8	13.4	16.3	16.1	19.6	7.1	8.7
Fiber	38 g	25 g	3.3	5.0	2.6	4.0	2.0	3.0	3.3	5.0	2.0	3.0	1.3	2.0	1.3	2.0
Carbohydrates		130 g	21.5		20.2		20.6		24.4			24.6		23.6		22.3
Energy	2200 Kcal	1800 Kcal	6.1	7.5	6.1	7.5	6.2	7.6	7.3	8.9	7.4	9.1	7.5	9.1	6.1	7.5
Iron	8 mg	18 mg	34.4	15.3	15.6	6.9	18.8	8.3	37.5	16.7	46.9	20.8	50.0	22.2	9.4	4.2
Potassium		4700 mg	7.4		8.1		9.6		11.3			12.1		13.9		3.9
Calcium		1000 mg	19.0		18.8		17.5		13.8			13.5		13.5		8.5
Sodium		1500 mg	2.2		2.3		2.3		2.7			3.0		3.0		1.5
Zinc	11 mg	8 mg	8.9	12.2	10.4	14.4	11.4	15.6	12.9	17.8	12.9	17.8	14.1	19.4	7.9	10.9
Vitamin C	90 mg	75 mg	5.0	6.0	ND	ND	ND	ND	8.9	10.7	ND	ND	ND	ND	3.6	4.3
Vitamin A, Retinol Equivalents (RE)	900 µg	700 µg	5.5	7.1	ND	ND	ND	ND	32.9	42.3	ND	ND	ND	ND	1.3	1.7

† Adapted from Kolahdooz et al.<sup>[3]</sup>

## Results and discussion

### Nutrients

The macronutrient, fiber, and energy of the flour raw materials are shown in Table 2. The nutrient composition of the different porridge types is shown in Table 3, and the nutrient contribution to the daily diet reference intake (DDRI) by one 250 g serving of the wet porridge is shown in Table 4.

A 250 g serving of the wet porridge #2–20%PF-CP, which is the highest in protein (Table 3), provides 16.1% and 19.6% of the DDRI of protein for men and women, respectively, which is twice as much as the maize reference (Table 4). Replacing unmodified flours with protein fractions of CP or BGN increases the protein content in the porridges by approx. 40% and 25%, respectively (Table 3), which is not surprising considering the much higher protein content in these flours (Table 2). Comparing the protein content in #1 and #2 containing unmodified flours with their counterparts containing 10% and 20% of PF-BGN and PF-CP, respectively (Table 3), reveals statistically significant higher values in both the 10% and the 20% ( $p < .05$ ) enrichment, and the 20% enrichments are also statistically significantly higher than the respective 10% enrichment ( $p < .05$ ).

According to Kolahdooz et al.,<sup>[3]</sup> the energy intake for adults in Africa exceeds the DDRI and most of the energy is provided by carbohydrates. A 250 g serving of the wet porridge presented here provides 6.1–9.1% of the DDRI of energy and 20.2–24.6% of the DDRI of carbohydrates (Table 4), but only 0.1–0.7 g of fat, which is very low and beneficial for adults trying to reduce fat intake. The calculated percent of energy derived from carbohydrates is relatively high (~80%). The carbohydrate values derived by the present estimation may include some Maillard products and other non-carbohydrate components such as organic acids, tannins, waxes, and lignin,<sup>[28]</sup> and thus may have been overestimated. Carbohydrates, however, may be provided from several dietary sources, and differ greatly in their content of nutrients. Preferably, carbohydrates should not be in the form of added sugar, but be complex and sourced from grains, legumes, vegetables, nuts, and low-fat milk,<sup>[29,30]</sup> as in the present proposed porridges.

The proposed porridges do not provide much fiber compared to the DDRI. However, they provide more fiber than the maize reference (Table 3), and the difference is statistically significant ( $p < .05$ ), except for the porridges containing 10% PF-CP and 20% PF-CP ( $p > .05$ ), which is not surprising since the fiber content is much lower in PF flours compared to unmodified flours (Table 2). In the porridges containing PF-BGN, this effect was not so evident because they also contained a high proportion of FM, which is very high in fiber compared to all other flours used (Table 2).

With the exception of #1–10%PF-BGN, all experimental porridges were significantly ( $p < .05$ ) higher in iron than the maize reference (Table 3); and #1–10%PF-BGN, #1–20%PF-BGN, #2-OFSP+CP+Maize+Amaranth, #2–10%PF-CP, and #2–20%PF-CP were significantly ( $p < .05$ ) higher in zinc than the maize reference. Porridge #2–20%PF-CP, which is the highest both in iron and zinc, provides approx. 50% and 22% of the DDRI of iron for men and women, respectively, and approx. 14% and 19% of the DDRI of zinc for men and women, respectively, in a 250 g serving (Table 4). There has been some debate whether a high intake of dietary fibers may enhance the bioavailability of iron and zinc.<sup>[31]</sup> If that is the case, a higher content of both fiber and iron/zinc may lead to a convergence of benefits. However, at present there is no conclusive evidence for a correlation between fiber content and iron or zinc bioavailability<sup>[31,32]</sup>. Since the current evidence may not be substantial to invalidate the recommendation of dietary fiber as an agent to improve dietary iron and zinc bioavailability, there is a need to conduct further clinical trials with long dietary fiber intervention focusing on population at high risk for deficiencies.<sup>[32]</sup>

All experimental porridges contained significantly higher potassium, calcium, sodium, and phosphorus ( $p < .05$ ) than the maize reference. Potassium can mitigate the negative effects of elevated sodium consumption on blood pressure.<sup>[33]</sup>

$\beta$ -carotene is a fat-soluble plant pigment found in red, orange, and yellow vegetables, and is a source of vitamin A which is lacking in the diets of African adults.<sup>[3]</sup> Notably, #2-OFSP+CP+Maize+Amaranth containing OFSP was significantly higher in both  $\beta$ -carotene and vitamin C ( $p < .05$ ) than the maize reference. Other OFSP containing variants were not analyzed for vitamin C and  $\beta$ -carotene (Table 3) but are presumed to be comparable to #2 based on the OFSP content. It has previously been shown that there is

a good correlation between the OFSP content and  $\beta$ -carotene in porridges and that OFSP is a good source of provitamin A.<sup>[21,34]</sup>

Maize is the main staple food crop for more than 300 million Africans.<sup>[35]</sup> The highest maize consumption is obtained in Southern and Eastern Africa, where it is three to five-fold higher than the world average<sup>[36]</sup>. Maize is a good source of nutrients and phytochemical compounds like carotenoids, phenolic compounds and phytosterols, which may play an important role in preventing chronic diseases,<sup>[11]</sup> but it is also lacking in e.g., iron, zinc, and vitamin A, as most other cereals. Thus, low dietary diversity combined with maize as the predominant food source has led to very high frequencies of deficiencies for these nutrients in Southern and Eastern Africa, particularly for women and children.<sup>[36]</sup> Complementation with other foods has been recommended for improving the maize diet nutritional quality. Several studies indicate that traditional indigenous crops are rich in micronutrients and other health-promoting phytochemicals and thus can complement staple foods and improve the nutritional quality of diets in Africa.<sup>[14,15,21,34,37]</sup>

### Rheological properties of porridges

Figure 1 presents the average viscosity at 50 s<sup>-1</sup> shear rate of the samples varying in types and concentrations of indigenous flours and protein fractions added. The viscosity at 50 s<sup>-1</sup> shear rate has been widely used to estimate the in-mouth viscosity of porridge for adults.<sup>[38,39]</sup> The viscosity of FM-based porridge samples #1-BGN+FM was generally higher than that of #2-OFSP+CP+Maize+Amaranth samples despite the relatively high proportion of maize in the latter formulations. High proportion of OFSP and amaranth in the formula have been previously associated with a decrease in viscosity<sup>[40,41]</sup>. There was an increase in the viscosity of #2 porridge when the CP flour was replaced by the corresponding protein fractions (PF), indicating that the lower amount of starch and fiber fractions in the PF contributed to the increase when incorporated in the OFSP and amaranth based porridge. However, PF-CP addition at the low (10%) concentration resulted in a significantly higher viscosity than at the high (20%) concentration ( $p < .05$ ) indicating that substitution at excessive concentration (~20%) may impair the product viscosity. This concentration-dependent difference could be related to the corresponding adjustment in maize concentrations (Table 1) expected to yield high viscosity and perceived stickiness.<sup>[41,42]</sup> The viscosity of the samples with added PF-CP was comparable to the reference consisting mainly of maize, which may pose nutrition implication. Similar increase in viscosity and concentration-dependent effects was observed in the FM-based porridge added 10% and

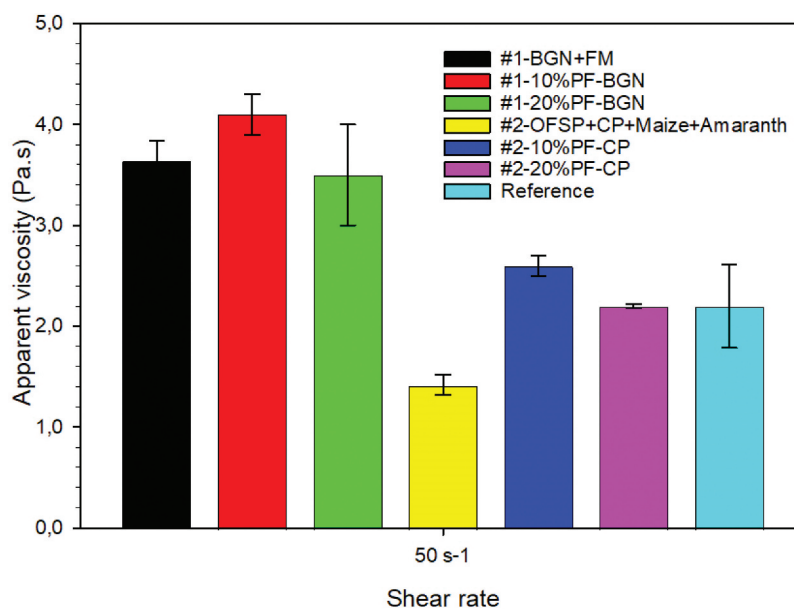


Figure 1. Viscosity at shear rate 50 s<sup>-1</sup> of the porridges.

20% PF-BGN, although the difference in the added PF-BGN concentrations (10 and 20%) did not significantly affect the porridge viscosity at shear rate  $50 \text{ s}^{-1}$  ( $p > .05$ ).

### Sensory properties of porridge

The Reference porridge (maize) had a significantly higher intensity of grain odor and flavor, milk odor and flavor, whiteness, bitter taste, watery flavor and aftertaste compared to all the other porridges (Table 5). #2-OFSP+CP+Maize+Amaranth, #2-10%PF-CP, and #2-20%PF-CP porridges had a significantly higher intensity of vegetable odor, caramelized odor and flavor, malt odor and flavor and sweet taste, and a significantly lower intensity of grain odor and watery flavor compared to the other samples. #1-BGN+FM, #1-10%PF-BGN, and #1-20%PF-BGN had a significantly higher intensity of color hue (more red/blue color) than the other samples and a lower intensity of whiteness. All samples had a significantly higher intensity of legume odor and flavor, and color intensity compared to the Reference, and a significantly lower intensity of milk odor and flavor, bitter taste and aftertaste (Table 5).

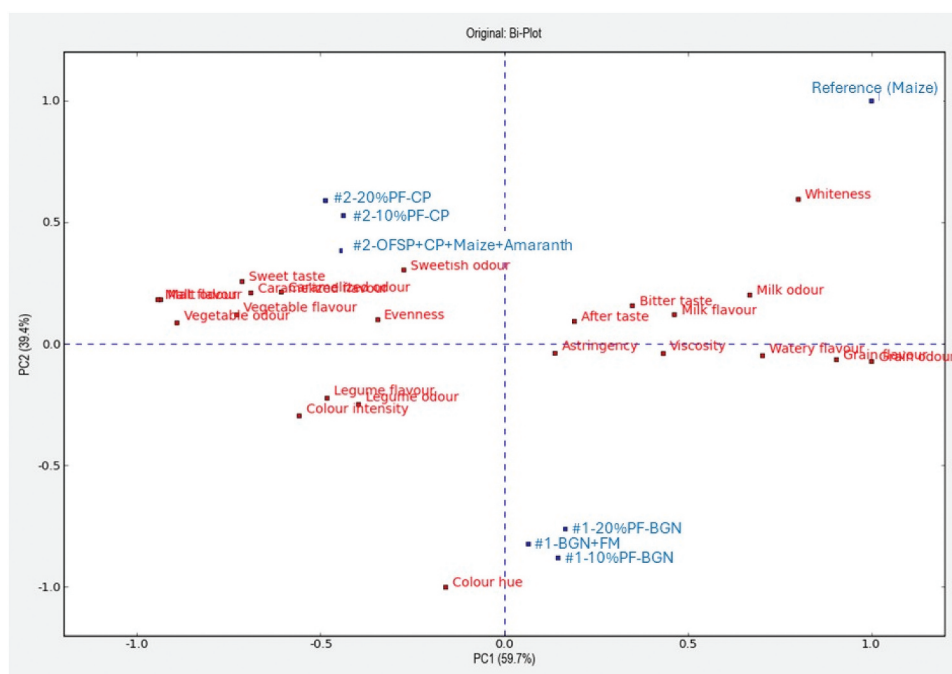
The PCA plot (Fig. 2) shows that the samples are distributed in three clusters with the Reference in one cluster (Cluster 1), sample #1-BGN+FM, #1-10%PF-BGN, and #1-20%PF-BGN in the second (Cluster 2) and #2-OFSP+CP+Maize+Amaranth, #2-10%PF-CP, and #2-20%PF-CP in the third (Cluster 3). The reference (Cluster 1) can be described by whiteness, grain, milk, watery, viscosity, and bitter taste. Sample #1-BGN+FM, #1-10%PF-BGN, and #1-20%PF-BGN (Cluster 2) can be described by color hue (more red/blue color) and the third cluster (#2-OFSP+CP+Maize+Amaranth, #2-10%PF-CP, and #2-20%PF-CP) can be described by sweet taste, sweetly, caramel, malt, vegetable and evenness.

The reference sample was quite unique in sensory profile as compared to the rest, not imparting much own flavor to the mix, described as watery, and rather taking flavor aspects of other components like the milk powder; previous works have suggested maize as a good base to mix with other components, because of the mild flavor and neutral aroma<sup>[43]</sup>; with regard to perceived texture it was described by its viscosity, low evenness and with also grainy taste; in line to what was reported by Onyango<sup>[44]</sup> that described the mouthfeel of maize porridges as creamy and often slightly grainy, depending on the fineness of the maize flour.

All samples with OFSP were clustered in the top left quadrant of the PCA, correlated with attributes related to sweetness and caramelized odor and flavor, typical from cooked OFSP<sup>[45]</sup> that when cooked releases flavors associated with the caramelization of sugars<sup>[46]</sup>, as well as evenness, in texture, in line with

**Table 5.** Mean values of the sensory attributes evaluated by the trained panel. Different letters indicate significant differences ( $p < .05$ ) according to Tukey's multiple comparison test.

Attribute	Porridge no.						Reference (Maize)	p-value
	#1-BGN+FM	#1-10%PF-BGN	#1-20%PF-BGN	#2-OFSP+CP+Maize+Amaranth	#2-10%PF-CP	#2-20%PF-CP		
Colour hue	7.58 <sup>A</sup>	7.57 <sup>A</sup>	7.47 <sup>A</sup>	3.86 <sup>B</sup>	3.43 <sup>B</sup>	3.11 <sup>B</sup>	1.19 <sup>C</sup>	<0.001
Colour intensity	4.81 <sup>A</sup>	5.09 <sup>A</sup>	4.71 <sup>A</sup>	4.69 <sup>A</sup>	4.47 <sup>A</sup>	4.40 <sup>A</sup>	1.75 <sup>B</sup>	<0.001
Whiteness	2.84 <sup>C</sup>	2.63 <sup>C</sup>	2.77 <sup>C</sup>	3.75 <sup>B</sup>	4.29 <sup>B</sup>	4.00 <sup>B</sup>	8.27 <sup>A</sup>	<0.001
Sweetly odor	3.12 <sup>C</sup>	3.18 <sup>BC</sup>	3.28 <sup>BC</sup>	4.76 <sup>A</sup>	4.89 <sup>A</sup>	5.22 <sup>A</sup>	4.33 <sup>AB</sup>	<0.001
Milk odor	1.92 <sup>B</sup>	2.17 <sup>B</sup>	2.06 <sup>B</sup>	1.78 <sup>B</sup>	1.92 <sup>B</sup>	1.82 <sup>B</sup>	4.90 <sup>A</sup>	<0.001
Vegetable odor	3.56 <sup>B</sup>	3.12 <sup>B</sup>	3.03 <sup>B</sup>	4.91 <sup>A</sup>	5.09 <sup>A</sup>	5.18 <sup>A</sup>	1.56 <sup>B</sup>	<0.001
Leguminous odor	4.13 <sup>A</sup>	4.12 <sup>A</sup>	3.96 <sup>A</sup>	3.65 <sup>A</sup>	3.60 <sup>A</sup>	3.66 <sup>A</sup>	1.61 <sup>B</sup>	<0.001
Caramelized odor	2.15 <sup>B</sup>	2.34 <sup>B</sup>	2.48 <sup>B</sup>	4.08 <sup>A</sup>	4.11 <sup>A</sup>	4.54 <sup>A</sup>	2.08 <sup>B</sup>	<0.001
Malt odor	2.70 <sup>B</sup>	2.49 <sup>BC</sup>	2.39 <sup>BC</sup>	4.81 <sup>A</sup>	4.84 <sup>A</sup>	4.91 <sup>A</sup>	1.31 <sup>C</sup>	<0.001
Grain odor	3.89 <sup>B</sup>	4.07 <sup>B</sup>	4.05 <sup>B</sup>	2.23 <sup>C</sup>	2.08 <sup>C</sup>	1.90 <sup>C</sup>	6.05 <sup>A</sup>	<0.001
Sweet taste	2.65 <sup>B</sup>	2.44 <sup>B</sup>	2.58 <sup>B</sup>	4.93 <sup>A</sup>	4.88 <sup>A</sup>	4.77 <sup>A</sup>	2.35 <sup>B</sup>	<0.001
Bitter taste	5.20 <sup>B</sup>	5.04 <sup>B</sup>	5.53 <sup>B</sup>	5.38 <sup>B</sup>	5.35 <sup>B</sup>	5.37 <sup>B</sup>	7.04 <sup>A</sup>	<0.001
Vegetable flavor	3.80 <sup>BC</sup>	3.06 <sup>CD</sup>	3.33 <sup>CD</sup>	4.99 <sup>AB</sup>	5.18 <sup>A</sup>	5.12 <sup>A</sup>	2.32 <sup>D</sup>	<0.001
Leguminous flavor	4.38 <sup>A</sup>	4.21 <sup>A</sup>	4.08 <sup>A</sup>	4.04 <sup>A</sup>	3.90 <sup>A</sup>	4.16 <sup>A</sup>	1.70 <sup>B</sup>	<0.001
Milk flavor	1.91 <sup>B</sup>	2.00 <sup>B</sup>	2.00 <sup>B</sup>	1.88 <sup>B</sup>	1.58 <sup>B</sup>	1.78 <sup>B</sup>	3.85 <sup>A</sup>	<0.001
Caramelized flavor	1.92 <sup>B</sup>	1.97 <sup>B</sup>	1.88 <sup>B</sup>	4.00 <sup>A</sup>	3.96 <sup>A</sup>	3.99 <sup>A</sup>	1.48 <sup>B</sup>	<0.001
Malt flavor	2.65 <sup>B</sup>	2.42 <sup>B</sup>	2.37 <sup>B</sup>	4.77 <sup>A</sup>	4.63 <sup>A</sup>	5.03 <sup>A</sup>	1.25 <sup>C</sup>	<0.001
Grain flavor	3.50 <sup>BC</sup>	4.14 <sup>B</sup>	4.10 <sup>B</sup>	2.46 <sup>CD</sup>	1.99 <sup>D</sup>	2.10 <sup>D</sup>	5.77 <sup>A</sup>	<0.001
Watery flavor	3.06 <sup>B</sup>	3.19 <sup>B</sup>	3.18 <sup>B</sup>	1.74 <sup>C</sup>	1.94 <sup>C</sup>	1.68 <sup>C</sup>	4.58 <sup>A</sup>	<0.001
Evenness	3.73 <sup>C</sup>	3.92 <sup>BC</sup>	3.85 <sup>BC</sup>	4.66 <sup>AB</sup>	4.80 <sup>A</sup>	5.01 <sup>A</sup>	3.56 <sup>C</sup>	<0.001
Viscosity	5.03 <sup>ABC</sup>	5.11 <sup>AB</sup>	4.83 <sup>BCD</sup>	3.92 <sup>E</sup>	4.18 <sup>DE</sup>	4.19 <sup>CDE</sup>	5.81 <sup>A</sup>	<0.001
Astringency	5.42 <sup>A</sup>	5.83 <sup>A</sup>	6.09 <sup>A</sup>	5.29 <sup>A</sup>	5.34 <sup>A</sup>	5.54 <sup>A</sup>	5.87 <sup>A</sup>	0.080
Aftertaste	5.55 <sup>B</sup>	5.54 <sup>B</sup>	5.74 <sup>B</sup>	5.53 <sup>B</sup>	5.70 <sup>B</sup>	5.85 <sup>B</sup>	6.62 <sup>A</sup>	<0.001



**Figure 2.** PCA - all attributes and samples - The variation of the samples can be explained to 59.7% of the PC1 and to 39.4% of the variation is explained by the PC2. The Figure presents the odor, flavor/taste and texture scores for the seven different samples. The closer a sample is to a sensory attribute in the plot, the higher the intensity of that attribute has been measured in the respective sample. Please note that the figure should not be interpreted directly as it only illustrates the relationship between samples and attributes.

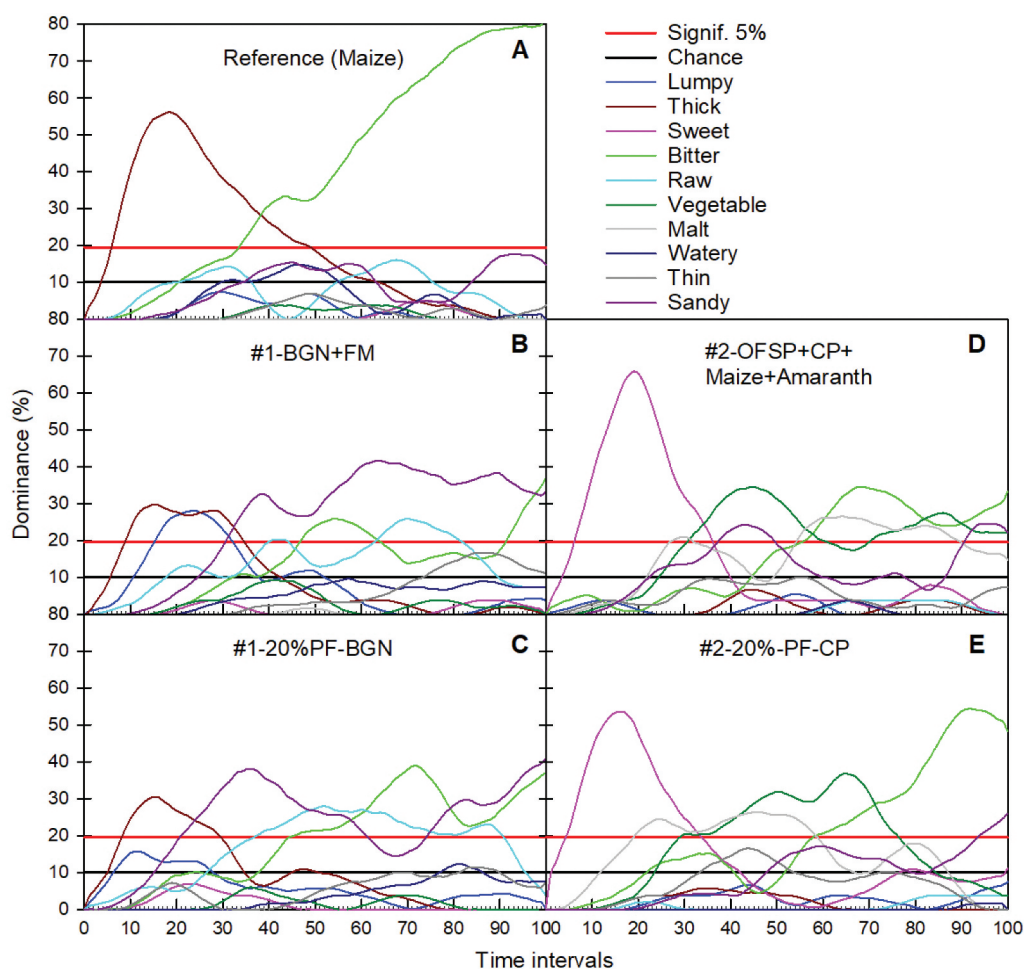
previous works that highlight that porridges with OFSP tend to have a smooth and creamy texture, which is generally well-received by consumers<sup>[47]</sup>.

The porridges #1 with Bambara groundnut, its protein fraction and finger millet were grouped together in the PCA, mostly driven by their color hue, but when looking into undefined five for further details into specific descriptions, these samples were significantly less sweet and caramelized and significantly more intense in grainy odor and flavor than the OFSP added ones.

With regard to the sensory dynamic profiles, the Reference (Fig. 3A) was first dominantly perceived as with thick texture at the beginning of the consumption, and bitter taste was significantly dominant during the second half of the consumption. #1BGN+FM (Fig. 3B) had first a thick and lumpy texture, then sandy, bitter taste, and grain flavor. In the end, the porridge was dominated by bitter taste and sandy texture. #1-20% PF-BGN (Fig. 3C) was first dominated by a thick and lumpy texture, then grain flavor and bitter taste. In the end, the porridge had a bitter taste and sandy texture. #2-OFSP+CP+Maize+Amaranth (Fig. 3D) had first a sweet taste, then vegetable flavor, malt, and bitter taste. In the end, the porridge was dominated by a bitter taste, sandy texture, and vegetable flavor. #2-20%PF-CP (Fig. 3E) was first dominated by a sweet taste, then malt flavor and vegetable flavor. In the end, the porridge had a bitter taste and a sandy texture. OFSP has a natural sweet flavor, usually enhanced by cooking<sup>[45]</sup> that may be responsible for the dominant sweet profile of OFSP containing porridge samples at the beginning of the consumption period (Fig. 3D,E).

### **Further remarks on the choice of canning as processing method and affordability**

The benefits of canning and why we chose this technology and packaging material over alternatives like e.g., cardboard carton or glass jars have been explained elsewhere<sup>[21,48]</sup>. In short, canning provides a very long shelf life at ambient temperatures without necessitating preservatives, and the thermal processing applied in the present study ensures food safety, so that the products may also be considered for emergency stocks. A techno-economics assessment of complementary porridge products based on African indigenous crops and processed in a similar way, and thus resembling the ones in the present study, indicated that they would be



**Figure 3.** Temporal Dominance of Sensations (TDS) plots of the reference (A), and prototypes #1 (B), #1–20%PF-BGN (C), #2 (D), and #2–20%PF-CP (E). Curves display the dominance rate (%) vs the standardized evaluation time in seconds. The black line marks the chance level (CL), and the red line marks the significance level (SL).

significantly cheaper than competitors on the market<sup>[21]</sup>. This is encouraging because it indicates that the nutritious formulations in the present study could be affordable to income-constrained families in Africa and provide yet another opportunity to strengthen the sustainability of the respective food crop value chains.

## Conclusions

Affordability likely presents substantial barriers to fulfilling most nutrient gaps among poorer African households. Maize flour is a relatively cheap staple and is therefore frequently used as the main food ingredient although its nutritional quality may not be satisfactory. The proposed porridges are low in fat and provide more protein and fiber than the maize reference and similar amounts of energy. They are also higher than the reference in all micronutrients analyzed, including iron and zinc. As an example, a 250 g serving of the prototype based on OFSP contributes >30% and >40% of the vitamin A DDRI for men and women, respectively, compared to only marginally (<2%) for the maize reference. Although for example, OFSP may be comparably expensive, it is an affordable source of vitamin A, because relatively small amounts are required to satisfy the need. It is therefore possible to utilize blends of flours from affordable raw materials to industrially produce nutritious and affordable foods for adults. Enrichment with legume protein isolates did not adversely affect the rheological or sensorial properties of the porridges and may be viewed as an additional means to substitute animal-based protein and thus further contribute to increased affordability and food security. The proposed prototypes are also gluten free, without added sugar, and with a beneficial viscosity, and may therefore also be suitable for adults with intolerances, diabetes, or dysphagia.

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## Author contributions

CRedit: **Trond Løvdal**: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing; **Josefine Skaret**: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing; **Izumi Sone**: Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing; **Gorana Drobac**: Formal analysis, Investigation, Methodology; **Natalia Rosa-Sibakov**: Funding acquisition, Methodology, Writing – review & editing; **Mohammad Naushad Emmambux**: Funding acquisition, Methodology, Writing – review & editing; **Yusuf B. Byaruhanga**: Funding acquisition, Methodology, Writing – review & editing; **Paula Varela**: Conceptualization, Funding acquisition, Writing – review & editing.






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No potential conflict of interest was reported by the author(s).

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## Data availability statement

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

## Ethical statement

Nofima's sensory panelists are employees hired for the sole task of sensory testing, and as such, protocols are standard and covered by contractual agreement, as such, we do not seek ethical approval for every project. However, all research related activities performed at Nofima are regulated under the Research Ethics Act 2017, and shall be carried out in accordance with relevant guidelines from national and international advisory bodies, conventions and agreements (cf. National Committee for Research Ethics in Science and Technology (NENT), National Committee for Research Ethics in Social Sciences and the Humanities (NESH), the European Group on Ethics in Science and New Technologies (EGE)/European Commission, the International Committee of Medical Journal Editors, and ICMJE (the Vancouver Convention)). Also, we comply with ethical principles and applicable international, EU and national law (in particular, EU Directive 95/46/EC).

Apart from this, the present study did not include experiments with human participants. No personal information, patient data, or case studies were performed, and no personal data or GDPR-related information were collected.

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