ISSN 0355-1180

UNIVERSITY OF HELSINKI

Faculty of Agriculture and Forestry

Department of Food and Nutrition

EKT Series 2055

Development of healthy gluten-free crackers by using African crops and bioprocessing

Mira Palsola

Helsinki 2022

HELSINGIN YLIOPISTO – HELSINGFORS UNIVERSITET – UNIVERSITY OF HELSINKI

Tiedekunta – Fakultet – Faculty Maatalous-metsätieteellinen	Koulutusohjelma – Utbildningsprogram – Degree Programme Elintarviketieteiden maisteriohjelma

Tekijä – Författare – Author
Mira Palsola

Työn nimi – Arbetets titel – Title
Terveellisten gluteenittomien voileipäkeksien kehittäminen afrikkalaisista viljelyskasveista ja niiden bioprosessointi

Oppiaine/Opintosuunta – Läroämne/Studieinriktning – Subject/Study track
Yleinen elintarviketeknologia

Työn laji – Arbetets art – Level Maisterintutkielma	Aika – Datum – Month and year Elokuu 2022	Sivumäärä – Sidoantal – Number of pages 41

Tiivistelmä – Referat – Abstract

Afrikkalaiset viljelyskasvit ovat kestävä ja terveellinen vaihtoehto käytettäväksi gluteenittomissa tuotteissa. Tutkimus käsittelee maissijauhopohjaisten (100 %) voileipäkeksien valmistamista korvaamalla 50 % jauhoista afrikkalaisilla viljoilla (amarantti, durra, teff) ja 50 % sekä 75 % palkokasveilla (maapapu, lehmäpapu), joista arvioitiin kesien leivottavuutta, teknologisia ominaisuuksia. Lisäksi tutkittiin bioprosessoinnin ja raaka-aineiden mekaanisen muokkaamisen vaikutusta durran ja lehmäpavun teknologisiin ja aistinvaraisiin ominaisuuksiin. Työn tavoitteena oli selvittää voiko afrikkalaisia viljoja käyttää voileipäkeksien valmistamiseen ja kuinka ne vaikuttavat keksien ravintoarvoihin, leivottavuuteen ja teknologisiin ja aistinvaraisiin ominaisuuksiin. Afrikkalaiset viljelyskasvit paransivat keksien ravintoarvoja lisäämällä niiden kuitu ja proteiinipitoisuutta. Myös leivottavuutta ja taikinan elastisuutta pystyttiin parantamaan. Korvaamiset tummensivat keksien väriä ja korkeampi proteiinipitoisuus lisäsi keksien kovuutta ja kohoamista. Lehmäpapuproteiinifraktio lisäsi keksien kovuutta eniten (31,55 ± 3,17 N, maissi 4,02 ± 1,79 N). Kohoavuus lisääntyi eniten käytettäessä maapapua (75 %) (43,57 ± 3,29 %, maissi 21,93 ± 0,002 %). Raaka-aine muokkaukset muuttivat huomattavasti durran ja lehmäpavun aistiprofiileja, vähentäen durran hiekkaisuutta ja lehmäpavun papuisuutta.

Avainsanat – Nyckelord – Keywords
Amarantti, maapapu, lehmäpapu, durra, teff, voileipäkeksit, gluteeniton

Ohjaaja tai ohjaajat – Handledare – Supervisor or supervisors
Mari Sandell, Natalia Rosa-Sibakov, Outi Mattila

Säilytyspaikka – Förvaringställe – Where deposited
Helsingin yliopiston digitaaliset opinnäytteet, E-thesis

Muita tietoja – Övriga uppgifter – Additional information
EKT-sarja 2055. Julkinen 01.10.2022.

HELSINGIN YLIOPISTO – HELSINGFORS UNIVERSITET – UNIVERSITY OF HELSINKI

Tiedekunta – Fakultet – Faculty Faculty of Agriculture and Forestry	Koulutusohjelma – Utbildningsprogram – Degree Programme Master’s programme in Food Sciences

Tekijä – Författare – Author
Mira Palsola

Työn nimi – Arbetets titel – Title
Development of healthy gluten-free crackers by using African crops and bioprocessing

Oppiaine/Opintosuunta – Läroämne/Studieinriktning – Subject/Study track
General Food Technology

Työn laji – Arbetets art – Level Master’s Thesis	Aika – Datum – Month and year August 2022	Sivumäärä – Sidoantal – Number of pages 41

Tiivistelmä – Referat – Abstract

African crops are sustainable and healthy alternative ingredients for potential use in various gluten-free products among traditional African foods. In this thesis maise-based, gluten-free crackers with 50% cereal (amaranth, sorghum and teff) and 50% and 75% legume (Bambara groundnut and cowpea) replacements were produced, and their baking performance and technological properties were examined. The effect of sorghum and cowpea flour's bioprocessing and mechanical raw material modifications on cracker technological and sensory properties was studied. The thesis aimed to solve whether maise and African crop flours could be used in gluten-free crackers and how would they affect nutritional values, baking performance and technological and sensory properties in gluten-free crackers. The nutritional calculations indicated that African crop replacement increased fibre content at least by 2.4% and protein by 1.9 E% compared to 100% maise cracker. Crop replacements improved the dough elasticity and bakability and darkened the cracker surface. African crops and higher protein content increased cracker hardness and improved the rising ability. The highest hardness rate was measured with protein fractionated cowpea (31.55 ± 3.17 N, maise 4.02 ± 1.79%) and puffiness with Bambara groundnut 75% (43.57 ± 3.29%, maise 21.93 ± 0.002%). Raw material modifications changed the sensory profile of sorghum and cowpea crackers significantly by decreasing graininess in sorghum and beaniness in cowpea.

Avainsanat – Nyckelord – Keywords
Amaranth, Bambara groundnut, Cowpea, Teff, Sorghum, Crackers, Gluten-free

Ohjaaja tai ohjaajat – Handledare – Supervisor or supervisors
Mari Sandell, Natalia Rosa-Sibakov, Outi Mattila

Säilytyspaikka – Förvaringställe – Where deposited
University of Helsinki, Digital Theses, E-Thesis

Muita tietoja – Övriga uppgifter – Additional information
EKT Series 2055. Public 01.10.2022.

Preface

The topic of this thesis was provided by VTT, and it was part of the InnoFoodAfrica project. The materials were provided by VTT and partners working with InnoFoodAfrica project. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862170. All research was conducted at VTT premises. This thesis was supervised by Senior Scientists Natalia Rosa-Sibakov and Outi Mattila from VTT and University vice dean and professor Mari Sandell.

APPENDICES

1 INTRODUCTION

Changing dietary lifestyles, consumer awareness, urbanisation, globalisation, and economic development guide people’s eating habits (Jnawali et al. 2016). Furthermore, health-enhancing and nutritionally valuable food products are in high demand. In addition, global warming affects food production, and manufacturers must produce sustainable food products that full fill the consumers’ demands (Thornton 2012). In developing countries protein and fibre sources are limited, so it is crucial to develop alternative healthy and palatable high protein and high fibre products based on their local ingredients. Furthermore, obesity and nutrient deficiency are enormous problems in developing countries. While snacking is a growing trend, ready-to-eat healthy snack products supply new options to be utilised among other snack products, such as chips (Govender et al. 2018).

Celiac disease and gluten-free trends have raised the demand for gluten-free products. The gluten-free statement may be used when the product contains a maximum of 20 mg/kg of gluten (FAO 2013). It is estimated that the demand for gluten-free products will increase by nearly 10% annually (Xu et al. 2020). Cereal-based bread, cookies and crackers are some of the most consumed and universally accepted gluten-free products globally (Jnawali et al. 2016). Crackers are thin, crisp biscuits made of unsweetened and unleavened dough (Han et al. 2010). Crackers can be divided into three categories by the production method and ingredients used, soda crackers (saltines or cream crackers), snack crackers (sprayed crackers) and flavoured or savoury crackers (Xu et al. 2020). Cracker dough is typically sheeted to 2-3 mm and cooked at 150-300 °C for 2–15 min depending on the ingredients used (Han et al. 2010). Generally, crackers are 8 cm or less in diameter and have small docking holes to prevent large air pockets form during baking (Carson et al. 2022).

In glutenous crackers, gluten is typically acting as a binder and providing the texture (Carson et al. 2022). Furthermore, gluten is the main component responsible for the crispiness of crackers. The cracker crispiness may be adjusted also by moisture content (1-5%), which also increases the microbiological stability of crackers and thereby prolongs products' shelf life (Han et al. 2010; Carson et al. 2022). The low moisture content combined with the lack of gluten in gluten-free products often shows poor mouthfeel and texture (Prinyawiwatkul et al. 1996; Busken 2011; Jnawali et al. 2016). These properties may be adjusted with additional ingredients, such as modified starch and hydrocolloids. So far, hydrocolloids, such as xanthan gum and guar gum, have been added for binders and improvers (Xu et al. 2020).

Mostly, gluten-free products are made from well-known cereals, such as maise, oat and rice, or legumes, such as soy. The nutritional quality of these products may be deficient due to the high starch and low protein and fibre quantity and quality (Han et al. 2010; Xu et al. 2020). The nutritional quality of protein depends on digestibility, bioavailability, and amino acid composition. Furthermore, antinutritional factors such as enzyme inhibitors, hemagglutinins, and polyphenols, which are present in legumes, can limit protein digestibility and availability. The nutritional quality could be improved by using blends of gluten-free cereal and legume flours that can provide higher protein, fibre and mineral content and a more balanced amino acid composition to gluten-free products (Sindhuja et al. 2005; Azman Halimi et al. 2019; Xu et al. 2020).

African crops, such as amaranth, Bambara groundnut, cowpea, sorghum and teff, have shown immense potential in gluten-free product development, such as biscuits, cookies, and crackers (Sindhuja et al. 2005; Omoba et al. 2015; Darmatika et al. 2018; Yeboah-Awudzi et al. 2018; Di Cairano et al. 2018). The studied crops vary in nutritional composition, shape, and size (Table 1). The cereal crops, amaranth, sorghum and teff, are smaller and contain higher amounts of starch, whereas the legume crops, Bambara groundnut and cowpea, contain certainly higher amounts of protein (Gamel et al. 2006a; Uppal and Bains 2012; Baye 2014; Tan et al. 2020). Furthermore, amaranth and Bambara groundnut contain higher amounts of lipids than the other studied crops. However, these crops are today highly understudied and underutilised commercially, and thus it is important to study their capability in gluten-free food production (Stefoska-Needham et al. 2015; Gulzar and Minnaar 2017; Aderibigbe et al. 2020; Tan et al. 2020).

Product acceptance and quality are tested by sensory evaluation where typically texture, appearance, odour, flavour, and taste are examined (Di Cairano et al. 2018). Gluten-free products tend to have a harder texture and darker colour combined with a dry and sandy mouthfeel and bland taste (Han et al. 2010; Di Cairano et al. 2018; Xu et al. 2020). Furthermore, gluten-free products containing pulses are rich in antinutritional compounds, such as tannins, which may lead to a bitter aftertaste. The reason for the darker colour may be due to higher phenolic compounds and ash content in gluten-free flours than for example in wheat flour (Di Cairano et al. 2018).

Table 1 The seed composition and appearance based on findings in the literature.

Parameters	Amaranth[α]	Bambara groundnut[β]	Cowpea[γ]	Sorghum[δ]	Teff[ε]
Energy (kcal/100 g)	357.4 ± 36.7	387.5 ± 2.5	333.0 ± 0.0	339.7 ± 21.8	348.5 ± 14.0
Carbohydrates (g/100 g)	59.2 ± 8.6	62.8 ± 1.5	59.6 ± 6.0	73.3 ± 1.3	72.8 ± 5.3
Starch (g/100 g)	61.5 ± 2.4	45.6 ± 8.7	46.4 ± 19.1	65.3 ± 3.3	50.6 ± 17.6
Protein (g/100 g)	15.9 ± 1.6	20.1 ± 2.5	25.9 ± 6.9	11.9 ± 4.3	10.8 ± 1.1
Dietary fibre (g/100 g)	13.0 ± 3.5	5.9 ± 4.5	13.9 ± 6.8	8.4 ± 0.8	7.0 ± 1.5
Fat (g/100 g)	7.1 ± 0.8	5.7 ± 2.2	2.0 ± 1.2	3.5 ± 0.3	2.3 ± 0.2
Moisture (%)	9.6 ± 1.8	8.7 ± 2.9	9.7 ± 0.3	9.9 ± 0.6	8.8 ± 0.5
Weight (g/1000 seeds or *g/100 seeds)	0.5-1.0	34.0-63.0*	10.5-27.1*	2.0-3.0	0.3
Seed length (mm)	1.0	11.0-12.0	5.9-7.6	2.9-5.9	1.0
Seed coat colour	White, yellow, red brown, black	Cream, brown, maroon, black and 'eyes'	White, cream, green, red, brown, black and hilum rings	White, yellow, red	White, brown, black
Seed shape	Flattened or lenticular	Round	Kidney, plump or round	Round or broad conic	Oval

[α] Lorenz and Wright (1984), Belton and Taylor (2002), Gamel et al. (2006b), Gamel et al. (2007), Alvarez-Jubete et al. (2009) and Mekonnen et al. (2018); [β]Nti (2009), Adebowale et al. (2011), Arise et al. (2017), Mubaiwa et al. (2017), Azman Halimi et al. (2019) and Tan et al. (2020); [γ]Prinyawiwatkul et al. (1996), Appiah et al. (2011), Uppal and Bains (2012), Gonçalves et al. (2016) and Mubaiwa et al. (2017); [δ]Virupaksha and Sastry (1968), Baye (2014), Stefoska-Needham et al. (2015), Rooney (2016) and Chavan and Kotecha (2019); [ε]Umeta and Faulks (1988), Bultosa (2007), Arendt and Zannini (2013), Baye (2014), Zhu (2018) and USDA (2019)

Amaranth, Bambara groundnut, cowpea, sorghum and teff are mainly used to produce traditional African foods, such as injera and okpa. Several studies regarding crops' use in bakery products were found but a limited amount of usage in gluten-free and cracker products. Regarding several studies, the typical acceptable amount of African crop addition varies between 10-40% (Sindhuja et al. 2005; Omoba et al. 2015; Chauhan et al. 2015; Darmatika et al. 2018; Yeboah-Awudzi et al. 2018). The amount of African crop supplementation is also highly dependent on eating habits and studied products. If gluten-free products were consumed before or regularly or the studied product typically has a wide range of textures and flavours, such as bread and cookies, higher amounts of crop supplementation were acceptable (Bhaduri et al. 2015; Darmatika et al. 2018). The functional properties of the African crop flours are important to understand due to their influence on the texture, mouthfeel, and consistency of the product (Yeboah-Awudzi et al. 2018). According to several studies, the presence of the African crop darkens the product colour and increases the protein, fibre, and fat content (Ayo 2001; Sindhuja et al. 2005; Chauhan et al. 2015; Darmatika et al. 2018; Yeboah-Awudzi et al. 2018). Furthermore, the supplementation increased the dryness, hardness and sandy mouthfeel of cookies and biscuits (McWatters 1978; Omoba et al. 2015; Mancebo et al. 2015; Chauhan et al. 2015; Yeboah-Awudzi et al. 2018). The higher the crop amount was the more notable the effect was.

Changes in texture and other sensory properties may be improved by bioprocessing or mechanical raw material modification. Bioprocessing is defined as a process that uses complete living cells or their components, such as microbes or enzymes, to obtain desired properties for products (Gebremariam et al. 2014). This thesis will focus on modifying the raw materials by germination, enzymes, and mechanical modification. Germination is a process where the seed is sprouted to form a seedling in favourable conditions. During germination, several enzymes become active, vitamin content may be increased and the content of antinutrients, such as phytate and tannins, may be decreased and degradation of starch and proteins may occur (Hallén et al. 2004; Elkhalifa and Bernhardt 2013). Enzymes are proteins that enhance chemical reactions and catalyse only specific reactions due to their selectivity for their substrates (Ahlawat et al. 2018). This thesis studies the effect of protease treatment on sorghum crackers. In this thesis mechanical raw material modification means milling and air-fractionation. According to Serrem et al. (2011) and Omoba et al. (2015), finer particle size may reduce the sandy and gritty mouthfeel of the product. However, smaller particle size has been reported to increase the product hardness (Kenney et al. 2011).

In gluten-free bakery products, wheat flour is typically replaced with rice flour (Nespeca et al. 2021). This thesis aims to understand whether maise and African crop flours could be used in gluten-free crackers and how would they affect baking performance and technological and sensory properties in gluten-free crackers. The thesis focuses on three cereal crops, amaranth, sorghum and teff and two legume crops Bambara groundnut and cowpea. Furthermore, this thesis attempts to find solutions to improve cracker structure and sensory properties by bioprocessing and mechanical raw material modification. All developed crackers should reach the criteria limit for high fibre nutrition claim, 6 g/100 g or 3 g/100 kcal (FAO 2013). Furthermore, the claims for the source of protein (12% of the product total energy value) and high protein (20% of the product total energy value) nutrition claims are attempted to reach with the legume flours.

2 MATERIALS AND METHODS

2.1 Materials

Baking powder (Pirkka), iodised salt (Jozo), rapeseed oil (Keiju), xanthan (Vuohelan) and sunflower lecithin (Foodin) was purchased in local stores (Espoo and Helsinki, Finland). Maise flour (Pringy, France) was purchased from Virtasalmen Viljatuote Oy. Amaranth (AMA) and sorghum (SOR) grains were obtained from local farmers from Uganda. Bambara groundnut (BAM) and cowpea (COW) grains were obtained from local farmers in South Africa. Crops were milled into flour by the local partners working on the InnoFoodAfrica project and delivered to Finland for the project. Teff (TEF) flour was purchased from Birkuta (Milton Keynes, UK) and it was originally cultivated and harvested in South Africa.

2.2 Development of the basic recipe and baking process

Preliminary tests were performed to optimise cracker dough consistency and baking performance to be used at later stages of the study. Testing was started with creating the basic recipe from gluten-free maise flour. After several tests, it was notable that maise flour needs to be gelatinised with boiling water to obtain a well-performing dough. The flour-water mixture temperature should reach at least 62 ˚C to gelatinise the maise flour and cool down to 40-45 ˚C (Delcour and Hoseney 2010). If the mixture was cooled below 40 ˚C the dough became crumbly and hard to handle. The dough temperature was measured by a digital thermometer (Greisinger GTH 175/Pt 1000, Germany). Furthermore, lecithin and xanthan were found to give the dough a more elastic structure. The ingredients used in the basic recipe can be seen in table 2. The basic recipe is modified from the recipe used in Kamel et al. (2020) study. All the dry ingredients were kept at room temperature and the oil was kept in the refrigerator and taken at room temperature before baking.

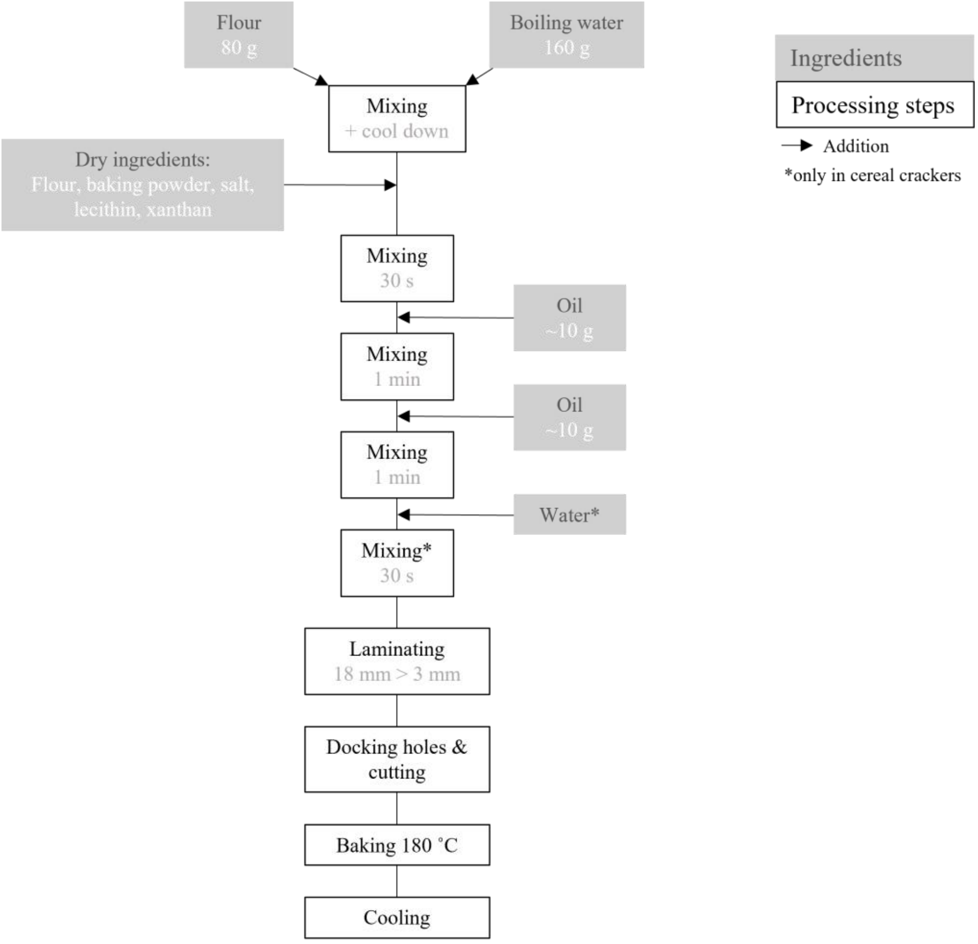
Table 2 Used ingredients in the basic recipe.

Ingredient	Amount (g)
Maise flour	240 (80^a + 160^b)
Water	175 (160^a + 20^c)
Oil	20
Baking powder	5
Lecithin	4
Salt	4
Xanthan	2.8

[a] Amounts used in the pre-gelatinisation step.
[b] amount mixed with other dry ingredients.
[c] Water added in the final mixing step

First, 80 g of maise flour and 160 g of boiling water were mixed by hand to gelatinise 1/3 of the total flour amount used in the recipe (Figure 1). Other dry ingredients were mixed by hand and then added to the cooled flour-water mixture and mixed in a Hobart mixer (N50, OH, USA) for 30 s. Oil was added in two parts and mixed for 1 min after each addition. 15 g of water were added to the dough and mixed for 30 s. The total mixing time was 3 min. The dough was shaped as a ball and laminated with a Rondo STE 53 dough sheeter (Seewer Ag, Switzerland) starting from 18 mm thickness. At 8 mm thickness, the dough was cut in half and rotated 90˚. The final thickness was 3 mm. After laminating, the dough was docked with a plastic spike roller and cut into oval-shaped crackers (70 x 47 mm) Crackers were baked at 180 ˚C in a rotating rack oven (Sveba Dahlen, Sweden) for 22 min and let cool down at room temperature.

Figure 1 Schematic flowchart of the baking process used in the thesis.



2.3 Baking of African crop crackers

All the African crop crackers were firstly baked with 25%, 50% and 75% replacement of maise flour. All crackers with 50% replacement and Bambara groundnut and cowpea crackers with 75% replacement were chosen to proceed with. All crackers prepared in this thesis were baked at 180 ˚C with different baking times, which were adjusted to obtain crackers with less than 5% moisture content. All bakings for technological property analysis were made in duplicate. For the descriptive sensory analysis, a total of 5 bakings were done for each sample and the different baches were mixed before the evaluation.

2.3.1 Recipes and processes for the African crop crackers

In the 50% flour replacement crackers African crop flours were added with other dry ingredients after gelatinising the maise flour (80 g) with boiling water. With cereal flours, other changes were not made to the recipe. In legume flour addition, the water amount was decreased and therefore the mixing time was decreased to 2 min 30 s. In 75% legume flour replacement, 20 g of legume flour and 60 g of maise flour were mixed and gelatinised with boiling water. The ingredients, amounts and baking times can be seen in table 3.

Table 3 Recipes and baking process parameters used in the African crop crackers. AMA50 = Amaranth 50% replacement, TEF50 = Teff 50% replacement, SOR50 = Sorghum 50% replacement, BAM50 = Bambara groundnut 50% replacement, BAM75 = Bambara groundnut 75% replacement, COW50 = Cowpea 50% replacement, COW75 = Cowpea 75% replacement

	AMA50	TEF50	SOR50	BAM50	BAM75	COW50	COW75
Mixing time (min)	3	3	3	2.5	2.5	2.5	2.5
Baking time (min)	20	20	17	20	13	15	13
Ingredient	Amount (g)						
Maise flour	120 ($80^a + 40^b$)	120 ($80^a + 40^b$)	120 ($80^a + 40^b$)	120 ($80^a + 40^b$)	60^a	120 ($80^a + 40^b$)	60^a
African crop	120^b	120^b	120^b	120^b	180 ($20^a + 160^b$)	120^b	180 ($20^a + 160^b$)
Water	175 ($160^a + 15^c$)	175 ($160^a + 20^c$)	175 ($160^a + 15^c$)	120^a	90^a	140^a	120^a
Oil	20	20	20	20	20	20	20
Baking powder	5	5	5	5	5	5	5
Lecithin	4	4	4	4	4	4	4
Salt	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Xanthan	2.8	2.8	2.8	2.8	2.8	2.8	2.8

^{a} Amounts used in the pre-gelatinisation step
^{b} Amounts mixed with other dry ingredients
^{c} Water added in the final mixing step

2.4 Raw material modifications

Ingredient modifications were done for two raw materials, sorghum, and cowpea. The recipes and baking times for prepared crackers are found in table 4, after section 2.4.3.

2.4.1 Milling and separation

Finely milled sorghum (SOR50F) was pin disc milled once with a 100 UPZ-lb Fine impact mill (Hosokawa Alpine, Germany) using 0.5 mm sieve size with a rotor speed of 17800 rpm.

Air-classified sorghum (SOR50A) was prepared from twice milled (17800 rpm) flour with a Minisplit classifier (British Rema Manufacturing Company Ltd, UK, Classifier speed: 2000 rpm, airflow 220 m^3/h) to separate coarse particles from the flour. Cowpea protein-rich fraction (COW40P) was prepared with a 50-ATP classifier (Hosokawa Alpine AG, Augsburg, Germany), with a 9000 rpm rotor speed and 50 m^3/h airflow. Dehulled sample for cowpea (COW75D) was prepared by detaching the hulls by crushing with a Retsch SM300 cutting mill (Retsch, Germany) and removing hulls by air-classification. The separated material was milled twice with a pin disk mill with a rotor speed of 17800 rpm. These ingredients have been prepared by other researchers working on the InnoFoodAfrica project.

2.4.2 Enzyme treatment

Enzyme treatment with alcalase (Novozymes) was done for a 10 kg sorghum-water slurry with 20% dry matter (SOR50E). Ingredients were mixed in a combi kettle (Metos Proveno 4G 60E) for 4 h at 50 ˚C with a rotor speed of 31 rpm. The sorghum-flour slurry was alkalised to pH 8 with 1M NaOH (300 ml) before the enzyme was added. 1M HCl (30 ml) was used to adjust the slurry back to sorghum's native pH (6.3) at the end of the treatment. The slurry was freeze-dried (Christ Epsilon, Martin Christ Gefriertrocknungsanlagen GmbH, Germany) and milled (Hosokawa Alpine 100UPZ-lb fine impact mill, Hosokawa Alpine AG, Germany, Speed: 17800 rpm) before use.

2.4.3 Germination

The germination process started by steeping the whole cowpea seeds in water at 25 ˚C, where the seeds were soaked for 2 h and 8 h and dried for 30 min in between. After that, the cowpeas were allowed to germinate for 32 h at 25 ˚C. Two different drying variations were tested. Mild temperature drying was done in two sections for a total time of 18 h 30 min, where drying was started at 50 ˚C for 4 h 30 min followed by 14 h at 60 ˚C dried in mild temperature for 18 h ($COW75G_1$). Intensive drying for a total of 21 h was done with a stepwise temperature increase from 50 ˚C to 83 ˚C ($COW75G_2$). After drying, the sprouts were removed mechanically. Both materials were milled twice by pin disc milling (17,800 rpm) with Hosokawa Alpine 100UPZ-lb fine impact mill (Hosokawa Alpine AG, Germany). These ingredients have been prepared by other researchers working on the InnoFoodAfrica project.

Table 4 Recipes and baking processes used for the modified crop crackers. SOR50A = Sorghum 50% air-classified, SOR50F = Sorghum 50% finely milled, SOR50E = Sorghum 50% enzyme protease treatment, COW75D = Cowpea 75% dehulled, COW75G1 = Cowpea 75% germinated mild temperature drying, COW75G2 = Cowpea germinated intensive drying, COW40P = Cowpea 40% protein-rich fraction

	SOR50A	SOR50F	SOR50E	COW75D	COW75G_1	COW75G_2	COW40P
Mixing time (min)	3	3	3	2.5	2.5	2.5	2.5
Baking time (min)	19	19	18	13	15	15	15
Ingredient	Amount (g)						
Maise flour	120 (80[a] + 40[b])	120 (80[a] + 40[b])	120 (80[a] + 40[b])	60[a]	60[a]	60[a]	144 (80[a] + 64[b])
African crop	120[b]	120[b]	120[b]	180 (20[a] + 160[b])	180 (20[a] + 160[b])	180 (20[a] + 160[b])	96[b]
Water	195 (160[a] + 35[c])	195 (160[a] + 35[c])	185 (160[a] + 25[c])	130[a]	130[a]	130[a]	130[a]
Oil	20	20	20	20	20	20	20
Baking powder	5	5	5	5	5	5	5
Lecithin	4	4	4	4	4	4	4
Salt	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Xanthan	2.8	2.8	2.8	2.8	2.8	2.8	2.8

[a] Amounts used in the first baking step to gelatinise flour
[b] Amounts mixed with other dry ingredients
[c] Water added in the final mixing step

2.5 Technological properties and nutritional values of the crackers

The technological properties of the cracker dough and baked cracker samples were determined to see how the African crop flours affect the baking performance, colour and appearance, microstructure, piece weight and dimensions, moisture content, and texture. Nutritional values were calculated from the given values using the standard conversion factors for each nutrient and a final moisture content of 4%. The baking performance was evaluated by the bakers’ assessment.

2.5.1 Colour and appearance

The Colour and appearance of the cracker samples were analysed by visual observation of photographs taken under similar lighting in a light tent (Caruba PFC-4040D, Beilen, Netherlands).

2.5.2 Microstructure

The cracker microstructures were analysed by visual observation of stereomicroscope images taken with a Zeiss SteREO Discovery V8 stereomicroscope equipped with Achromat S 0.5× objective (Carl Zeiss MicroImaging GmbH, Göttingen, Germany). Crackers were cut in half and settled parallel under the microscope and photographed. Images were acquired using an Olympus DP-25 single-chip colour CCD camera (Olympus Life Science Europa GmbH, Hamburg, Germany) and the Cell^P imaging software (Olympus). Samples were photographed with 1x and 3.2x magnification.

2.5.3 Diameter, piece weight, spread ratio and puffiness

Both the length and width of the cut dough pieces, and baked crackers were measured with a digital caliper similarly as in Zolias et al. (2000) study. Both measurements were made by lining two random samples and measuring the total length and width and calculating the average. Thickness was measured from four random samples stacked in piles. For the dough samples stacking was done only once and for the baked samples restacking and measuring were done 4 times, from where the mean and standard deviation was calculated. The spread ratio for baked crackers was calculated by dividing the mean width by mean thickness. The puffiness was determined as in Xu et al. (2020) study, by calculating the ratio of the difference between baked crackers’ mean thickness and cracker dough's mean thickness. Four dough and baked cracker samples were weighted individually with Sartorius lab balance (AX6202, Göttingen, Germany).

2.5.4 Moisture content

Moisture content was determined using an OHAUS MB120 dryer (Switzerland) at 105 °C. Two crackers from each baking for each sample were crumbled with an immersion blender (Bamix M133, Switzerland). Two replicate measurements were done for 1 g of crumble.

2.5.5 Texture analysis

Texture properties were determined by a three-point bending test using a TA-XT.plus texture analyser (Stable Microsystems, Godalming, UK) with a 30 kg load cell. A total of 20 samples, 10 replicates from both duplicate bakings, were measured. Crackers were placed surface up, across two supports with a span distance of 34 mm (Figure 2). Loading force was applied to the centre of each cracker by a 90mm wedge with a travel distance of 5 mm and a trigger force of 20 g. The data acquisition rate was 500 pps and the pre-test, test and post-test speeds for the wedge were 1, 3 and 10 mm/s, respectively. Values for maximum force (F_{max}, N) and deformation at the beam centre under the failure load (D, mm) from each force-displacement curve were calculated with Texture Exponent software v.5.1.2.0 (Stable Microsystems, Godalming, UK).

Figure 2 The set-up for the 3-point bending test texture analyse

2.6 Sensory analysis

Sensory analysis was done in two parts. Firstly, sorghum and cowpea crackers were screened with a mini panel (n=4) to figure out if there were enough differences between the samples for a larger-scale descriptive sensory analysis. The second sensory analysis was held with a trained panel (n=10) only for cowpea-based crackers.

2.6.1 Small-scale sensory screening

A small-scale sensory panel of four members evaluated individually all produced sorghum and cowpea crackers in the given order and freely described the differences between samples. Crackers were evaluated in two parts, where the first four sorghum samples were evaluated for odour, appearance, taste, flavour, and texture, followed by a round table discussion regarding the best fitting attributes. This was repeated for the five cowpea samples. Furthermore, the intensity of sorghum crackers' graininess and cowpea crackers' beany flavour, was evaluated on a numerical scale of 0-10, where 10 was the most intense. Carr’s Original cracker was used as a reference for graininess intensity 0 and no reference for beany flavour was used. The panellists were advised to focus especially on the discriminant attributes of the samples and write describing attributes on the paper for the following discussion. This minipanel aimed to find out whether there were enough differences between the samples keeping the focus point on sorghum samples’ graininess and cowpea samples’ beany flavour. Sensory evaluation booths contained a glass of water, a pencil, an eraser, a sensory evaluation ballot and a tray with samples and a paper towel (Figure 3).

Figure 3 The set-up for small-scale sensory screening in the sensory evaluation booth

2.6.2 Descriptive sensory analysis sample selection

Based on the results gained from the small-scale sensory screening only cowpea samples were decided to evaluate with a trained panel (Table 5). Based on the small-scale sensory screening results, COW40P was decided to be replaced with lower protein content protein fraction flour (from 55% to 40%) to increase the flour replacement percentage. Furthermore, COW75G2 was decided to remove from the samples and replace with flour where germinated (mild temperature dried) and protein fractionation treatments were combined. COW75 was decided to be made from similarly milled flour to the other samples in the next sensory evaluation to minimize the effect of coarser flour on the results. Furthermore, all samples were prepared with the same protein content (20%), water content (130 g) and baking time (16 min at 180 °C).

Table 5 Cowpea samples used in the descriptive sensory analysis

Abbreviation	Sample
CW	Cracker containing Cowpea White
CW-D	Cracker containing Cowpea White Dehulled
CW-PF	Cracker containing Cowpea White Protein-rich Fraction
CW-G	Cracker containing Cowpea White Germinated
CW-G-PF	Cracker containing Cowpea White Germinated Protein-rich fraction

2.6.3 Descriptive sensory analysis lexicon creation

The lexicon for cowpea samples was created based on odour, appearance, taste and flavour and mouthfeel with four panellists working at VTT. Odour and appearance were evaluated by looking at and smelling each sample followed by a round table discussion. Taste, flavour, and mouthfeel were evaluated by tasting the samples. During the discussion, suitable attributes were chosen for the panellists' training. Furthermore, suitable reference samples for training were discussed during the lexicon creation (Table 6). In this session, the samples were served on plates, but the panellists preferred similar serving as in the sensory screening.

Table 6 References and attributes used in the descriptive sensory analyse

Attribute	Reference product
Oily odour and flavour/crispness/roasted flavour (R)	RITZ original cracker
Beany odour and flavour (P)	2% cowpea flour water suspension
Roasted odour/cereal flavour/sweetness/Hardness (D)	LU Classic Digestive
Golden brown colour/Crispness (J)	Twist Snack Cheese (Griesson)
Greyish brown colour (M)	Special K Original Cereal multigrain (Kellogg's)
Saltiness (T)	TUC Original Crackers

2.6.4 Descriptive sensory analysis panel training

The trained panel consisted of 10 panellists each of whom attended a training session where odour and taste and flavour attributes were gone through. The training sessions were held in two groups of five panellists. All the panellists gave their consent to be involved in the trial based on the prior information given about the study, allergens and used materials. A ballot was created based on the lexicon creation and held in the same order as the attributes were in the ballot (Appendix 1). For each attribute panellists were asked first to smell the reference and then taste the sample most likely having the attribute based on the lexicon. References and sample attribute intensity were evaluated on a scale of 0-10. After the second group had tasted a reference for the first time, they were told how intense the first group rated it, and whether they agreed with the score the first group gave the reference. The main goal of this training session was to have an agreement on the intensity scale and to identify attributes found in the lexicon creation. After each attribute panellists were asked to give their opinion on whether the instructions were clear enough, the references were suitable and whether the attribute should be included in the final ballot.

2.6.5 Descriptive sensory analysis

Each sample was served in a plastic cup covered with a plastic lid and coded with a 3-digit code number. Samples were evaluated in randomised order so that each sample occurs in the same spot an equal number of times. Sensory evaluation booths contained a computer, glass of water, notepad, pencil, eraser, sensory evaluation ballot, a tray with samples, references, and a paper towel. The trays were numbered from 1 to 10, which panellists had to enter into the software to get the evaluating order. At first, the odour intensity attributes (total, beany, oily and roasted) were evaluated, followed by appearance and tactile texture (colour and crispiness), taste and flavour (total intensity, beany flavour, roasted flavour, cereal flavour, sweetness, saltiness, and oily flavour) and finally mouthfeel and texture (crispness, graininess, and hardness). Between each sample, panellists were asked to drink and smell water. Analysis was done by Compusence Five Version 5.6 sensory analysis software (Compusence Inc., Guelph, Ontario Canada). Trays were numbered from 1 to 10, which was used as an alias for the panellist and for creating the sample testing order. Analysis was done as a replicated complete block design descriptive sensory analysis in two sessions.

2.7 Statistical analysis

Averages and standard deviations on the technological properties were analysed with Microsoft Excel (Version 2108) software. For sensory analysis, the average and standard deviation were calculated from the results to observe the scores from the whole group. IMB SPSS Statistic version 28.1 was used for two-way mixed model ANOVA where samples were as a fixed factor and assessors as a random factor. Furthermore, statistical differences for baked samples' weight, thickness, spread ratio, puffiness, texture, and sensory analyses were determined by analysis of variance (One-Way ANOVA), with mean separations performed by Tukey's honest significant difference test. A 95% confidence level was presumed with a statistical significance level of $p < 0.05$.

3 RESULTS

All the African crop replacements improved the crackers' nutritional value when compared to the control cracker (Table 7). Furthermore, all crop replacements increased the fibre content to the level where high fibre nutrition claim can be used. All legume crackers, except BAM50, reached the criteria limit for the claim *source of protein* and with protein fraction replacement (COW40P) the criteria limits for *high protein* claim could be reached.

The baking performance was affected by the African crop addition. The cracker dough was more elastic, and it was easier to handle after African crop addition. Legume crops had a more severe effect than cereal crops. For the legume crackers, the water amount had to be decreased from 175 g to avoid increasing dough stickiness, and the total mixing time was decreased to 2 min 30 s. With similar water amounts used with cereal crackers, the dough development for legume crackers happened between 15 and 45 s. Bambara groundnut replacement increased the softness and elasticity of the dough the most when compared to other doughs. With cowpea replacement, the dough became harder. Despite the hard structure, the dough was still elastic and easy to handle. From cereal crops, amaranth increased the dough elasticity the most whereas sorghum had the least effect of all samples. The raw material modification had a more notable effect on the dough consistency with SOR samples than with cowpea samples. For modified sorghum raw materials, the water amount had to be increased to prepare a workable dough. The finer particle size made the dough more brittle in sorghum samples, but with the correct water amount, the dough was easier to work with than SOR50.

Table 7 The calculated nutritional values for fibre (g/100 g) and protein from total energy (E%) and the claims that can be used. All nutritional values were calculated based on 4% final moisture. AMA50 = Amaranth 50% replacement, TEF50 = Teff 50% replacement, SOR50 = Sorghum 50% replacement, SOR50A = Sorghum 50% air-classified, SOR50F = Sorghum 50% finely milled, SOR50E = Sorghum 50% enzyme protease treatment, BAM50 = Bambara groundnut 50% replacement, BAM75 = Bambara groundnut 75% replacement, COW50 = Cowpea 50% replacement, COW75 = Cowpea 75% replacement, COW75D = Cowpea 75% dehulled, COW75G1 = Cowpea 75% germinated mild temperature drying, COW75G2 = Cowpea germinated intensive drying, COW40P = Cowpea 40% protein-rich fraction

Sample	Fibre (g/100 g)	Protein (E%)	High Fibre	Source of protein	High Protein
Control	3.7	5.7			
AMA50	6.8	10.2	x		
TEF50	6.1	7.6	x		
SOR50	6.6	7.9	x		
SOR50A	6.3	7.6	x		
SOR50F	6.3	7.6	x		
SOR50E	6.6	7.9	x		
BAM50	12.3	11.5	x		
BAM75	16.6	14.0	x	x	
COW50	13.2	14.1	x	x	
COW75	18.0	17.9	x	x	
COW75D	18.0	17.9	x	x	
COW75G1	17.1	18.7	x	x	
COW75G2	16.9	18.9	x	x	
COW40P	10.8	20.3	x	x	x

3.1 Colour and appearance

As expected, all the crops increased the crackers' brown colour. BAM50 was the most yellow of all samples and COW75 had the darkest colour (Figure 4). The brown colour increased when the replacement amount increased. Dehulling lightened the brown colour whereas germination increased the yellowness of the cowpea samples. Germination and air-fractionation decreased the large white particles on cowpea crackers' surface. Germination and protein fractionation evened the cracker surface compared to COW75. Larger particles and parts of seed coats were seen only in the COW75 sample. Furthermore, COW40P did not have dark particles like other cowpea samples. In sorghum samples, the raw material modification decreased the yellowness of the cracker and gave greyer colour. SOR50E was the most similar to SOR50 when comparing the colour and appearance. Air-fractionating and fine milling evened the surface of the crackers compared to SOR50 and removed the large white particles that were present in both SOR50 and SOR50E samples. SOR50A did not have the small black particles as other sorghum samples. Furthermore, SOR50A had the most cracks on the cracker surface compared to other sorghum crackers. The cereal crackers, excluding AMA50, had a curvier appearance than the legume crackers.

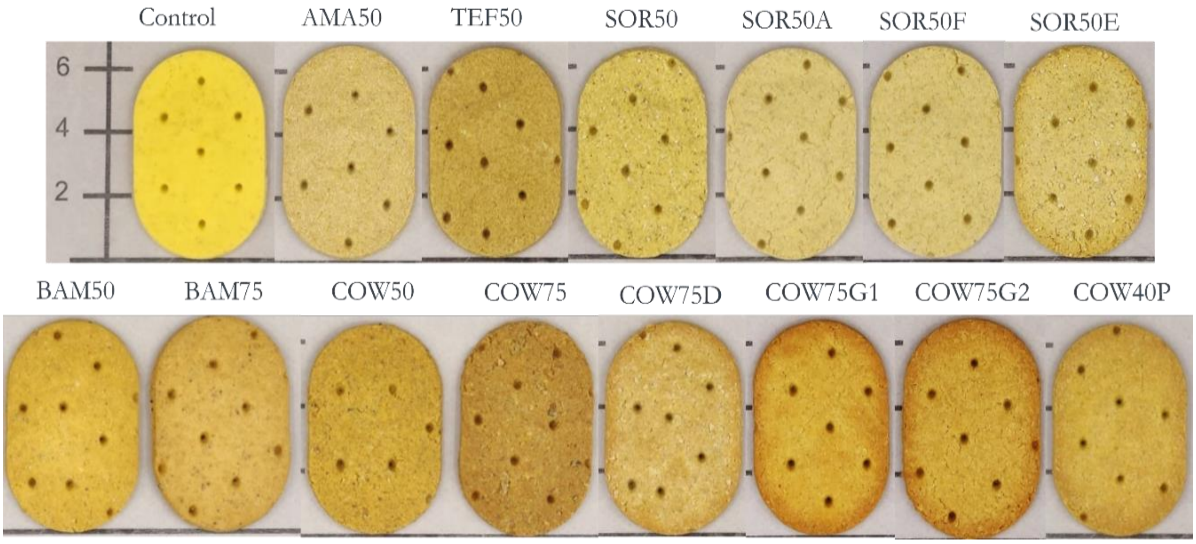


Figure 4 Samples photographed in a photobooth for colour and appearance analysis. AMA50 = Amaranth 50% replacement, TEF50 = Teff 50% replacement, SOR50 = Sorghum 50% replacement, SOR50A = Sorghum 50% air-classified, SOR50F = Sorghum 50% finely milled, SOR50E = Sorghum 50% enzyme protease treatment, BAM50 = Bambara groundnut 50% replacement, BAM75 = Bambara groundnut 75% replacement, COW50 = Cowpea 50% replacement, COW75 = Cowpea 75% replacement, COW75D = Cowpea 75% dehulled, COW75G1 = Cowpea 75% germinated mild temperature drying, COW75G2 = Cowpea germinated intensive drying, COW40P = Cowpea 40% protein-rich fraction

3.2 Structure

TEF50 had the densest and most even structure when compared to other samples and it was the most similar to the control sample, as analysed by visual observation of stereomicroscope images (Figure 5). The control sample had a firm surface and was more porous inside than the other samples. SOR50 had large white particles in the structure which made it more porous than the control or TEF50. The raw material modification increased the air-cell formation in SOR50A and SOR50F. SOR50E did not have a notable difference from SOR50. AMA50 had a layered and clustered air-cell structure, which was notably different from other samples. Bambara groundnut and COW75 samples had more evenly spread air-cells than AMA50. COW50 and all the modified cowpea samples had a denser structure than COW75.

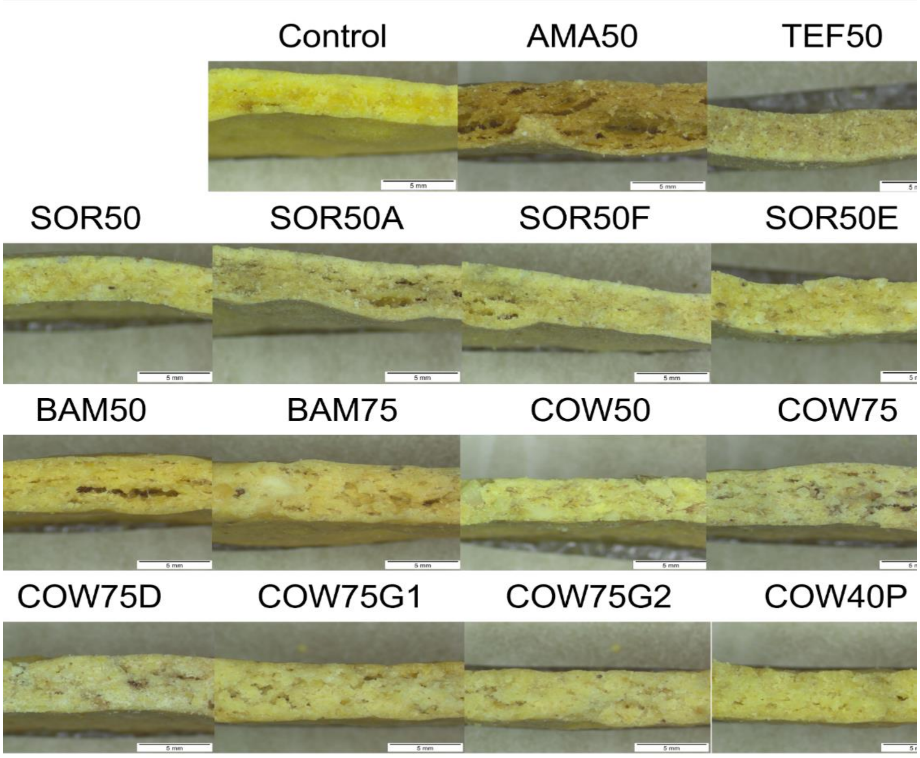


Figure 5 Microstructure of crackers imagined by stereomicroscope in 5mm scale bar. AMA50 = Amaranth 50% replacement, TEF50 = Teff 50% replacement, SOR50 = Sorghum 50% replacement, SOR50A = Sorghum 50% air-classified, SOR50F = Sorghum 50% finely milled, SOR50E = Sorghum 50% enzyme protease treatment, BAM50 = Bambara groundnut 50% replacement, BAM75 = Bambara groundnut 75% replacement, COW50 = Cowpea 50% replacement, COW75 = Cowpea 75% replacement, COW75D = Cowpea 75% dehulled, COW75G1 = Cowpea 75% germinated mild temperature drying, COW75G2 = Cowpea germinated intensive drying, COW40P = Cowpea 40% protein-rich fraction

3.3 Moisture content, weight, dimensions, spread ratio, and puffiness

The moisture contents of crackers varied notably between the samples and replicate bakings (Table 8). Aimed final moisture content was between 1-5%, which was reached with all samples. The highest moisture contents were noticed with COW75 (3.87 ± 1.01) and COW75D (4.49 ± 0.03). As presented in Table 8, all African crop flour replacements, except SOR50 (7.00 ± 0.07 g), increased the dough and baked cracker weight. The higher replacement levels and the legume flours increased the cracker weight more than cereal replacements. Furthermore, the amount of added water and crackers' final moisture content had a slight effect on the weight. Differences between the length and width were small, whereas thickness varied more between the samples. AMA50 (22.66 ± 0.20) and BAM75 (22.69 ± 0.22) samples were the thickest and the control (18.05 ± 0.11) and SOR50 (18.52 ± 0.43) thinnest.

Table 8 The average moisture, weight, and dimensions of the crackers from two replicate baking. For each baking, moisture, length, and width were determined from two replicates and weight and thickness for dough and baked crackers from four replicates. AMA50 = Amaranth 50% replacement, TEF50 = Teff 50% replacement, SOR50 = Sorghum 50% replacement, SOR50A = Sorghum 50% air-classified, SOR50F = Sorghum 50% finely milled, SOR50E = Sorghum 50% enzyme protease treatment, BAM50 = Bambara groundnut 50% replacement, BAM75 = Bambara groundnut 75% replacement, COW50 = Cowpea 50% replacement, COW75 = Cowpea 75% replacement, COW75D = Cowpea 75% dehulled, COW75G1 = Cowpea 75% germinated mild temperature drying, COW75G2 = Cowpea germinated intensive drying, COW40P = Cowpea 40% protein-rich fraction

Sample	Moisture (%)	Weight (g)		Thickness 4x (mm)		Length (mm)	Width (mm)
		Dough	Baked	Dough	Baked		
Control	1.12 ± 0.40	11.57 ± 0.09	7.16 ± 0.47^{a}	14.80 ± 0.09	18.05 ± 0.11^{a}	64.43 ± 2.31	43.43 ± 0.78
AMA50	1.17 ± 0.47	12.68 ± 0.26	7.78 ± 0.28^{a}	16.00 ± 0.22	22.66 ± 0.20^{e}	65.52 ± 0.72	43.99 ± 0.44
TEF50	1.59 ± 0.50	12.31 ± 0.23	7.50 ± 0.04^{ab}	15.23 ± 0.14	18.97 ± 0.40^{ab}	64.68 ± 0.40	43.87 ± 0.22
SOR50	2.13 ± 0.04	11.41 ± 0.01	7.00 ± 0.07^{a}	15.13 ± 0.03	18.52 ± 0.43^{a}	65.33 ± 0.54	43.63 ± 0.00
SOR50A	3.03 ± 0.58	12.59 ± 0.17	7.55 ± 0.23^{ab}	16.02 ± 0.12	20.01 ± 0.28^{bc}	65.54 ± 0.02	43.26 ± 0.20
SOR50F	2.18 ± 0.29	12.01 ± 0.15	7.46 ± 0.06^{ab}	15.68 ± 0.10	19.49 ± 0.13^{abc}	65.40 ± 0.47	43.53 ± 0.10
SOR50E	2.70 ± 1.08	12.05 ± 0.37	9.56 ± 0.11^{fg}	15.30 ± 0.61	19.14 ± 0.60^{ab}	65.89 ± 0.32	43.56 ± 0.50
BAM50	1.82 ± 0.06	12.65 ± 0.09	8.29 ± 0.11^{cd}	15.57 ± 0.13	21.38 ± 0.21^{d}	65.51 ± 0.04	44.12 ± 0.11
BAM75	2.49 ± 1.39	12.76 ± 0.07	9.47 ± 0.07^{fg}	15.82 ± 0.51	22.69 ± 0.22^{e}	66.93 ± 0.32	45.77 ± 0.01
COW50	1.64 ± 0.91	12.67 ± 0.02	8.46 ± 0.04^{de}	15.80 ± 0.15	19.64 ± 0.14^{abc}	65.98 ± 0.20	44.26 ± 0.19
COW75	3.87 ± 1.01	12.72 ± 0.20	9.15 ± 0.45^{fg}	15.45 ± 0.13	20.01 ± 0.54^{bc}	67.01 ± 0.16	44.61 ± 0.08
COW75D	4.49 ± 0.02	13.43 ± 0.01	9.73 ± 0.14^{g}	15.95 ± 0.01	21.44 ± 0.04^{de}	67.09 ± 0.23	45.95 ± 0.09
COW75G1	2.34 ± 0.06	13.26 ± 0.02	9.47 ± 0.02^{fg}	15.66 ± 0.32	20.68 ± 0.26^{cd}	66.40 ± 0.17	44.82 ± 0.06
COW75G2	1.71 ± 0.11	13.48 ± 0.18	9.55 ± 0.11^{fg}	15.50 ± 0.35	20.69 ± 0.25^{cd}	66.57 ± 0.05	44.65 ± 0.03
COW40P	3.47 ± 1.23	13.43 ± 0.23	9.08 ± 0.05^{ef}	16.43 ± 0.01	21.52 ± 0.21^{de}	66.46 ± 0.13	45.16 ± 0.08

$^{a, b, c, d, f, g}$ Values in the same column with a different superscript differ significantly at 0.05 level

The control (9.06 ± 0.34), TEF50 (9.26 ± 0.15) and SOR50 (9.43 ± 0.22) had the highest spread ratio (Figure 6). AMA50 (7.76 ± 0.01) had the lowest spread ratio of all samples. A slight decrease in spread ratio could be noticed with higher crop replacement levels. All the raw material modifications decreased the spread ratio in sorghum samples, whereas COW75G$_1$ (8.58 ± 0.07), COW75G$_2$ (8.46 ± 0.32) and COW40P (8.52 ± 0.06) had higher spread ratios than COW75 (8.32 ± 0.25). The lower spread ratio implies that all African crop crackers had better rising ability than the control cracker. The control cracker had the lowest puffiness (21.93 ± 0.002%) of all samples whereas BAM75 had the highest (43.57 ± 3.29%). Puffiness compared to control was increased 2-50% depending on the crop. The increased replacing amount increased the puffiness notably with Bambara groundnut and cowpea samples. All raw material modifications increased the puffiness in sorghum and cowpea samples compared to the unmodified raw material. AMA50 (41.73 ± 3.13%) had the highest puffiness compared to other cereal crackers. The puffiness was highly affected by the cracker's final moisture content. Higher puffiness percentages were reached with higher moisture contents.

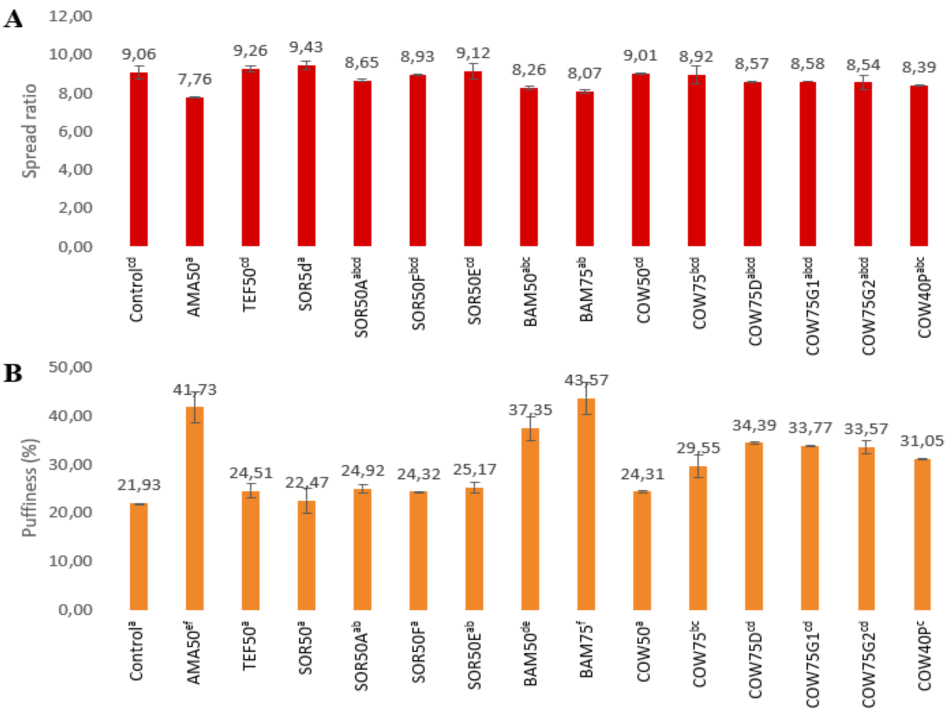


Figure 6 The spread ratio (A) and puffiness (B) for crackers were calculated from the measured dimensions done for 2 replicates. Both results are presented as averages and standard deviations for two separate bakings. $^{a, b, c, d}$ Values in the same figure with a different superscript differ significantly at 0.05 level. AMA50 = Amaranth 50% replacement, TEF50 = Teff 50% replacement, SOR50 = Sorghum 50% replacement, SOR50A = Sorghum 50% air-classified, SOR50F = Sorghum 50% finely milled, SOR50E = Sorghum 50% enzyme protease treatment, BAM50 = Bambara groundnut 50% replacement, BAM75 = Bambara groundnut75% replacement, COW50 = Cowpea 50% replacement, COW75 = Cowpea 75% replacement, COW75D = Cowpea 75% dehulled, COW75G1 = Cowpea 75% germinated mild temperature drying, COW75G2 = Cowpea germinated intensive drying, COW40P = Cowpea 40% protein-rich fraction

3.4 Texture analysis

The control (4.02 ± 1.83 N) and SOR50 (4.99 ± 1.94 N) crackers had the lowest peak forces of all samples (Table 9). COW40P (31.55 ± 6.06 N) had significantly higher ($p < 0.05$) peak force than any other sample. Higher moisture and protein content and finer particle size affected increasingly the peak force, which indicates the increased hardness of the crackers. Furthermore, the higher replacement amount increased the hardness of BAM75 (21.64 ± 5.25 N) and COW75 (13.47 ± 2.34 N) samples significantly compared to BAM50 (12.54 ± 3.27 N) and COW50 (6.46 ± 2.22 N) ($p < 0.05$). Sorghum and cowpea samples' hardness was increased with raw material modifications. Small cracks and large air-cells on the cracker structure caused a larger deviation between replicate samples. Furthermore, higher moisture content of the samples increased the force notably.

Table 9 Texture analysis measured by 3-point bending test from a total of 20 replicates from 2 replicate bakings. Peak forces (N) and coefficient of variation (%) are presented as an average of all measurements. AMA50 = Amaranth 50% replacement, TEF50 = Teff 50% replacement, SOR50 = Sorghum 50% replacement, SOR50A = Sorghum 50% air-classified, SOR50F = Sorghum 50% finely milled, SOR50E = Sorghum 50% enzyme protease treatment, BAM50 = Bambara groundnut 50% replacement, BAM75 = Bambara groundnut 75% replacement, COW50 = Cowpea 50% replacement, COW75 = Cowpea 75% replacement, COW75D = Cowpea 75% dehulled, COW75G1 = Cowpea 75% germinated mild temperature drying, COW75G2 = Cowpea germinated intensive drying, COW40P = Cowpea 40% protein-rich fraction

Sample	Peak force (N)			Coef. of Variation (%)
Control	4.02	±	1.83^{a}	45.04
AMA50	15.66	±	6.20^{efg}	36.15
TEF50	21.66	±	4.51^{h}	18.66
SOR50	4.99	±	1.94^{ab}	38.98
SOR50A	9.94	±	2.80^{cd}	27.44
SOR50F	7.94	±	2.47^{bc}	29.49
SOR50E	8.66	±	1.50^{bc}	16.78
BAM50	12.54	±	3.27^{de}	24.57
BAM75	21.64	±	5.25^{def}	24.37
COW50	6.46	±	2.22^{abc}	33.40
COW75	13.47	±	2.34^{def}	14.96
COW75D	18.71	±	3.63^{gh}	19.94
COW75G1	17.27	±	1.49^{fg}	8.73
COW75G2	18.81	±	1.78^{gh}	9.02
COW40P	31.55	±	6.06^{i}	10.16

$^{a, b, c, d, f, g}$ Values in the same column with a different superscript differ significantly at 0.05 level

3.5 Small-scale sensory screening

All modified samples decreased the perceived intensity of grainy mouthfeel in sorghum and beany flavour in cowpea compared to the unmodified sample used as a control (Table 10). Milling and air-classification decreased the graininess intensity the most in sorghum samples compared to control. Enzyme treatment changed the sensory profile the most by increasing the bitter and whole-grain flavour compared to the control. All samples were evaluated to have a dry mouthfeel. The control sample was sensed as the crispiest and the air-classified sample the softest. Enzyme treated sample was the most similar to the control in every evaluated parameter, excluding flavour.

Germinated cowpea samples were evaluated as the crispiest and the control sample the softest in texture. Furthermore, germinated samples were sensed the most decreased beany flavour based on the order median, where three of four panellists sensed the germinated samples less beany compared to protein fractionated sample. In addition, the protein fractionated sample was evaluated to have the hardest first bite of all samples. Dehulling did not have a significant effect on the beany flavour. Germination of the cowpea samples gave the samples a more sweet and roasted flavour, whereas dehulling was sensed as more umami-like and grassy flavoured when compared to the control. Protein fractionation was evaluated to give a more maise-like flavour than other samples, which may be due to the lower cowpea replacement percentage (40%).

Table 10 Small-scale sensory screening of the crackers (n=4). Mean descriptive analysis ratings on a 0-10 intensity scale and order median for intensity orders. SOR50 = Sorghum 50% replacement, SOR50A = Sorghum 50% air-classified, SOR50F = Sorghum 50% finely milled, SOR50E = Sorghum 50% enzyme protease treatment, COW75 = Cowpea 75% replacement, COW75D = Cowpea 75% dehulled, COW75G1 = Cowpea 75% germinated mild temperature drying, COW75G2 = Cowpea germinated intensive drying, COW40P = Cowpea 40% protein-rich fraction

Sample	Intensity (0-10)	Order (median)
SOR50	9.0 ± 1.73^{b}	1
SOR50A	2.8 ± 2.59^{a}	3
SOR50F	3.3 ± 2.38^{a}	3
SOR50E	6.6 ± 1.63^{ab}	2
COW75	6.5 ± 2.29	1.5
COW75D	6.0 ± 1.73	2
COW75G1	5.0 ± 3.39	3
COW75G2	4.5 ± 3.50	4
COW40P	3.5 ± 1.12	2.5

$^{a, b}$ Values in the same column with a different superscript differ significantly at 0.05 level (analysis performed separately for SOR and COW samples).

3.6 Descriptive sensory analysis

The descriptive sensory analysis was done for unmodified (control), dehulled, protein fractionated, germinated and germinated-protein fractionated samples to observe the differences between the odour, taste and flavour, colour, and mouthfeel. The unmodified cowpea sample had the most intense total flavour, beany flavour and odour, and grainy mouthfeel (Figure 7). Other tested samples were more similar to each other, and the odour attributes were more similar than the evaluated flavour attributes. All the modified samples increased the oily flavour and odour and roasted cereal flavour and odour, sweetness, pungency, yellowness, and hardness significantly ($p < 0.05$) compared to the control. Germination increased the roasted, cereal, sweet, pungent, and oily flavour, and crispiness the most. Both germinated samples were scored the least beany flavoured. Dehulling increased the hardness and tactile crispiness and decreased the crispy mouthfeel the most.

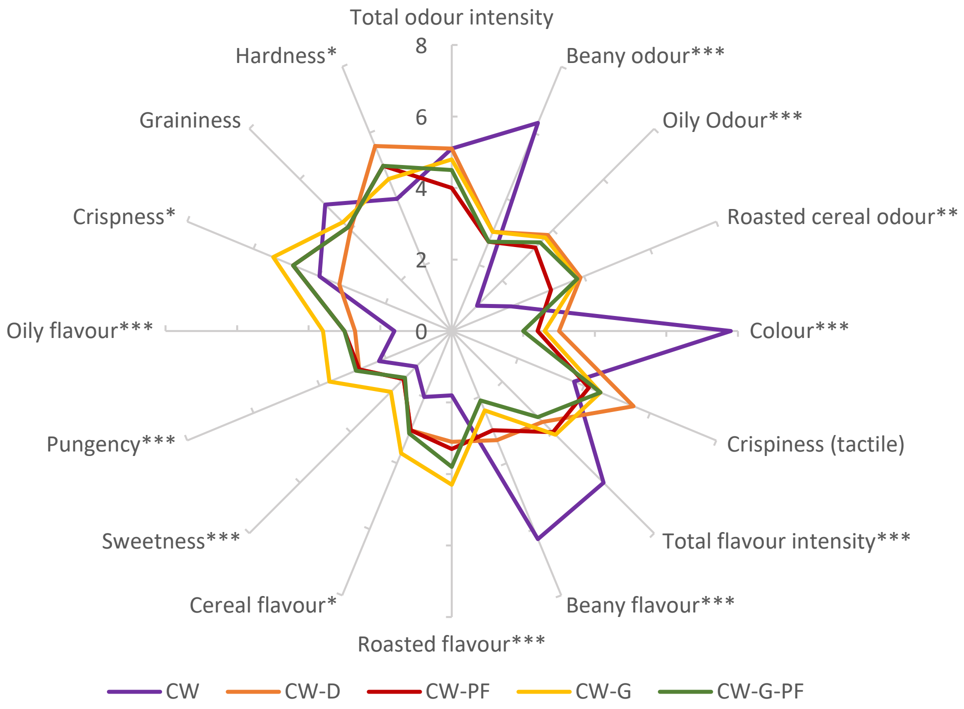


Figure 7 Comparison of sensory profiles of cowpea crackers (CW=Cowpea white, CW-D=Cowpea white dehulled, CW-PF=Cowpea white protein-fraction, CW-G=Cowpea white germinated, CW-G-PF=Cowpea white germinated protein-fraction) as evaluated by a trained panel. Each attribute was rated on a scale from 0-10. The mean difference is significant at * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

4 DISCUSSION

The higher nutritional quality of the African crop crackers can be attributed to the nutritional composition of the studied African crops, with higher fibre and protein content than maise. Comparable results have been shown in several studies of the studied crops (Sindhuja et al. 2005; Omoba et al. 2015; Darmatika et al. 2018; Yeboah-Awudzi et al. 2018). Amaranth's nutritional composition is closer to the legume crops, with higher protein and lipid content than the other cereal crops which can be seen as a higher increase in the protein content (Virupaksha and Sastry 1968; Hugo et al. 2003; Rooney 2016). To get the exact nutritional composition of the crackers, they should be analysed experimentally, but the calculations gave a realistic estimate of the composition.

4.1 Baking performance

In this study, the baking performance was affected by the replacement of maise flour with African crop flours, which can be mainly attributed to the lower starch and higher protein content of the supplemented flours. The lower starch content and difference in the starch composition of Bambara groundnut and cowpea samples compared to the control sample made from 100% maise may have led to a decrease in added water. Higher levels of amylose decrease the water binding by increasing the hydrogen bonding between and within the amylose molecules, which decreases the water binding (Wootton and Bamunuarachchi 1978; Sirivongpaisal 2008; Hoover et al. 2010; Rema and Jyothi 2015). Mancebo et al. (2015) observed that pre-gelatinisation and fine-grained flour, due to increased damaged starch content, increases the hydration capacity of the flour. Similar findings were done by Patel et al. (2005) and Nammakuna et al. (2016), who indicated that starch increases the viscosity of dough through gelatinisation. Finer particle size could also explain the need to increase water amount to air-classified and finely milled sorghum samples compared to unmodified sorghum. Furthermore, amaranth starch has a low amylose content which increases the viscosity of the dough (Belton and Taylor 2002). The combination of the starch composition and the high protein content increases the amaranth water binding compared to the control. According to Kaushal et al. (2012), the flours water and oil binding capacity also depend on the amino acid composition, protein conformation and surface polarity.

Globulins which are present in amaranth, Bambara groundnut and cowpea may form gels during heating when protein denaturation occurs (Taylor et al. 2014). This may also be one of the reasons for more elastic dough formation, especially in Bambara groundnut and cowpea. According to Yeboah-Awudzi (2018), Bambara groundnut may provide enough protein to the dough matrix to overcome the lack of gluten and provide an elastic structure through protein interactions. The same conclusion could be made for cowpea and amaranth samples. According to Nammakuna et al. (2016), the dough elasticity is highly dependent on the protein nature and functional properties, which may explain the differences between the studied doughs. The higher lipid content of amaranth and Bambara groundnut crops increases the softness of the dough. According to Yeboah-Awudzi et al. (2018), the softening may be due to lipids acting as lubricating agent. In addition, according to Pareyt’s and Delcour’s (2008) article, high fat content of a dough reduces the need for water addition, due to the lubricating effect, and this could also be the reason for the lowest water amount used in the Bambara groundnut dough. With the higher fat content of the Bambara groundnut flour, the water amount can be decreased to make a workable dough.

4.2 Technological properties

According to Mancebo et al. (2015) and Yeboah-Awudzi et al. (2018), protein increase in crackers increases the dark colour due to the Maillard reaction. Similar findings of darker colour and protein increase occurred in this study. The decrease of yellowness in the African crop crackers may also be due to the decrease in carotenoids which are present in maise flour. Similar results of darker colour when increasing the replacement amount of cowpea was gained in Hallén et al. (2004) study. Furthermore, a similar observation of increased yellowness whereas using germinated cowpea flour was seen in the Hallén et al. (2004) article, where fermented and germinated cowpea flours were studied.

According to Pareyt and Delcour (2008), lipids are present as large globules of interconnecting masses between the starch and protein in cookies and crackers, which also enhances the air-cell formation and coalescence. This is in line with the finding in amaranth and Bambara groundnut structure analysis where larger air-cells were present due to the crops higher lipid content compared to other samples. Yeboah-Awudzi et al. (2018) presented, that higher replacement levels of Bambara groundnut increase the air-cell formation, which can also be seen in the Bambara groundnut samples where increased replacement amount increased the air-cell size and amount. Protein is responsible for layer formation by helping starch granules to adhere to one another (Nammakuna et al. 2016). According to Nammakuna et al. (2016), rice flour dough is not strong enough to hold air cells and it is not cohesive and lacks good viscoelastic properties, which is seen as a dense and unlayered structure. This could also be the case with maise flour crackers developed in this thesis, as both cracker structures are mainly based on starch gelatinisation.

The final moisture content of the crackers was highly affected by the fluctuating temperature of the used rotating rack oven. The oven uses an average temperature, which means that the temperature may change during the baking. Furthermore, the humidity and temperature in the bakery may change due to weather changes and may have caused differences in the moisture content. According to Wani et al. (2015) and Wang et al. (2016), the particle size and protein content have an impact on the final moisture. Furthermore, Nammakuna et al. (2016) found equivalent results on increasing moisture contents when protein isolates were added to gluten-free cracker dough. The moisture contents could be standardised for all samples by different baking times or secondary drying phases. A standardised moisture content would be optimal to make a proper comparison between the samples. As mentioned before, an optimal moisture content for crackers is between 1-5% which was acceptably reached in this thesis.

In Nammakuna et al. (2016) study, where the effects of protein isolates on gluten-free cracker physicochemical properties were studied, it was concluded that higher protein content increases the thickness of the cookies due to the created protein matrix. This explains the slightly increased thicknesses of the African crop crackers. Furthermore, the higher protein content crackers had greater thickness than the other samples. Amaranth samples' significantly higher thickness compared to other cereal crackers may be explained by the air-cell formation. According to Singh et al. (2018) and Elkhalifa and Bernhardt (2010), germination decreases sorghum flours swelling power. This might explain the slightly decreased thicknesses of germinated cowpea samples when compared to the dehulled sample, where similar particle-sized flour was used. The decrease in thickness might be due to the enzyme activity during germination, which restricts starch swelling. According to Zoulias et al. (2000), if cookies expand in the early stages of baking and do not spread it is shown as greater thickness. Furthermore, according to Serrem et al. (2011) and Omoba et al. (2015), in finely milled sorghum the endosperm proteins, which are limiting starch hydration and swelling are slightly destroyed. This could explain the increase in thickness in air-classified and finely milled sorghum samples. The spread ratio describes the rising ability of the cracker. The spread ratio is highly dependent on the dough viscosity and highly influenced by the water-binding components in the dough (Pareyt and Delcour 2008; Mancebo et al. 2015). Therefore, higher protein content restricts the spread when compared to lower protein content crackers (Cheng and Bhat 2016). Comparable results were indicated by Yeboah-Awudzi et al. (2018), where a higher supplementation level (18%) of Bambara groundnut flour in crackers decreased the spread ratio compared to lower supplementation (9%) from 4.73 to 4.08. According to Cheng and Bhat (2016), lower spread ratios might also be attributed to higher protein content exhibiting water binding ability which restricts the spread. Flours with high hydration properties will have less water to dissolve sugars in the cracker matrix, which increases the dough viscosity and restricts the spread (Mancebo et al. 2015).

Gaines (1985) presented that the spread ratio is highly dependent on flour particle size. In some doughs, finer particle-sized flour reduces the diameter of the cracker, but with soft flours, finer particle size decreases density and is shown as a more developed dough with a lower spread ratio. This could be the reason for lower spread ratios seen with air-classified and finely milled sorghum samples when compared with unmodified sorghum. Similar findings were done by Mancebo et al. (2015), where coarse-grained flours produced the greatest spread for gluten-free cookies.

Puffiness describes the final quality of the crackers and correlates positively with acceptability. Puffiness occurs when moisture which is trapped within a starch matrix evaporates due to high temperature (Akonor et al. 2017). In this study, finer particle size and higher protein content increased puffiness. According to Nammakuna et al. (2016), protein addition may produce protein matrixes to replace the lack of gluten in gluten-free crackers which is seen as increased puffiness. Furthermore, puffiness is highly dependent on the ability to hold air cells (Nammakuna et al. 2016; Qadri et al. 2018). According to Cauvain (2016), fat plays a vital role in layer separation in crackers. Fat with small crystal size and high solid fat index at room temperature will give good layer separation and greater puffiness. Both amaranth and Bambara groundnut samples had higher lipid content with a palmitic acid content of around 20% of the total lipids due to the lipid composition of the crop. Palmitic acid has a small crystal size and high solid fat index, which may have affected increasingly to puffiness.

According to Yeboah-Awudzi et al. (2018) study, where the effect of Bambara groundnut flour supplementation on rice flour crackers was studied, the crackers' hardness is increased mainly due to the increased protein content. Similar findings were made in this study. Furthermore, Mancebo et al. (2015) presented that the smaller particle size of the flour increases the cracker hardness. As seen in the results, the cracker structure became more compact with finer particle size, and it may be related to the increased hardness. Furthermore, similar results were presented in Wang et al. (2016) article. Wang et al. (2016) also presented a correlation between moisture content and hardness. According to the study lower moisture content crackers resulted in lower breaking forces than the higher moisture content crackers. This is due to the leather-like texture of higher moisture content crackers (Wang et al. 2016). The correlation was also seen in this study when samples with different moisture content from replicate bakings were tested. Chauhan et al. (2015) presented that, germination softened cookies made from amaranth flour, which was due to the degradation of starch and protein during the germination process. Comparable results can be seen between the cowpea samples with similar particle sizes, where germination has softened the cracker texture.

4.3 Sensory properties

The results of the small-scale sensory screening provided important data on how the raw material modifications affected the samples' sensory properties. The small-scale sensory screening and descriptive sensory analysis both indicated that raw material modification decreases the intensity of beany flavour. The results gained from the sensory screening could be fortified by the descriptive sensory analysis results.

Similar findings in decreased graininess by finer particle size were found in several articles (Serrem et al. 2011; Omoba et al. 2015; Marston et al. 2016). The sorghum's grainy texture is mainly due to the endosperm proteins, which may be destroyed during milling. This could also be seen in unmodified and enzyme-treated sorghum samples where white specks were visible and affecting the grainy mouthfeel. According to Serrem et al. (2011), the dryness of the sorghum crackers may be due to the hydrophobic kafirin proteins present in the endosperm. Similar dry mouthfeel was also seen in this study.

According to Okaka and Potter (1979) and Anyango et al. (2011), the beany flavour of cowpea is attributed to the lipoxygenase enzyme, which catalyses the formation of pentyl furans from the *cis*-1,4-pentadiene system containing components. The decrease of beany flavour by germination was shortly discussed in Duarte's (2020) article, where a slight decrease in beany flavour was noticed after germination. However, a cooking step after germination must be present to have a clear decrease in beany flavour. This could explain a slight difference in the sensed beany flavour between COW75G$_1$ and COW75G$_2$, where the latter had a higher drying temperature which may have affected decreasingly to the beany flavour. According to McWatters (1978), the beany flavour could be decreased by steaming for several minutes or soaking in acidified water. It is possible, that the soaking step prior to germination has slightly decreased the beany flavour of the cowpea flours before baking.

The decrease in beany flavour in the germinated crackers was most likely due to the reduction in lipoxygenase activity and amino acid degradation during germination, which was also found in Kaczmarska et al. (2018) and Xu et al. (2019) studies. Similar findings were done in Akkad et al. (2021) study, where the bitter compounds (tannins) and beany flavours (hexanal, nonanal, 2-heptanone and 2-pentylfuran) were decreased after germination. However, according to Xu et al. (2019), a longer germination time (over 4 days) may increase the beany flavour. According to Kaczmarska et al. (2018), germination also increased the sweet roasted and baked aroma of lupin and soybean, which relates well with the results gained in this study. The increase in sweetness in germinated samples may be due to the degradation of oligosaccharides during germination (Megat et al. 2016). The increased sweetness in dehulled cowpea samples may be attributed to the relative increase of reducing sugars after dehulling (Onigbinde and Akinyele 1983). The cowpea seed coat contains fibre and polyphenols which may dilute or mask the sweet taste without raw material modifications which could explain the intense beany flavour in unmodified cowpea (CW)

(Dankwa et al. 2021). Furthermore, the increase in oily flavour and odour may be due to the increased lipid oxidation during the raw material modifications (Xu et al. 2019).

In this study, crispiness was defined based on Tunick et al. (2013) review as a dry rigid food that, when bitten with the incisors, fractures quickly, easily, and totally while emitting a relatively loud, high-pitched sound. This may result in different scoring in crispiness values between the tactile and mouthfeel. Similar findings in colour changes were observed in Dankwa's (2021) study, where dehulling increased the yellowness of the cowpea flours and flatbreads compared to the whole cowpea. The increased cereal odour and taste in modified samples may be due to the lower cowpea flour replacement and higher maise flour amount in the crackers. Furthermore, using an untrained panel and the lack of proper reference samples affected the results of the sensory screening session, which can be seen in the scaling.

5 CONCLUSIONS

This study showed that the African crop replacement affect notably cracker technological and sensory attributes and those could be adjusted with bioprocessing or raw material modification. All variations could supply high fibre and healthy options for gluten-free crackers. African crop replacements improved the nutritional quality of the crackers by increasing the fibre and protein content. All the African crop crackers reached the criteria of *high fibre* nutrition claim. Furthermore, Bambara groundnut 75% and cowpea crackers reached the claim for the *source of protein* and only the protein fractionated cowpea reached the criteria limit for the claim of *high protein.* Compared to the control cracker (100% maise), African crops gave the crackers browner colour and harder texture as expected. Raw material modifications changed the colour and appearance of the crackers. Sorghum crackers' colour was detected lighter and greyer compared to the unmodified sorghum cracker (SOR50), whereas cowpea samples were lighter and yellower compared to the unmodified cowpea cracker (COW75). High protein content and compact structure due to small particle size flour increased the hardness the most compared to the control. Furthermore, high protein content correlated negatively with spread ratio and positively with puffiness. Due to this, it can be concluded that higher protein level flour replacement and higher amounts of replacement improve the rising ability of the crackers. Furthermore, the raw material modifications had a notable effect on the cracker structure and sensory properties. Finer particle size made the cowpea samples more compact in structure whereas milling increased the air-cell formation in sorghum samples. A significant ($p < 0.05$) decrease in the graininess of sorghum crackers was observed by air-classification and fine-milling when compared to unmodified sorghum. Beany flavour of cowpea crackers was decreased significantly ($p < 0.001$) by all raw material modifications, most by germination when compared to unmodified cowpea. Graininess is probably easier to evaluate than beany flavour, which may be sensed differently worldwide. This should be taken into notice while developing the crackers further.

More detailed information regarding the baking performance is needed for proper analysis and further studies to solve the exact nutritional quality of the crackers. Furthermore, the used recipes could be further optimised to secure the optimal ingredient amounts and baking times. In addition, it could be interesting to study how the raw material modification affects the cracker's technological properties by using the same fibre or protein content in all samples against the same replacement amount.

REFERENCES

Adebowale YA, Schwarzenbolz U, Henle T (2011) Protein Isolates from Bambara Groundnut (Voandzeia Subterranean L.): Chemical Characterization and Functional Properties. Int J Food Prop 14:758–775. https://doi.org/10.1080/10942910903420743

Aderibigbe OR, Ezekiel OO, Owolade SO, Korese JK, Sturm B, Hensel O (2020) Exploring the potentials of underutilized grain amaranth (Amaranthus spp.) along the value chain for food and nutrition security: A review. Crit Rev Food Sci Nutr 0:1–14. https://doi.org/10.1080/10408398.2020.1825323

Ahlawat S, Kumawat M, Babele PK (2018) Microbial Enzymes in Food Technology. In: Kuddus M (ed) Enzymes in Food Technology: Improvements and Innovations. Springer, Singapore, pp 1–17

Akkad R, Buchko A, Johnston SP, Han J, House JD, Curtis JM (2021) Sprouting improves the flavour quality of faba bean flours. Food Chem 364:130355. https://doi.org/10.1016/j.foodchem.2021.130355

Akonor PT, Dziedzoave NT, Buckman ES, Mireku Essel E, Lavoe F, Tomlins KI (2017) Sensory optimization of crackers developed from high-quality cassava flour, starch, and prawn powder. Food Sci Nutr 5:564–569. https://doi.org/10.1002/fsn3.431

Alvarez-Jubete L, Holse M, Hansen Å, Arendt E, Gallagher E (2009) Impact of Baking on Vitamin E Content of Pseudocereals Amaranth, Quinoa, and Buckwheat. Cereal Chem - CEREAL CHEM 86:0909041222–515. https://doi.org/10.1094/CCHEM-86-5-0511

Anyango JO, de Kock HL, Taylor JRN (2011) Evaluation of the functional quality of cowpea-fortified traditional African sorghum foods using instrumental and descriptive sensory analysis. LWT - Food Sci Technol 44:2126–2133. https://doi.org/10.1016/j.lwt.2011.07.010

Appiah F, Asibuo JY, Kumah P (2011) Physicochemical and functional properties of bean flours of three cowpea (Vigna unguiculata L. Walp) varieties in Ghana. Afr J Food Sci 5:100–104. https://doi.org/10.5897/AJFS.9000232

Arendt EK, Zannini E (2013) Cereal Grains for the Food and Beverage Industries. Elsevier Science & Technology, Cambridge, UNITED KINGDOM

Arise AK, Nwachukwu ID, Aluko RE, Amonsou EO (2017) Structure, composition and functional properties of storage proteins extracted from bambara groundnut (Vigna subterranea) landraces. Int J Food Sci Technol 52:1211–1220. https://doi.org/10.1111/ijfs.13386

Ayo JA (2001) The Effect of Amaranth Grain Flour on the Quality of Bread. Int J Food Prop 4:341–351. https://doi.org/10.1081/JFP-100105198

Azman Halimi R, Barkla BJ, Mayes S, King GJ (2019) The potential of the underutilized pulse bambara groundnut (Vigna subterranea (L.) Verdc.) for nutritional food security. J Food Compos Anal 77:47–59. https://doi.org/10.1016/j.jfca.2018.12.008

Baye K (2014) Teff: nutrient composition and health benefits. Ethiop Strategy Support Program

Belton PS, Taylor JRN (eds) (2002) Pseudocereals and Less Common Cereals: Grain Properties and Utilization Potential. Springer-Verlag, Berlin Heidelberg

Bhaduri S, Tess M, Navder KP, Ghatak R (2015) Physical, Textural and Sensory Characteristics of Gluten Free Muffins Prepared with Teff Flour (Eragrostistef (ZUCC) Trotter). J Food Process Technol 06. https://doi.org/10.4172/2157-7110.1000490

Bultosa G (2007) Physicochemical characteristics of grain and flour in 13 tef [Eragrostis tef (Zucc.) Trotter] grain varieties. J Appl Sci Res 3:2042–2051

Busken DF (2011) Understanding the Challenges of Gluten-Free Baking. Cereal Foods World 56:42–43

Carson L, Floerke M, Bock J, Adeniji MM (2022) Cracker | Commercial Baking. In: BAKERpedia. https://bakerpedia.com/specialties/cracker/. Accessed 23 Mar 2022

Cauvain SP (2016) Cookies, Biscuits and Crackers: Formulation, Processing and Characteristics. In: Wrigley C, Corke H, Seetharaman K, Faubion J (eds) Encyclopedia of Food Grains (Second Edition). Academic Press, Oxford, pp 37–43

Chauhan A, Saxena DC, Singh S (2015) Total dietary fibre and antioxidant activity of gluten free cookies made from raw and germinated amaranth (Amaranthus spp.) flour. LWT - Food Sci Technol 63:939–945. https://doi.org/10.1016/j.lwt.2015.03.115

Chavan U, Kotecha P (2019) Evaluation of initial advance hybrid sorghum genotypes for roti and nutritional quality. Int J Chem Sci 7:19–23

Cheng YF, Bhat R (2016) Functional, physicochemical and sensory properties of novel cookies produced by utilizing underutilized jering (Pithecellobium jiringa Jack.) legume flour. Food Biosci 14:54–61. https://doi.org/10.1016/j.fbio.2016.03.002

Dankwa R, Aisala H, Kayitesi E, de Kock HL (2021) The Sensory Profiles of Flatbreads Made from Sorghum, Cassava, and Cowpea Flour Used as Wheat Flour Alternatives. Foods 10:3095. https://doi.org/10.3390/foods10123095

Darmatika K, Ali A, Pato U (2018) RATIO OF WHEAT FLOUR AND COWPEA FLOUR (Vigna unguiculata) IN MAKING CRACKERS. J Online Mhs JOM Bid Pertan 5:1–14

Delcour JA, Hoseney RC (2010) Principles of cereal science and technology, 3rd ed. AACC Internalional, St. Paul, Minn.

Di Cairano M, Galgano F, Tolve R, Caruso MC, Condelli N (2018) Focus on gluten free biscuits: Ingredients and issues. Trends Food Sci Technol 81:203–212. https://doi.org/10.1016/j.tifs.2018.09.006

Duarte C (2020) Legume Beverages from Chickpea and Lupin, as New Milk Alternatives. Foods 9:1458. https://doi.org/10.3390/foods9101458

Elkhalifa AEO, Bernhardt R (2010) Influence of grain germination on functional properties of sorghum flour. Food Chem 121:387–392

Elkhalifa AEO, Bernhardt R (2013) Some physicochemical properties of flour from germinated sorghum grain. J Food Sci Technol 50:186–190. https://doi.org/10.1007/s13197-011-0315-2

FAO (2013) GUIDELINES FOR USE OF NUTRITION AND HEALTH CLAIMS CAC/GL 23-1997. In: Fao.org. https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXG%2B23-1997%252FCXG_023e.pdf. Accessed 2 Dec 2021

Gaines CS (1985) Associations Among Soft Wheat Flour Particle Size, Protein Content, Chlorine Response, Kernel Hardness, Milling Quality, White Layer Cake Volume, and Sugar-Snap Cookie Spread. Am Assoc Cereal Chem 62:290–292

Gamel TH, Linssen JP, Mesallam AS, Damir AA, Shekib LA (2006a) Seed treatments affect functional and antinutritional properties of amaranth flours. J Sci Food Agric 86:1095–1102. https://doi.org/10.1002/jsfa.2463

Gamel TH, Linssen JP, Mesallam AS, Damir AA, Shekib LA (2006b) Effect of seed treatments on the chemical composition of two amaranth species: oil, sugars, fibres, minerals and vitamins. J Sci Food Agric 86:82–89. https://doi.org/10.1002/jsfa.2318

Gamel TH, Mesallam AS, Damir AA, Shekib LA, Linssen JP (2007) Characterization of Amaranth Seed Oils. J Food Lipids 14:323–334. https://doi.org/10.1111/j.1745-4522.2007.00089.x

Gebremariam MM, Zarnkow M, Becker T (2014) Teff (Eragrostis tef) as a raw material for malting, brewing and manufacturing of gluten-free foods and beverages: a review. J Food Sci Technol 51:2881–2895. https://doi.org/10.1007/s13197-012-0745-5

Gonçalves A, Goufo P, Barros A, Domínguez-Perles R, Trindade H, Rosa EAS, Ferreira L, Rodrigues M (2016) Cowpea (Vigna unguiculata L. Walp), a renewed multipurpose crop for a more sustainable agri-food system: nutritional advantages and constraints. J Sci Food Agric 96:2941–2951. https://doi.org/10.1002/jsfa.7644

Govender K, Naicker A, Napier CE, Singh D (2018) School snacking preferences of children from a low socio-economic status community in South Africa. J Consum Sci. https://doi.org/10.4314/jfecs.v0i0

Gulzar M, Minnaar A (2017) Chapter 12 - Underutilized Protein Resources From African Legumes. In: Nadathur SR, Wanasundara JPD, Scanlin L (eds) Sustainable Protein Sources. Academic Press, San Diego, pp 197–208

Hallén E, İbanoğlu Ş, Ainsworth P (2004) Effect of fermented/germinated cowpea flour addition on the rheological and baking properties of wheat flour. J Food Eng 63:177–184. https://doi.org/10.1016/S0260-8774(03)00298-X

Han J (Jay), Janz JAM, Gerlat M (2010) Development of gluten-free cracker snacks using pulse flours and fractions. Food Res Int 43:627–633. https://doi.org/10.1016/j.foodres.2009.07.015

Hoover R, Hughes T, Chung HJ, Liu Q (2010) Composition, molecular structure, properties, and modification of pulse starches: A review. Food Res Int 43:399–413. https://doi.org/10.1016/j.foodres.2009.09.001

Hugo LF, Rooney LW, Taylor JRN (2003) Fermented Sorghum as a Functional Ingredient in Composite Breads. Cereal Chem 80:495–499. https://doi.org/10.1094/CCHEM.2003.80.5.495

Jnawali P, Kumar V, Tanwar B (2016) Celiac disease: Overview and considerations for development of gluten-free foods. Food Sci Hum Wellness 5:169–176. https://doi.org/10.1016/j.fshw.2016.09.003

Kaczmarska KT, Chandra-Hioe MV, Frank D, Arcot J (2018) Aroma characteristics of lupin and soybean after germination and effect of fermentation on lupin aroma. LWT 87:225–233. https://doi.org/10.1016/j.lwt.2017.08.080

Kamel MA-A, Aly MHH, Abd-El-Khalek MH (2020) Preparation of Gluten-Free Corn Crackers Supplemented with Legume Flours. J Adv Res Food Sci Nutr 3:42–49

Kaushal P, Kumar V, Sharma HK (2012) Comparative study of physicochemical, functional, antinutritional and pasting properties of taro (Colocasia esculenta), rice (Oryza sativa) flour, pigeonpea (Cajanus cajan) flour and their blends. LWT - Food Sci Technol 48:59–68. https://doi.org/10.1016/j.lwt.2012.02.028

Kenney E, Butler C, Moore C, Bhaduri S, Ghatak R, Navder K (2011) The Effect of Substituting Teff Flour in Gluten-Free Sugar Cookies and Peanut Butter Cookies. J Am Diet Assoc - J AMER DIET ASSN 111. https://doi.org/10.1016/j.jada.2011.06.230

Lorenz K, Wright B (1984) Phytate and tannin content of amaranth. Food Chem 14:27–34. https://doi.org/10.1016/0308-8146(84)90015-3

Mancebo CM, San Miguel MÁ, Martínez MM, Gómez M (2015) Optimisation of rheological properties of gluten-free doughs with HPMC, psyllium and different levels of water. J Cereal Sci 61:8–15. https://doi.org/10.1016/j.jcs.2014.10.005

Marston K, Khouryieh H, Aramouni F (2016) Effect of heat treatment of sorghum flour on the functional properties of gluten-free bread and cake. LWT - Food Sci Technol 65:637–644. https://doi.org/10.1016/j.lwt.2015.08.063

McWatters KH (1978) Cereal Chem 1978 | Cookie Baking Properties of Defatted Peanut, Soybean, and Field Pea Flours. Cereal Chem 55:853–863

Megat, Azlan A, ME N (2016) Effect of germination on total dietary fibre and total sugar in selected legumes. Int Food Res J 23:257–261

Mekonnen G, Woldesenbet M, Teshale T, Biru T (2018) Amaranthus Caudatus Production and Nutrition Contents for Food Security and Healthy Living in Menit Shasha, Menit Goldya and Maji Districts of Bench Maji Zone, South Western Ethiopia. Nutr Food Sci Int J 7:7. https://doi.org/doi: 10.19080/NFSIJ.2018.07.555712

Mubaiwa J, Fogliano V, Chidewe C, Linnemann AR (2017) Hard-to-cook phenomenon in bambara groundnut (Vigna subterranea (L.) Verdc.) processing: Options to improve its role in providing food security. Food Rev Int 33:167–194. https://doi.org/10.1080/87559129.2016.1149864

Nammakuna N, Barringer SA, Ratanatriwong P (2016) The effects of protein isolates and hydrocolloids complexes on dough rheology, physicochemical properties and qualities of gluten-free crackers. Food Sci Nutr 4:143–155. https://doi.org/10.1002/fsn3.266

Nespeca L de S, da Silva Paulino HF, Barlati Vieira da Silva T, Bona E, Leimann FV, Marques LLM, Cardoso FAR, Droval AA, Fuchs RHB (2021) How does the replacement of rice flour with flours of higher nutritional quality impact the texture and sensory profile and acceptance of gluten-free chocolate cakes? Int J Food Sci Technol 56:2019–2029. https://doi.org/10.1111/ijfs.14833

Nti CA (2009) Effects of bambara groundnut (Vigna subterranea) variety and processing on the quality and consumer appeal for its products. Int J Food Sci Technol 44:2234–2242. https://doi.org/10.1111/j.1365-2621.2009.02064.x

Okaka JC, Potter NN (1979) Physico-Chemical and Functional Properties of Cowpea Powders Processed to Reduce Beany Flavor. J Food Sci 44:1235–1240. https://doi.org/10.1111/j.1365-2621.1979.tb03488.x

Omoba OS, Taylor JRN, de Kock HL (2015) Sensory and nutritive profiles of biscuits from whole grain sorghum and pearl millet plus soya flour with and without sourdough fermentation. Int J Food Sci Technol 50:2554–2561. https://doi.org/10.1111/ijfs.12923

Onigbinde AO, Akinyele IO (1983) Oligosaccharide Content of 20 Varieties of Cowpeas in Nigeria. J Food Sci 48:1250–1251. https://doi.org/10.1111/j.1365-2621.1983.tb09203.x

Pareyt B, Delcour JA (2008) The Role of Wheat Flour Constituents, Sugar, and Fat in Low Moisture Cereal Based Products: A Review on Sugar-Snap Cookies. Crit Rev Food Sci Nutr 48:824–839. https://doi.org/10.1080/10408390701719223

Patel BK, Waniska RD, Seetharaman K (2005) Impact of different baking processes on bread firmness and starch properties in breadcrumb. J Cereal Sci 42:173–184. https://doi.org/10.1016/j.jcs.2005.04.007

Prinyawiwatkul W, McWatters KH, Beuchat LR, Phillips RD, Uebersak MA (1996) Cowpea flour: A potential ingredient in food products. Crit Rev Food Sci Nutr 36:413–436. https://doi.org/10.1080/10408399609527734

Qadri T, Hussain SZ, Rather AH, Amin T, Naseer B (2018) Nutritional and storage stability of wheat-based crackers incorporated with brown rice flour and carboxymethyl cellulose (CMC). Int J Food Prop 21:1117–1128. https://doi.org/10.1080/10942912.2018.1485033

Rema RR, Jyothi A (2015) A Comparative Study on the Resistant Starch Content from Different Botanical Sources in Relation to their Physicochemical Properties. 37–47

Rooney WL (2016) Sorghum: Production and Improvement Practices. In: Wrigley C, Corke H, Seetharaman K, Faubion J (eds) Encyclopedia of Food Grains (Second Edition). Academic Press, Oxford, pp 201–206

Serrem CA, de Kock HL, Taylor JRN (2011) Nutritional quality, sensory quality and consumer acceptability of sorghum and bread wheat biscuits fortified with defatted soy flour. Int J Food Sci Technol 46:74–83. https://doi.org/10.1111/j.1365-2621.2010.02451.x

Sindhuja A, Sudha ML, Rahim A (2005) Effect of incorporation of amaranth flour on the quality of cookies. Eur Food Res Technol 221:597. https://doi.org/10.1007/s00217-005-0039-5

Singh SB (2018) Enzyme Catalysis and Its Role in Food Processing Industries. In: Kuddus M (ed) Enzymes in Food Technology: Improvements and Innovations. Springer, Singapore, pp 143–165

Sirivongpaisal P (2008) Structure and functional properties of starch and flour from bambara groundnut. Songklanakarin J Sci Technol 30

Stefoska-Needham A, Beck EJ, Johnson SK, Tapsell LC (2015) Sorghum: An Underutilized Cereal Whole Grain with the Potential to Assist in the Prevention of Chronic Disease. Food Rev Int 31:401–437. https://doi.org/10.1080/87559129.2015.1022832

Tan XL, Azam-Ali S, Goh EV, Mustafa M, Chai HH, Ho WK, Mayes S, Mabhaudhi T, Azam-Ali S, Massawe F (2020) Bambara Groundnut: An Underutilized Leguminous Crop for Global Food Security and Nutrition. Front Nutr 7:601496. https://doi.org/10.3389/fnut.2020.601496

Taylor JRN, Belton PS, Beta T, Duodu KG (2014) Increasing the utilisation of sorghum, millets and pseudocereals: Developments in the science of their phenolic phytochemicals, biofortification and protein functionality. J Cereal Sci 59:257–275. https://doi.org/10.1016/j.jcs.2013.10.009

Thornton PK (2012) Recalibrating Food Production in the Developing World: Global Warming Will Change More Than Just the Climate

Tunick MH, Onwulata CI, Thomas AE, Phillips JG, Mukhopadhyay S, Sheen S, Liu C-K, Latona N, Pimentel MR, Cooke PH (2013) Critical Evaluation of Crispy and Crunchy Textures: A Review. Int J Food Prop 16:949–963. https://doi.org/10.1080/10942912.2011.573116

Umeta M, Faulks RM (1988) The effect of fermentation on the carbohydrates in tef (Eragrostis tef). Food Chem 27:181–189. https://doi.org/10.1016/0308-8146(88)90061-1

Uppal V, Bains K (2012) Effect of germination periods and hydrothermal treatments on in vitro protein and starch digestibility of germinated legumes. J Food Sci Technol 49:184–191. https://doi.org/10.1007/s13197-011-0273-8

USDA (2019) FoodData Central: Teff, uncooked. In: USDA - US Dep. Agric. https://fdc.nal.usda.gov/fdc-app.html#/food-details/169747/nutrients. Accessed 17 Nov 2021

Virupaksha TK, Sastry LVS (1968) Protein content and amino acid composition of some varieties of grain sorghum. J Agric Food Chem 16:199–203. https://doi.org/10.1021/jf60156a022

Wang N, Hou GG, Kweon M, Lee B (2016) Effects of particle size on the properties of whole-grain soft wheat flour and its cracker baking performance. J Cereal Sci 69:187–193. https://doi.org/10.1016/j.jcs.2016.03.010

Wani SH, Gull A, Allaie F, Safapuri TA (2015) Effects of incorporation of whey protein concentrate on physicochemical, texture, and microbial evaluation of developed cookies. Cogent Food Agric 1:1092406. https://doi.org/10.1080/23311932.2015.1092406

Wootton M, Bamunuarachchi A (1978) Water Binding Capacity of Commercial Produced Native and Modified Starches. Starch - Stärke 30:306–309. https://doi.org/10.1002/star.19780300905

Xu J, Zhang Y, Wang W, Li Y (2020) Advanced properties of gluten-free cookies, cakes, and crackers: A review. Trends Food Sci Technol 103:200–213. https://doi.org/10.1016/j.tifs.2020.07.017

Xu M, Jin Z, Lan Y, Rao J, Chen B (2019) HS-SPME-GC-MS/olfactometry combined with chemometrics to assess the impact of germination on flavor attributes of chickpea, lentil, and yellow pea flours. Food Chem 280:83–95. https://doi.org/10.1016/j.foodchem.2018.12.048

Yeboah-Awudzi M, Lutterodt HE, Kyereh E, Reyes V, Sathivel S, Manful J, King JM (2018) Effect of bambara groundnut supplementation on the physicochemical properties of rice flour and crackers. J Food Sci Technol 55:3556–3563. https://doi.org/10.1007/s13197-018-3281-0

Zhu F (2018) Chemical composition and food uses of teff (Eragrostis tef). Food Chem 239:402–415. https://doi.org/10.1016/j.foodchem.2017.06.101

Zoulias EI, Piknis S, Oreopoulou V (2000) Effect of sugar replacement by polyols and acesulfame-K on properties of low-fat cookies. J Sci Food Agric. 80(14):2049–2056. https://doi.org/10.1002/1097-0010(200011)80:14<2049::AID-JSFA735>3.0.CO;2-Q

APPENDICES

Appendix 1. Descriptive sensory analysis ballot

DESCRIPTIVE PROFILING OF COWPEA CRACKERS

2.6.2022 Attribute list and definitions

The evaluation will be performed with a 0-10 line scale. Carefully open the lid of the sample vial, smell it, and evaluate all odour attributes. Then evaluate the appearance properties of the sample. Proceed to do the same for the other samples. In the second section, follow up with all taste, flavour, and mouthfeel properties from the first sample before moving on to the second sample etc. Familiarise yourself with the reference products first before proceeding with the samples. This helps you in understanding the attributes in question and in binding the scale values.

Remember to keep adequate pauses and remember to drink (and smell) water between the samples.

ODOUR

Trust in your first impression when you evaluate the samples; the odour will be milder after the first try.

Total odour intensity very mild --- very intense
Smell the sample and evaluate the total intensity of all odours.

Beany odour intensity not beany --- very beany
The odour might remind you of different types of legumes. Reference: P (8)

Oily odour intensity not oily --- very oily
The odour of oils and fats. Reference: R (7)
Roasted cereal odour intensity not roasted --- very roasted
The odour might remind you of roasted cereal. Reference: D (6)

APPEARANCE AND TACTILE TEXTURE

Colour golden brown --- greyish brown
Look at the top of the cracker and evaluate the overall colour of the cracker.
References: J (2) look at the "inner helix", the lighter curve that's deeper
M (8) look at the top side with the brand markings

Crispness (with two hands) not crisp --- very crisp
Hold the cracker half with two hands. Snap it in two pieces. Evaluate the force required to break it in two. A crispy sample breaks easily in half. Reference: R (5)

TASTE AND FLAVOUR

Total flavour intensity very mild --- very intense
Taste the sample and evaluate the total intensity of all taste and flavour attributes right after placing the sample in your mouth.

Beany flavour not beany --- very beany
Evaluate the beany intensity of the sample. The flavour can remind you of dried beans. Reference: P (7)

Roasted flavour not roasted --- very roasted
Taste the sample and evaluate the roasted flavour intensity. The flavour might remind you of the golden crust on crackers.
Reference: R (6)

Cereal flavour not cereal-like --- very cereal-like

Taste the sample and evaluate the intensity of cereal flavour.
Reference: D (8)

Sweetness not sweet --- very sweet
Evaluate the sweetness of the sample.
Reference: D (8)

Saltiness not salty --- very salty
Evaluate the saltiness of the sample.
Reference: T (8)

Oily flavour not oily --- very oily
Evaluate the oily flavour intensity of the sample.
Reference: R (8)

MOUTHFEEL AND TEXTURE

Crispness not crispy --- very crispy
Bite the sample with your front teeth and evaluate how crispy the sample is. Crispy fractures quickly and easily and emit a loud sound while fracturing.
Reference: J (9)

Graininess not grainy --- very grainy
Chew the sample. A grainy sample has many particles that you can feel in your mouth while chewing.

Hardness not hard--- very hard
Chew the sample. A hard sample has high biting resistance that stays high on successive chewings.
Reference: D: (1)