Effect of partial mutton meat substitution with Bambara groundnut (*Vigna subterranea* (L.) Verdc.) flour on physicochemical properties, lipid oxidation and sensory acceptability of low-fat patties

by

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Abstract

Health concerns regarding fat consumption, as well as shifts in customer preference, have prompted substantial studies into low-fat products. This study examined the nutritional, colour, functional, and antioxidants properties of Bambara groundnut (BGN) flour varieties (cream, brown, and red-coated) grains as well as their influence on the physicochemical properties, lipid oxidation, and sensory acceptability of reduced-fat mutton patties. The patties were formulated with 2.5%, 5%, 7.5%, and 10% of BGN flours for each variety, and 100% mutton patties were used as a control. The BGN flours showed significant ($p < 0.05$) differences in their nutritional composition (except for ash content), colour, functional (excluding the emulsion stability), antioxidant properties. The inclusion of BGN flours significantly increased the fibre (0.00 to 0.79%) and ash (1.16 to 1.99%) contents of the formulated mutton patties. However, moisture, protein contents, and carbohydrates decreased. The cooking yield of the formulated patties significantly increased with values ranging from 76.39 to 86.80% but the diameter decreased. The inclusion of BGN flours significantly increased the lightness, hue angle, colour difference and whiteness of patties. Nevertheless, the redness, yellowness, chroma, and yellowness index of the patties decreased. The hardness and resilience of formulated patties significantly increased with values varying from 16.41 to 17.66 N, and from 0.35 to 0.48 J/J, respectively, whereas the springiness, cohesiveness, and chewiness decreased. The lipid oxidation of formulated mutton patties significantly increased from day 7 to 21 but was still less than that of the control sample within storage days. The sensory properties of formulated patties were not significantly different from the control sample and were above the acceptable score of five. Different types of BGN flour varieties can each be utilised as additives in mutton patties without detrimental effects on the quality parameters of the patties.

Key words: Bambara groundnut flour, mutton patties, physicochemical properties, lipid oxidation, and sensory acceptability.

Declaration

I, **Ramatsetse Kgaogelo Edwin**, student number 16014230, hereby declare that this research project for Master of Food Science and Technology under the supervision of Dr. S.E. Ramashia and Mr. M.E. Mashau has been submitted to the Department of Food Science and Technology, Faculty of Science, Engineering and Agriculture at the. University of Venda and has not been previously submitted to any other institution for any degree. All citations and sources of information have been duly acknowledged in the text.

______________________ 15 February 2023

Student signature Date

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List of Abbreviations

a*	Redness of meat
$AlCl_3.6H_2O$	Aluminium chloride hexahydrate
AOAC	Association of Agricultural Chemists
b*	Yellowness of the meat
BGN	Bambara groundnut
BHA	Butylated hydroxyanisole
BHT	Butylated hydroxytoluene
C*	Chroma
CHO	Carbohydrates
CVDs	Cardiovascular diseases
DPPH	1,1-diphenyl-2-picryl hydrazyl radical
Fe^{2+}	Ferrous ions
Fe^{3+}	Ferric ions
FRAP	Ferric reducing antioxidant power
H_2SO_4	Sulphuric acid
L*	Lightness of the meat
$NaNo_2$	Sodium nitrite
$NaNo_2$	Sodium nitrite
NaOH	Sodium hydroxide
O_2	Oxygen molecule
OAC	Oil absorption capacity
R•, ROO•	Free radicals
ROOH•, RH, ROOR	Hydroperoxides
TBARS	Thiobarbituric acid reactive substances
TBHQ	Tertbutyl hydroquinone
TFC	Total flavonoids content
TPC	Total phenolic content
WAC	Water absorption capacity
WI	Whiteness index
YI	Yellowness index
ΔE	Colour difference

CHAPTER 1: INTRODUCTION

1.1 Background

Meat is a nutrient-dense food made up of water, proteins, lipids, vitamins, and minerals, as well as little amount of carbohydrates (Aminzare *et al*., 2019). Mutton meat is from an adult sheep, and it is less tender. It is India and South Africa's most common meat, owing to its lack of social and religious restrictions (Mendiratta *et al*., 2013; Mazhangara *et al*., 2022). This is the primary motive why mutton meat is still more expensive than other meat. Nevertheless, consuming a lot of processed meat has negative effects such as causing cardiovascular disease or colon cancer (Willett *et al*, 2019; Grosso *et al*., 2022). However, adding non-meat additives such as soybeans, eggs, durum wheat powder, potato mash, rice, and milk products are widely utilised as extenders, binders, and fillers in minced meat products may be beneficial in preventing nutrition-related disorders and for the mental-physical wellbeing, as well as increase quality features and minimise production losses (Yang, 2019; Possidonio *et al*., 2021; Owusu-Ansah *et al*., 2022).

Consumers are currently very concerned with their well-being and the food products they consume. Therefore, the meat industry must process meat that is less fat, and rich in protein to meet the claim for nourishing and balancing the diet. Health concerns regarding fat consumption, as well as shifts in customer liking, have prompted substantial studies into low-fat products (Yogesh, 2021; Di Vita *et al*., 2022). The addition of legumes as non-meat additives in manufactured meat products is a potential answer to the current market trend for low fat and great amount of fibre in meat products (Ponnampalam *et al*., 2019). For example, Bambara groundnut (*Vigna subterranea* (L.) Verdc.) contains a 5.8% level of crude fat, and it can be categorised as a source of healthy fat that can be employed in less-fat diet formulations such as lean meat (Oyeleke *et al*., 2012). Beside their intrinsic functional properties, incorporation of legumes, fruits and vegetables into comminuted meat products increases yield, oxidative stability, nutritional composition, and fibre content and reduces production costs (Kumar *et al*., 2016; Beriain *et al*., 2018).

There is significant information that the consumption of legumes including Bambara groundnut (BGN) and other crop products is good for human well-being and decreases the chances of being exposed to cardiovascular diseases (Schwingshackl *et al*., 2018; Ramatsetse *et al*., 2023). The antioxidant properties of BGN can prevent non-transmissible diseases such as diabetes, malignancy, Alzheimer, and arthritis (Ramatsetse *et al*., 2023). Moreover, rising consumers' desire for healthier food products is spurring the production of novel products that are more sustainable such as incorporating plant sources such as BGN (Rout *et al*., 2022). Mubaiwa *et al*. (2018) state that the high amount of protein in BGN provides the spotlight more on creating new updated processes for its production and extending its utilisation. According to Jideani and Diedericks (2014), the varied nutritional component of BGN grains implies that they have the capacity to fulfil the nutritional demands of a significant number of people.

Meat fat serves as a flavour compound reservoir and contributes to food texture. As a result, moisture drip and fat may affect or change product quality (Alves *et al*., 2016). The loss of liquid decreases the sensory result, the heaviness of the commodity, and possibly its selling value. Shrinkage may also be caused by a lack of fluid in the product. Utilising plant-based protein derivatives can help to lessen the moisture loss that takes place when cooking (Aslinah *et al*., 2018; Ravani and Sharma, 2022). Different non-meat additives have been used in processed meat products. For instance, Bagdatli (2018) added quinoa flour to beef meatballs, Amadi (2020) added soybean to buffalo meat patties, and Ayandipe *et al*. (2020) added cassava and coconut composite powder to chicken sausages. Introduction of non-meat ingredients such as quinoa and BGN flours in processed meat products improves the sensory properties such as chewiness, juiciness, and taste (Alakali *et al*., 2010; Muchekeza *et al*., 2021).

There is little data regarding the utilisation of BGN flour in processed meat products. Alakali *et al*. (2010) investigated the impact of BGN flour on the nutritional qualities and sensory properties of beef patties stored at 4C for 21 days. The physicochemical, microbiological, and sensory properties of the formulated patties were acceptable over 21 days of refrigeration. Nevertheless, consumers preferred formulated beef patties added with up to 5% BGN flour. Dzudie *et al*. (2002) state that BGN flour was used because it is a cheaper source of protein and improves water retention and the production of structure in processed meat products. The limited use of BGN, like with other pulses, is associated with several problems, including the hard-to-cook and hard-to-mill characteristics of the grains, which also affect the nutritional quality (Gwala *et al*., 2019; Diedericks *et al*., 2020). To overcome these problems, the BGN grains are processed into flour. The incorporation of BGN flour in different foods could improve its utilisation, especially in developing countries. To fully explore the use of BGN flours in meat products, it is crucial to assess their effect on physicochemical, lipid oxidation and sensory acceptability of low-fat meat products. Therefore, this study assessed the nutritional, colour, functional and antioxidants properties of BGN flour varieties (cream, brown, and red coated grains) as well as their influence on the physicochemical properties, lipid oxidation, and sensory acceptability of mutton patties. The novelty of this research arises from the utilisation of cream, brown and red BGN flours in the development of low-fat mutton patties and reporting the results for the very first time. The results obtained from this study may promote the utilisation of BGN flours in food products, improve the nutritional value, technological properties, and sensory characteristics of mutton patties.

1.2 Problem statement

The desire for less-fat meat products has risen dramatically in recent years, since consumption of great amount of fat, particularly saturated fats, has been linked to an elevated risk of cardiovascular disorders and some various malignancies. (Price *et al*., 2013; Paglarini *et al*., 2020). However, reduction of fat content can affect product quality by making it stiffer, rubberier, less juicy, and dark in colour (Alves *et al*., 2016; Gómez *et al*., 2020). As results, the mouthfeel of low-fat meat products sought by customers may be improved by adding various alternative fat replacers (Paglarini *et al*., 2020; Kumar, 2021). Fat substitutes in meat products are additives that add a small number of calories to treated meat and do not drastically change organoleptic and processing qualities. They change viscosity, softness, flavour and mouth feel, and other processing and sensory qualities (Purohit *et al*., 2016). Modified starches, proteins, gums, cereals, and legume flours are added to decrease the negative effects of low fat (Al-Juhaimi *et al*., 2016), thereby increase the retention of moisture and fat in meat products, enhancing juiciness and lowering brittleness.

Artificial antioxidants including propyl gallate, butylated hydroxyanisole (BHA), butylated hydroxytoulene (BHT), and tertbutyl hydroquinone (TBHQ) are usually utilised to delay oxidation processes or reactions as well as preservative to extend the durability of minced meat products. Nevertheless, these artificial antioxidants have been assessed as potential cause of cancer (Choi *et al*., 2019). Therefore, the utilisation of natural antioxidant such as tocopherols, ascorbic acid, flavonoids, and phenolic compounds from plants extracts has piqued customer interest because of their possible health advantages, safety (Mishra *et al*., 2021; Bag *et al*., 2022) and ability to increase meat products shelf life (Falowo *et al*., 2017). Additionally, the utilisation of natural preservatives has rendered high nutritional value foods to be safe from microorganisms and free from chemical preservatives (Olatunde and Benjakul, 2018; Mashau *et al*., 2021). Due to increased consumers' intervention in the utilisation of artificial antioxidants, the utilisation of natural antioxidants in muscle foods is becoming extremely relevant and important in the meat industry.

1.3 Rationale of the study

The study is important to meat industry, consumers, and researchers**.** It may provide the meat industry with healthier and safer alternatives for meat preservation increasing the healthy consumer base and serving. The research may potentially improve consumer health and customer satisfaction as they request the use of natural preservatives to replace chemical compounds. The study may widen the researcher's knowledge on the application of natural preservatives.

1.4 Aim and objectives

1.4.1 Aim

Evaluation of the effect of partial mutton meat substitution with Bambara groundnut flour on physicochemical properties, lipid oxidation and sensory acceptability of low-fat patties

1.4.2 Specific objectives:

- To determine the effect of Bambara groundnut flour on proximate composition (fat, protein, ash, moisture, crude fibre, carbohydrate, & energy content) of low-fat mutton patties
- To examine the effect of Bambara groundnut flour on physical properties (colour properties, cooking yield, & diameter reduction) of low-fat mutton patties.
- To analyse the effect of Bambara groundnut flour on lipid oxidation of low-fat mutton patties
- To assess the effect of Bambara groundnut flour on sensory attributes of low-fat mutton patties.

1.5 Hypotheses

- Alternative hypothesis: The addition of Bambara groundnuts flour may have effect on physicochemical properties, lipid oxidation and sensory acceptability of low-fat mutton patties.
- Null hypothesis: The addition of Bambara groundnuts flour may not have effect on physicochemical properties, lipid oxidation and sensory acceptability of low-fat mutton patties.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Bambara groundnut (*Vigna subterranean*) is a legume belonging to the family and subfamily of *Fabaceae* and *Faboidea*, respectively (Ibny *et al*., 2019). Bambara groundnut is a legume indigenous to Africa and it is believed that its origin is between west and central Africa (Temegne *et al*., 2018). It grows in the wild in northern Nigeria and eastwards to southern Sudan and is currently grown across tropical Africa and to a smaller range in tropical portions of America, Asia, and Australia (Adeleke *et al*., 2018). Bambara groundnut (BGN) is the third most significant legume after groundnut (*Arachis hypogaea*) and cowpea (*Vigna hypogea*) (Arise *et al*., 2015; Oyeyinka and Oyeyinka, 2018). It plays a crucial socio-economic impact in the semi-arid regions globally and contains sufficient protein. Therefore, if combined with some native protein sources, it could help improve the nutritional issues globally (Massawe *et al*., 2005; Mbosso *et al*., 2020).

Bambara groundnut grain is a proper healthy food due to its high iron (4.9–48 mg/100 g) and protein contents (18.0–24.0%) when compared to other legume products, with great amount of amino acids content, fibre (5.0–12%), fat (5.0–7.0%), carbohydrate (57.43–63.09%), calcium (95.8–99 mg/100 g), potassium (1144–1935 mg/100 g), and sodium (2.9–12.0 mg/100 g) (Mbosso *et al*., 2020; Tan *et al*., 2020). Bambara groundnuts diverse nutritional composition suggests that it can meet dietary needs of people globally. Its high protein content maintains a greater focus on improving procedures for processing its grains and expanding food applications (Jideani and Diedericks *et al*., 2014). Bambara groundnut also contains several polyphenols such as flavonoids (medioresinol, catechin, catechin dimer anthocyanin, and epicatechin) and phenolic acids (quinic acid, chlorogenic acid, caffeic acid, and ellagic acid) that have positive health benefits and strengthen the immune system against infectious diseases (Onyilagha *et al*., 2009; Nyau *et al*., 2015; Harris *et al*., 2018; Okafor *et al*., 2021). Furthermore, antioxidants properties from plant extracts including BGN have also been reported to inhibit lipid oxidation in food products, thereby preventing transition metals and oxygen from reacting with food (Oyeyinka *et al*., 2017; Manessis *et al*., 2020; Oyeyinka *et al*., 2021).

Bambara groundnut thrives at temperatures ranging from 20 to 28 ^{o}C and grows to maturity in three to five months. The plant is extremely versatile and can withstand extreme weather conditions than other crops. It thrives in well-drained soil and may even thrive in low-nutrient soil, with a pH range of 5.0 to 6.5. It is not susceptible to total crop failure resulting from rainfall scarcity or other unpredictable weather conditions (Bamshaiye *et al*., 2011; Hillocks *et al*., 2012). Given these factors, BGN can improve malnutrition and poverty in this period of global warming and food security threats globally, particularly in places with severe water problems (Chai *et al*., 2016; Tan *et al*., 2020).

Bambara groundnut variants include the red seed with huge kernels that mature late and has a high production rate. The seven types of BGN seeds from various landraces are depicted in Figure 1. The black-coloured seed matures quicker than other cultivars and often has a one seed in a tiny to medium sized kernel. The cream/brown eye produces sizable kernel. The cream/no eye has a relatively little kernels and pods, produces mostly one seed, and has low productivity. The speckled or spotted variety has a strong purple colour, small kernels, and primarily one-seeded pods. Finally, the brown variety contains medium to big kernels that varies in colour from pale to dark brown (Department of Agriculture, Forestry and Forestry and Fisheries, 2011).

Figure 1: Seven different colour types of BGN seeds: black, red, cream/black eye, cream/brown eye, cream with no eye, purple, and brown colour (A to G)**,** respectively (Kone *et al*., 2007).

2.2 Utilisations of Bambara groundnut grains

Legumes have long been a staple food of low-cost meals around the globe. Thus, it is important that their low levels of intake be elevated (Temba *et al*., 2016; Maphosa and Jideani., 2017). Plant protein contributes about 64% of the world's protein supply for human beings, with cereals accounting for 44% – 50% and legumes for 10% – 15%. Legumes are rich in unprocessed protein, valuable for urban and rural inhabitants, particularly in developing countries (Bamshaiye *et al*., 2011). After being picked and dried, BGN is processed and consumed in a variety of ways (Table 1).

Table 1. Various foods products of Bambara groundnut produced in selected African countries.

Country	Product name and processing of the product	References
South Africa	*"Tshipupu"* in Tshivenda- (Soup or porridge is made by boiling and stirring BGN).	(Harris, 2017)
Nigeria	"*Okpa*"- BGN is steamed into pudding.	(Okwunodulu *et al*., 2019)
Kenya	"*Njugumawe*"- BGN grains are soaked, then cooked with maize, crushed, and fried into a stew maize.	(Harris, 2017)
Zimbabwe	"*Matakura*"- BGN grains are boiled to prepare *Matakura.*	(Mubaiwa *et al*., 2018)
Zambia	"*Ntoyo* or *Katoy*"- BGN is ground into flour to bake bread.	(Cook, 2017; Harris, 2017)
Ghana	"*Koose*"- A paste of fried BGN grains. "*Tubani*"- BGN powder is mixed with water to make a stiff paste.	(Nti, 2009; Tan *et al*., 2020)
Botswana	"*Ditloo*"- BGN is boiled and salted, and then eaten as a snack. "*Dikgobe*"- A porridge prepared by boiled BGN grains mixed with dry maize.	(Nti, 2009; Tan *et al*., 2020)
Cameroon	"*Akara*"- It is made by rolling BGN grain paste into balls and fried immediately in oil. BGN grains are milled into powder, other times following roasting to prepare a porridge. BGN flour is also mixed with maize flour to enrich traditional meals.	(Temegne *et al*., 2018; Olatunde *et al*., 2021)
Sudan	Dried grains powder is utilised to prepare a stiff porridge.	(Tan *et al*., 2020)
Mali	BGN grain powder is incorporated with sorghum or millet powder to prepare croquettes and grilled bread.	(Tan *et al*., 2020)
Tanzania	Ground roasted BGN grains are roasted to prepare a soup or stiff porridge.	(Tan *et al*., 2020)

After being grilled or boiled for almost an hour, picked fresh grains are eaten as snacks (Azam-Ali *et al*., 2001; Jideani and Diedericks., 2014). Boiling dry grains makes them a functional food. Furthermore, after scorching or roasting, BGN can be eaten matured and consumed as a snack or as porridge (Stephens, 2012; Jideani and Diedericks, 2014). Dry grains are hard to ground because of their stiff and closely fitting grain coats. The grains are ground into powder, which is utilized to bake little flat cakes, make biscuits, bread and as additives to yogurt and vegetable milk (Murevanhema and Jideani *et al*., 2013; Okafor *et al*., 2015; Adu-Dapaah *et al*., 2016). Bambara groundnut is roasted and ground in Eastern Africa, and the powder is utilized to produce relish, soup, and coffee. The powder is also utilized to make a thin or hard porridge (De Kock, 2013; Esho *et al*., 2018). Figure 2 indicates various foods products produced from BGN.

Interestingly, several tribes in Africa utilise BGN as traditional remedy for various ailments. For instance, in Senegal, the grains are crushed and mixed with water to treat vision problems and nausea and vomiting in pregnant women in South Africa (Murevanhema and Jideani, 2013) as well as nausea and diarrhea in Kenya (Khan *et al*., 2021). In Ghana, white BGN grains are blended with Guinea fowl meat to treat diarrhea, whereas children with diarrhea are treated by mixing black grains with water (Damfami and Namo, 2020). Joint pains, bone decalcification, stomach pains, sore throats and amoebic dysentery are treated by BGN in Cameroon (Damfami and Namo, 2020). Bambara groundnut is utilized to treat sexually transmitted infections by the Ibo people of Nigeria (Brink *et al*., 2006). It aids in digestion due to its laxative qualities. It helps to breastfeed mothers to produce more milk and is given to new mothers to cure their wounds (Temegne *et al*., 2018; Mbosso *et al*., 2020). Kaempferol, an antioxidant found in BGN, lowers the risk of numerous long-lasting diseases, including malignancy (Jideani and Diedericks, 2014; Yao *et al*., 2015).

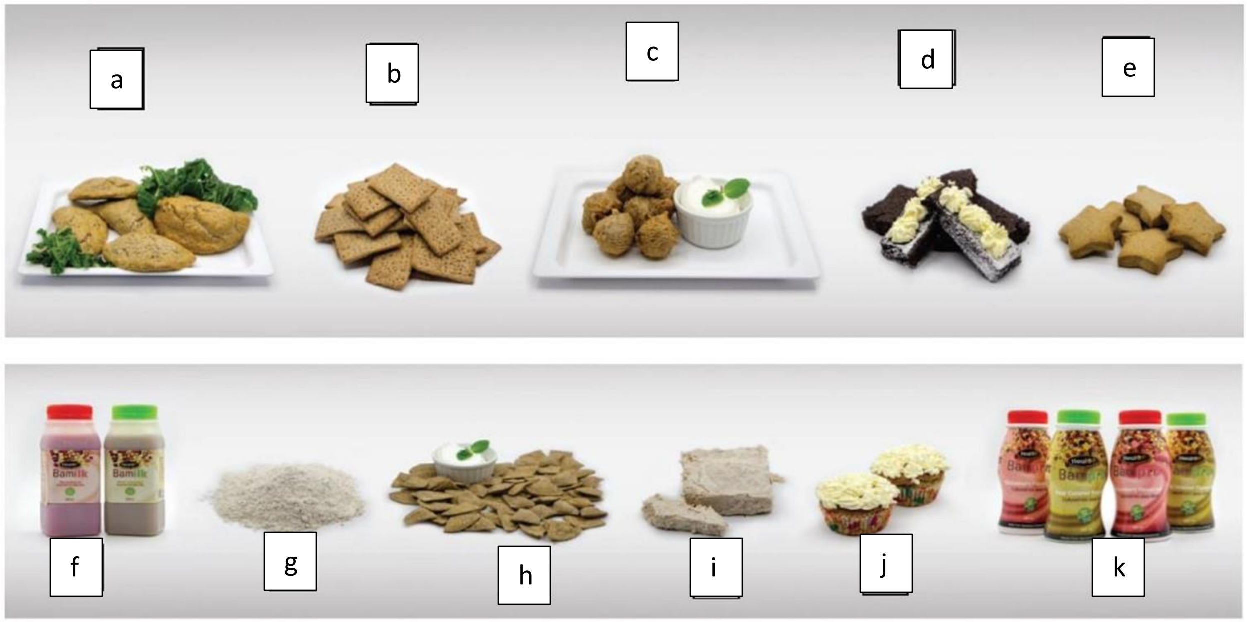


Figure 2. Various products produced from Bambara groundnut flours/ grains: a - crackers, b - chili-bite, c - brownie, d- tofu, e - cake, f - biscuits, g - milk, h - baking flour, i - chips, j - tofu, and k - pro beverages, https://www.innovationbridge.info/ibportal/sites/default/files/bambara-tia-brochure-2019.pdf (innovationbridge.info). (Accessed 19 March 2022).

2.3 Nutritional composition and health benefits of Bambara groundnut

The BGN grains have proteins, fat, carbohydrates, and ash (Table 2), which serve as a major source of nutrients in developing countries. Bambara groundnut is a balance food product for a nutritionally balanced diet because it has enough crude fiber, proteins, carbohydrates, fats, and minerals (Halimi *et al*., 2019). Compared to other legumes, they contain high protein quality and has an excellent balance of essential amino acids such as tryptophan, lysine, valine, threonine, isoleucine, and phenylalanine, with relatively high lysine (8.5%) and methionine (6.4%) (Olaleke *et al*., 2006; Baptista *et al*., 2016). Olaleke *et al*. (2006) found 2.84% of total crude protein in cream testa BGN. Therefore, due to ongoing studies on therapeutic benefits of the grains and its high protein content, its consumption is expected to rise in future. Polyunsaturated fatty acid makes up most of the oil (Adeleke *et al*., 2017). The grains of BGN contain 5.8% level of crude fat and is a source of healthy fat for low-fat diet food formulations (Oyeleke *et al*., 2012). Okpuzor *et al*. (2010) stated that BGN is composed of polyunsaturated fatty acids (linolenic & linoleic acids) and saturated fatty acids (stearic & palmitic).

Table 2. The nutritional profile of various types of Bambara groundnut grains, flour and grain coat

Cultivars	Crude protein (%)	Fat (%)	Moisture (%)	CHO (%)	Ash (%)	References
				Seeds		
Red	19.5- 20.57	5.2- 6.5	8.0- 8.7	54.4- 63.9	2.4- 3.4	(Bamshaiye *et al*., 2011; Oyeyinka *et al*., 2021)
Black	21.7- 26.3	5.2- 8.5	8.9- 9.0	52.8- 57.4	2.2- 3.5	(Bamshaiye *et al*., 2011; Oyeyinka *et al*., 2021)
Cream	19.5- 23.51	6.0- 7.8	8.9- 9.7	56.0- 58.6	2.5- 2.9	(Bamshaiye *et al*., 2011; Kaptso *et al*., 2015; Hlanga *et al*., 2021)
Brown	19.0- 24.3	5.3- 8.0	8.7- 10.3	54.4- 59.4	2.4- 3.0	(Jideani and Diedericks, 2014; Hardy, 2016; Oyeyinka *et al*., 2021)
				Flour		
Red	17.1- 20.9	3.0- 7.0	7.7- 9.3	48.0- 57.43	2.0- 3.90	(Bamshaiye *et al*., 2011; Jideani and Diedericks, 2014; Shanono and Muhammad, 2015)
Black	22.6- 25.3	4.0- 5.9	9.0- 11.3	32.0- 61.7	2.0- 3.8	(Bamshaiye *et al*., 2011; Jideani and Diedericks, 2014; Kaptso *et al*., 2015)
Cream	22.3	3.0	9.0	49.6	1.5	(Bamshaiye *et al*., 2011)
Brown	19.4- 20.9	3.5- 8.5	6.41- 10.0	48.0- 56.87	2.0- 4.12	(Bamshaiye *et al*., 2011; Shanono and Muhammad, 2015)
				Grain coat		
Red	5.7	0.5	3.0	8.4	1.0	(Bamshaiye *et al*., 2011)
Black	6.1	2.0	2.0	6.0	1.5	(Bamshaiye *et al*., 2011)
Cream	6.8	1.0	1.0	9.2	1.0	(Bamshaiye *et al*., 2011)
Brown	6.3	2.0	3.0	9.1	1.0	(Bamshaiye *et al*., 2011)

Note: CHO = Carbohydrate

Dietary fiber in BGN decreases blood pressure and serum cholesterol and protects against cardiovascular diseases (Tan et al., 2021). They contain oligosaccharides carbohydrates such as raffinose (0.4 g/mg) and stachyose (1.6 g/mg), which cause flatulence (Hardy and Jideani., 2016, Halimi et al., 2019). It also contains reducing sugars (3.6 g/mg). Its chemical makeup of legume starch is characterized by high amylopectin concentration (Schuster-Gajzago, 2004; Iwe et al., 2006), indicating that BGN is rich in energy. The grains are abundant in minerals such as iron, phosphorus, potassium, magnesium, sodium, and calcium as shown in Table 3.

Iron contributes to the synthesis of proteins myoglobin and haemoglobin by functioning as an oxygen transporter, thereby reducing chances of getting diseases such as anaemia, physical weakness, and fatigue (Fasoyiro et al., 2012; Atoyebi et al., 2017). Phosphorus assists in the development of bones, proper functioning of kidneys and formation of cells. Potassium helps to adjust the human's body acid-alkaline balance (Ndamitso et al., 2017). Calcium is significant for blood coagulation, contraction of muscles, and the metabolic activity of certain enzymes. Magnesium activates many enzyme systems. Water-soluble vitamins, including niacin, riboflavin and thiamine is essential for carbohydrate, lipid, and protein metabolism (Okpuzor et al., 2010).

Table 3. Mineral composition of Bambara groundnut grains.

Mineral content (mg/100g)	**Bambara groundnut**	**References**
Calcium	0.3- 76.01	(Atoyebi *et al*., 2017; Halimi *et al*., 2019, Hussin, *et al*., 2020)
Potassium	31.50- 2200.00	(Halimi *et al*., 2019; Musah, *et al*., 2021)
Magnesium	1.30- 555.10	(Halimi *et al*., 2019)
Sodium	0.10- 25.20	(Halimi *et al*., 2019; Musah, *et al*., 2021).
Phosphorus	17.40- 563.00	(Halimi *et al*., 2019; Musah, *et al*., 2021).
Iron	0.10- 180.2	(Atoyebi *et al*., 2017; Musah, *et al*., 2021)
Sulphur	0.34	(Hussin *et al*., 2020)
Zinc	2.14- 139.00	(Atoyebi *et al*., 2017; Halimi *et al*., 2019)
Copper	0.26- 30.00	(Atoyebi *et al*., 2017; Musah, *et al*., 2021)

Bambara groundnut also has vitamin C (1.170.20 mg/100 g), vitamin E (3. 180.15 mg/100 g) and vitamin A (26.050.14 mg/100 g) (Brink *et al*., 2006; Jideani and Diedericks, 2014). However, the mineral composition of BGN grains might vary depending on the variety of the grain. For example, Kaptso *et al*. (2015) found significant difference in phosphorus content of black and white BGN flours, with the white variety having lower content (216.8 mg/100 g) than the black variety (231.9 mg/100 g). Furthermore, several studies reported significant difference of mineral composition in different BGN accessions from wide geographical areas (Amarteifio *et al*., 2006; Alake and Alake, 2016; Atoyebi *et al*., 2017). These variations might be due to environmental factors and crop management.

The grains have a lot of amino acids, which are the building blocks of protein and are molecules with amino (-NH_2) and carboxyl (COOH) group (Kamei *et al*., 2020). Amino acids are essential for metabolism, anabolism, and neuron transmission in human body. They assist in curing injury, tissue regeneration, nutrients transportation and storage, cell structuring, body strengthening and the creation of arteries (Adebiyi *et al*., 2019; Kamei *et al*., 2020). Amino acids are divided into two groups, essential and non-essential amino acids. Bambara groundnut has a lot of essential amino acids (Table 4). Human cells cannot synthesize essential amino acids, which is why their consumption via food is critical. However, non-essential amino acids can be produced by human bodies (Bujang and Taib., 2014).

Table 4. Amino acids content of Bambara groundnut grains

Amino acids (g/100g)	**Bambara groundnut**	**References**
	Essential amino acids	
Valine	0.70- 0.98	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
Lysine	1.15- 5.91	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
Histidine	0.50- 2.44	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
Phenylalanine	0.80- 4.13	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
Threonine	0.53- 3.04	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
Methionine	0.24- 1.22	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
Leucine	1.16- 6.92	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
	Non-essential amino acids	
Proline	0.61- 2.86	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
Alanine	0.65- 4.04	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
Serine	0.79- 3.33	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
Glycine	0.58- 2.38	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
Arginine	1.18- 5.68	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
Glutamic acid	2.56- 10.01	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
Aspartic acid	1.63- 10.03	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)
Tyrosine	0.56- 3.21	(Adeyeye *et al*., 2012; Adebiyi *et al*., 2019)

Amino acids are commonly used to complement the nutritional content of some food products. For example, lysine and methionine are not available in some grains but are present in

BGN (Arise *et al*., 2017; Arise *et al*., 2017). Therefore, they can be utilized to complement the amino acids content of such products when introduced. Amino acids are also used as flavouring agent in food because they are sweet, salty, sour, and bitter or possess umami taste (Ninomiya, 2016). For example, they contain great amounts of glutamic acid (2.56 g/100 g) that can be utilized as a flavouring substance in food products (Adebiyi *et al*., 2019; Kamei *et al*., 2020; Tan *et al*., 2020). Bambara groundnut is rich in lysine and glutamic acid and contains considerable quantities of phenylalanine, aspartic acid, leucine, valine, arginine, and isoleucine (Adebiyi *et al*., 2019).

2.4. Antimicrobial activities of Bambara groundnut

This section examines the most current research on raw legume extracts and compounds to evaluate their anti-microbiological properties (Klompong and Benjakul, 2015; Pina-Pérez *et al*., 2017; Adebiyi *et al*., 2019). The section also addresses unanswered questions about bioactivity and sustainability of legume additives and compounds as anti-microbes, bioavailability, influence on microbiological cells and metabolic process and pathogenicity production (Adebiyi *et al*., 2019). Table 5 shows the ability of BGN to fight several foodborne pathogens.

Table 5. Antimicrobial activities of Bambara groundnut grains and against crucial foodborne pathogens

Legume	Extracts	Microorganisms	Effect	References
Bambara groundnut	BGN seed	*Escherichia coli* *Candida albicans* *Staphylococcus aureus*	Growth inhibition	Oyeyinka *et al*., 2021
Bambara groundnut	BGN seed coat, 99.9% ethanol extracts	*Escherichia coli* *Staphylococcus aureus* *Bacillus cereus*	Growth inhibition	Klompong and Benjakul, 2015
Bambara groundnut	BGN red and brown hulls, 70% methanol and 70% ethanol extracts	*Staphylococcus aureus* *Candida albicans* *Pseudomonas aeruginosa*	Growth inhibition	Harris, 2017

Different authors have reported an increase in inhibition of gram-negative bacteria such as *Klebsiella pneumonia*, *Klebsiella aerogenes*, and *Pseudomonas aeruginosa*, as well as gram-positive bacteria such as *Escherichia coli*, *Candida albicans*, *Staphylococcus aureus*, *Bacillus aureus*, and *Aspergillus Niger* with an increase in BGN grain extracts (Klompong and Benjakul, 2015; Harris, 2017; Wanyama *et al*., 2017; Wanyama, *et al*., 2018; Oyeyinka *et al*., 2021).

Moreover, Udeh *et al*. (2020) states that the anti-microbiological properties of BGN are also dependent on the concentration of the extract and the variety of the legume. The ability of BGN grains extracts to inhibit microbial growth is due to polyphenols such as flavonoids, anthocyanins, and tannins in the hulls of BGN grains that exhibit antimicrobiological and antioxidant potentials (Klompong and Benjakul, 2015; Tsamo *et al*., 2018).

Harris (2017) found antibacterial action of raw BGN extract and no antibacterial action in BGN milk and yogurt extracts; possibly indicating that phytochemical concentration was lower than in a raw BGN grains. The author further concluded that incorporating food products with high BGN hulls can improve their antioxidant and anti-microbiological properties. Moreover, Alakali *et al*. (2010) found an elevation of total plate count in beef patties incorporated with BGN powder for the first 14 storages days of the samples. However, after 14 days of storage to 21 days, the elevation of total plate in untreated beef patties was substantially greater than of treated patties with BGN powder.

Significant polyphenolic compounds in legumes can be found in the roots and seeds, depending on a particular product (Chon, 2013). Many polyphenolic compounds in legumes have been thoroughly investigated and linked with antimicrobial activity against extensive range of microbes. Chelation of crucial micro minerals such as iron and zinc, suppression of cell surface microbiological enzymes and straight forward intervention in microbiological activity are processes that are widely recognized as liable for polyphenols' antimicrobial capability (Heinonen, 2007; Daglia, 2012). Moreover, polyphenol compounds present in BGN such as tannins and flavonoid have been reported to possess antimicrobial activities (Klompong and Benjakul, 2015; Ajiboye and Oyejobi, 2017).

Antimicrobial activity has also been discovered in proteinase inhibitors found in plants, especially legumes. Plant-derived substances that protect from pests and pathogens have great prospects for application as anti-microbiological agents in products. These substances work by inhibiting enzyme activity in response to proteinases generated by phytopathogenic microbes attacking them (Arulpandi and Sangeetha, 2012; Lopes and Brandelli, 2018). Sitohy *et al*. (2013) determined the impact of chickpea, broad bean, and soybean proteins extracted and esterified with methanol that they inhibited microbial development. By utilizing the agar, a concentrated-dependent suppression area was noted against Gram-positive (*Bacillus subtilis* and *Staphylococcus aureus*) and Gram-negative (*Pseudomonas aeruginosa*, and *Escherichia coli*) bacterial upon adding methylated proteins at concentrations between 0.1 and 10 mg/ml (Sitohy et al., 2013). Similarly, Kanatt *et al*. (2011) found growth inhibition against *Bacillus cereus*, *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas fluorescens* by chickpea, mung, and pigeon pea extracts at concentration of 0.05%.

2.5 Natural antioxidants of Bambara groundnut

Natural antioxidants are substances that are utilized to prevent fat oxidation from occurring, as well as to prolong shelf-life of food (Glodde *et al*., 2018). Moreover, natural antioxidants protect food from spoilage due to oxidation, which may lead to lipid rancidity or alterations of colour in products (Aminzare *et al*., 2019). Despite their lower efficiency, natural antioxidants are well tolerated by consumers and are safe for consumption. Moreover, other natural substances possess greater antioxidant potential compared to artificial compounds and others have beneficial impacts on processed meat sensory attributes (de Florio Almeida *et al*., 2017; Oyeyinka *et al*., 2017).

Bambara groundnut has natural antioxidants such as flavonoids and phenolic, as well as DPPH and ferric reducing antioxidant power (Table 6). Thus, the shelf life of products containing fats can be extended due to availability of such substances. Natural antioxidants from BGN grains also help to maintain health. Antioxidant qualities of BGN are influenced by different ways of processing, crop variant and assay methodologies. The availability of phenolic substances in the grains is responsible for these qualities. Oyeyinka *et al*. (2017) found that antioxidant activities of BGN decrease significantly after the removal of hulls. Furthermore, Xu and Chang (2008) reported that most phenolic substances which are contained in hulls are mostly accountable for antioxidant activities. The reason for this is presumable due to the uneven distribution of phenolic compounds in plants. For instance, the seed coats of grains have greater concentrations of phenolic compounds than those present in the inner portions (Laura *et al*., 2019; Oyedeji *et al*., 2021).

Table 6. Phytochemicals of Bambara groundnut grains and their health benefits**.**

Phytochemicals	**Quantity (mg/g)**	**Health benefit**	**References**
Flavonoids			
Kaempferol	0.05- 2.18	Boost the body's antioxidant defence over free radicals, which lowers the chances of developing chronic diseases, particularly cancer and stroke.	(Chen and Chen, 2013; Salawu, 2016; Harris *et al*., 2018; Alam *et al*., 2020; Silva Dos Santos *et al*., 2021)
Anthocyanin	0.038	Regulate signalling pathways, aid in improving vision, controls weight, lowers the chances of developing cardiovascular	(Adedayo *et al*., 2021; Gonçalves *et al*., 2021)

		diseases, malignancy, and neurodegenerative disorders.	
Medioresinol	0.0008	Prevents CVDs and metabolic syndrome by lowering glucose and cholesterol levels.	(Hwang *et al*., 2018; Adebiyi *et al*., 2021)
Myricetin	0.062-1.80	Protect liver injuries, lowers hepatic triglycerides, inhibits hyperglycemia, reduces oxidative stress.	Salawu, 2016; Semwal *et al*., 2016; Harris *et al*., 2018; Imran *et al*., 2021
Catechin	0.01- 2.34	Prevents cancer, obesity, diabetes, liver injuries, CVDs, and lowers cholesterol level.	Salawu, 2016; Isemura, 2021; Kim and Heo, 2022
Quercetin	0.007-6.39	Lowers high glucose level, prevent kidney failure, heal wounds, prevents Alzheimer's disease, and eases arthritis-related pain and inflammation.	Salawu, 2016; Thomas *et al*., 2017; Borghi *et al*., 2018; Harris *et al*., 2018; Salehi *et al*., 2020
Epicatechin	1.15	Decreases chances of CVDs and diabetes.	Salawu, 2016; Aina *et al*., 2017
Phytic acids			
Ellagic acid	0.0005-1.09	Heal wounds, reduce exhaustion and insomnia. prevents liver damage, heart disease, skin damage, atherosclerosis, fibrosis, and nociceptive.	Salawu, 2016; Harris *et al*., 2018
Chlorogenic acid	0.03- 2.37	Prevents diabetes, cancer, stroke, Alzheimer disease, blood pressure, and obesity.	Salawu, 2016; Tajik *et al*., 2017; Harris *et al*., 2018; Yan *et al*., 2020
Caffeic acid	3.65	Prevents cancer, neurological disorders, diabetes, inflammation, and premature aging and improves collagen synthesis.	Magnani *et al*., 2014; Salawu, 2016; Harris *et al*., 2018; Cizmarova *et al*., 2020
Gallic acid	0.05- 1.03	Ability to treat cancer, neoplastic, diabetes, Alzheimer disease, hepatitis C virus, Parkinson's disease, and CVDs.	Salawu, 2016; Harris *et al*., 2018; Samad and Javed, 2018; Kahkeshani *et al*., 2019
Quinic acid	0.00309	Inhibit Human Immunodeficiency Virus, Hepatitis B virus, and Herpes Simplex virus loads. Improves immunological functioning and improves DNA repair.	Bhatia *et al*., 2015; Zanello *et al*., 2015; Adebiyi *et al*., 2021

Note: CVDs = cardiovascular diseases.

Most research on antioxidant activities of BGN utilised entire grain or grains without hulls which probably lowered the levels of antioxidants tested. Therefore, extracting phenolic compounds from the grains and determining antioxidant activities is essential.

Bambara groundnut contains variety of phytochemicals with different physiological active constituents; therefore, BGN constituents should be utilised as an additive in the production of nutraceuticals and functional foods (Okafor *et al*., 2022). Dried grains are an excellent source of phenolic compounds, and they can contribute to antioxidants consumption in other foods. Phenolic compounds in legumes can attach to proteins, minerals and amino acids that lack some of their electrons, therefore lowering the digestibility of crucial minerals and possibly improving the uptake of the nutrients (Thakur *et al*., 2019; Ahmmed *et al*., 2020). Phenolic compounds possess health benefits due to several biological processes by acting as free radical scavenger, reducing potential, chain breaking agent and changing of signal transduction pathways (Moyo *et al*., 2018). Flavonoids are a type of aromatic secondary metabolites from plants. Plants primarily utilise them to make essential pigments that are vital in forming colour (Karak *et al*., 2019; Khatun, 2021). Anthocyanidins, flavones, flavanols, and flavan-3-ols are among flavonoids found in BGN grains (Oyedeji *et al*., 2021).

Ferric reducing antioxidant power (FRAP) of legumes such as BGN grains demonstrates their potential to decrease ferric ions (Fe^{3+}) to ferrous ions (Fe^{2+}) while changing the colour from yellow to blue green (Oluwatoyin, 2014; Masek *et al*., 2018). In general, the existence of components that disrupt the free radical chains by acting as hydrogen-donor indicates FRAP (Ahmmed *et al*., 2020). The 1,1-diphenyl-2-picryl hydrazyl radical (DPPH) of legumes is a steady nitrogen-centered free radical donor that is mostly utilised to determine the scavenging activity of plant extracts. Extracts that possess antioxidant potential to alter DPPH colour from violet to yellow, due to their ability of donating electrons to a steady DPPH radical (Vijayaraghavan *et al*., 2018; Ahmmed *et al*., 2020). Oyeyinka *et al*. (2021) found comparatively greater DPPH activity in maroon and black BGN grains aqueous extract, due to possibly greater amount of protic flavonoids in them than in brown BGN grains (Ahmed *et al*., 2015). In addition, the differences in composition of the BGN grains may affect how differently the hydrogen atoms are donated to DPPH, which could be possibly account for variations in antioxidant content across varied BGN grains extract (Klompong and Benjakul, 2015). Chinnapun and Sakorn (2022) discovered a new substance in BGN grains that was classified as luteolin glycoside ($C_{20}H_{18}O_9$), which inhibited DPPH radical in them.

However, the quantity of antioxidant properties of the same or different BGN cultivars as well as other legumes vary depending on various factors such as legume breed, soil characteristics, growing parameters and solvents used for extracting samples (Yusnawan *et al*., 2019; Okafor *et al*., 2021). Total phenolic and flavonoid content of BGN grains are more reliant on their coat colour. Therefore, the darker the seed coat, the higher its antioxidant properties and the lighter the seed coat, the lower its antioxidant properties (Parikh and Patel, 2018; Adedayo *et al*., 2021). For instance, Adedayo *et al*. (2021) found higher flavonoid, phenolic and FRAP content of Black BGN variety compared to red and brown variety. Similar trends were also reported by Oyeyinka *et al*. (2021) for maroon, black, brown, and maroon BGN grains. Furthermore, Malik and Kapoor (2015) found that 70% acetone was the most effective solvent for extracting antioxidant properties of varieties of Indian lentils compared to pure methanol and 80% acetone. Similarly, Yusnawan and Kristiono (2019) found that 70% acetone generated higher flavonoid and phenolic content, as well as antioxidant activity of Mungbean varieties, compared to 70% methanol and 70% ethanol. Tsamo *et al*. (2018) found a range of total phenolic content (0.75–17.71 mg GAE/g) and total flavonoids content (0.01–2.51 mg GAE/g) in 21 BGN landraces. Since BGN grains contain considerable amount of phytochemicals, it is essential to further explore their utilisation and how new processing techniques affect their phytochemical composition (Oyedeji *et al*., 2021).

2.6. Limitation of Bambara groundnut production

In underdeveloped areas, BGNs are essential part of people's diet by supplementing the shortage of protein in grains, stems, and tubers. Nevertheless, owing to the emergence of difficult to cook phenomena while storing at extreme conditions (above 26 ^{o}C) and relative humidity (above 75 ^{o}C) as is prevalent in African countries, limits the use of BGN (Azam-Ali *et al*., 2001; Mubaiwa *et al*., 2017; Mubaiwa *et al*., 2018;). Two mechanisms occur at those temperatures, (1) lignification (the binding among branched-chain amino acids and liberated polyphenols in the cells results in lignin production and promotes cell wall strengthening) (Mubaiwa *et al*., 2017; Chigwedere *et al*., 2019), (2) pectin-phytase: phytase results in hydrolysis of positive charged phytate when stored, freeing bivalent charged ions. At the same time, pectin methyl esterase destroys the methyl esters of pectin, releasing liberated carboxyl group, that prefer to bind with bivalent positively charged ions. Therefore, the cell wall is solidified by the formation on non-soluble magnesium and calcium pectate compounds prevents cell detachment and weakens upon cooking (Chigwedere *et al*., 2019; Tan *et al*., 2020;). Grain outer layer, starch particles, polyphenols, phytic acid, proteins, lignins, tannins and cell wall are linked with difficult to cook phenomena (Aguilera and Rivera, 1992; Garcia *et al*., 1998; Gwala *et al*., 2019).

Individuals in affluent areas that have energy supplies and cutting-edge technology to use grains do not consider difficult-to-cook phenomena to be problematic because they can afford various products rich in protein (Chazovachii *et al*., 2013; Mubaiwa *et al*., 2018). Challenging to cook BGN grains need more time (3 to 4 h) to be boiled and thus elevated heat so that they can be consumable. However, since most villagers are dependent on firewood for cooking, the longer boiling durations needed for BGN grains processing are not sustainable based on expenses and power usage. The need for fuel wood in several African areas keeps rising, rising in land usage, and cutting down of trees have limited their availability, forcing people to fetch firewood far away from their homes (Mubaiwa *et al*., 2017; Temudo *et al*., 2020).

Furthermore, difficult to cook BGN also display difficult to mill qualities and difficult to cook issues owing to the solid bonding among husks and cotyledons due to gums and mucilage at the interaction (Mubaiwa *et al*., 2017; Muhammad *et al*., 2020). Another impediment to the utilization of this significant legume is the low production of BGN in African countries (Khan *et al*., 2016; FAOSTAT, 2020). Lack of modern equipment for post-harvest processes such as the removal of hulls, have also led to its under-use (Berchie *et al*., 2010; Majola *et al*., 2021). Altogether, these undesirable physical features contribute to reduction in BGN utilisation and reduces its application in various food products and increases its economic costs (Mubaiwa *et al*., 2018; Temudo *et al*., 2020).

2.7. Solutions to limitations of Bambara groundnut and future scope

Difficult to cook occurrence in BGN grains can be managed by storing them at lower temperatures in refrigerators. However, individuals living in poor areas cannot access such ideal conditions.[26] Turning difficult to cook BGN grains to consumable and nutrient-rich products; efficient and effective preparation methods are needed (Annan *et al*., 2003; Jideani and Diedericks, 2014). For instance, chemical procedures (cooking aids), biological procedures (germinating & fermenting), and physical procedures (milling, roasting, & canning) are all utilised when processing legumes (Mubaiwa *et al*., 2017). Although these procedures minimise cooking time, Annan *et al*. (2003) found that most participants during sensory evaluation indicated that processing methods change the taste and texture of products. Due to BGN hard to cook phenomena which is a constraint for its utilisation, understanding advanced science using various fourth industrial revolution technologies, including green technology is essential (Jideani and Jideani, 2021).

Thus, to promote the use of BGN in areas with a shortage of resources, appropriate techniques to shorten cooking duration, conserving power, and grinding qualities should be designed and deployed in local circumstances (Mubaiwa *et al*., 2018). Developing and promoting of local preparation procedures that can reduce existing post-harvest costs may be essential to the wide utilisation of BGN (Matsa and Mukoni, 2013; Mubaiwa *et al*., 2018). Those procedures should conform to the standards for competence, digestion of nutrients, and customer satisfaction requirements (Mubaiwa *et al*., 2018). As a result, it is critical to learn from and improve on procedures which have proven successful in preparing difficult to cook grains (Gbaguidi *et al*., 2018; Mubaiwa *et al*., 2018).

Between 1999 and 2018 there was a decline in the production of BGN which also resulted in less yielding cultivars and low standards grains (Annan *et al*., 2003; Khan *et al*., 2016). Therefore, initiating studies on breeding and the advancement of cultivars with improved agricultural methods targeting to improve yields is required. In future, trials to breed cultivars would be vital to examine local techniques, appropriateness, and personal participation of farming community to permit them to suggest viable lines to satisfy their urgent needs (Mubaiwa *et al*., 2018). Bambara groundnut is a climate smart plant because of thriving in different agricultural soils and varied climate conditions (Gbaguidi *et al*., 2018; Tan *et al*., 2020). Therefore, investors, sponsors, or departments of agriculture should assist farmers with funding to plant a lot of BGN crops by increasing labour and farming equipment. To improve the utilisation of BGN, food manufacturers with advanced fourth industrial revolution equipment machinery should collaborate with farmers to improve the availability of the product in the market.

2.8 Effect of legumes on sensory attributes of meat products

Meat tenderness, juiciness, flavour, colour, palatability, neatness, and cooking loss are some of the sensory attributes that consumers commonly use to assess meat quality (Calvo *et al*., 2016). Tenderness and juiciness are two factors that influence total meat consuming quality, whereas meat pH and colour have an impact on meat storage quality and appearance (Geletu *et al*., 2021). Meat patties are popular products eaten globally, often made with 70 % meat and about 26 to 32 % fat as major additives (De Oliveira Fagundes *et al*., 2017; Moghtadaei *et al*., 2018). Meat patties are typically made from beef (Polizer-Rocha *et al*., 2020), nevertheless novel formulas encompass of mutton and deer meat (Vargas-Ramella *et al*., 2020). Reduced fat content in patties is linked to issues with hardness, flavour, and moistness (Heck *et al*., 2019).

Nevertheless, it is important to keep in mind that not all customers are able to explore new products. Other customers are hesitant to explore that contain unique components or are made utilising new technology (Siegrist and Hartmann, 2020). Products neophobia consumers' segmentation enables for development of particular approaches depending on the likings of these individuals who are prepared to test novel or modified foods (Giacalone and Jaeger., 2023; Jin *et al*., 2023). It is broadly understood that new formulations of foods should be indeed centered on the consumer and in addition to the consumer's interest in healthy food. Sensory analysis of novel products is critical to their success and researchers have examined individual's perceptions on new products, with the majority of them focusing solely on product features (Câmara *et al*., 2020).

Improving the nutritional composition of meat patties whilst preserving consumer approval has been demonstrated to be achievable. In light of this, Argel *et al*. (2020) found that employing legumes powder as partial pork meat substitute's improved overall acceptability of patties. Currently, Vargas-Ramella *et al*. (2020) also stated that customers did not notice any major changes among patties made with animal fat and those made by substituting fat with chia, linseed, and tiger nut oils. The sensory attributes of pork burgers treated with green pea, chickpea, bean, and lentil powder emulsions were determined satisfactory to consumers by Argel *et al.* (2020) with no significant variations between the pulse kinds. According to Alakali *et al*. (2010) there was no significant difference between any sensory properties of non-formulated and BGN flour formulated beef burgers over 21 day's storage period.

2.9. Nutritional properties and health benefits of mutton meat

Meat consumption is very significant in the diet of human with respect to completely developing and sustaining optimal physiological and mental performances. Mutton meat (Figure 3) is composed of essential amino acids, water, lipids, vitamins and minerals, and small portion of carbohydrates (Mashau *et al*., 2021). It is also comprised of fats, as well as wide range of essential omega-3- polyunsaturated fats (Ponnampalam *et al*., 2021).

Figure 3: Boneless mutton meat composed of meat and fat with the ratio of 80/20, respectively (https://www.murgaca.com/en/products/mutton-trunks-8020.html).

2.9.1. Minerals

Red meat is very rich in micro-minerals, which are needed by the body in small quantity such as iron, copper, zinc, and selenium (Table 7). It also contains macro-minerals such as sodium, phosphorus, and sodium, which are needed by the body in large quantity. All these minerals are crucial since they serve significant part in antioxidative system and in the metabolism pathways (Zerabruk *et al*., 2019).

2.9.1.1 Iron

Meat is very rich in iron, as well as heme iron that contain myoglobin and haemoglobin proteins, which are crucial for respiratory systems and oxygenation of tissues (Fowler *et al*., 2019; Adeyeye *et al*., 2020). Nevertheless, iron deficiency, which is responsible for anaemia, is widespread globally, more especially in woman and is associated with lethargy, headache, stress, and extreme fatigue when training (Tardy *et al*., 2020; Abdelnabi, 2022). Furthermore, anaemia also results in low productivity and lowers the health of an individual (Ahmad *et al*., 2018). However, consumption of mutton meat can help to prevent such disorders due to present of iron.

Table 7. Nutritional composition of mutton patties

Nutrients	Meat cut (Mutton, chop or meat, raw)	References
Protein (g)	18.42- 22.85	(Khomola *et al*., 2021; Mashau *et al*., 2021)
Saturated fat (g)	2.4- 2.47	(Sainsbury *et al*., 2011; Ahmad *et al*., 2018)
Fat (g)	4.80- 11.62	(Ahmad *et al*., 2018; Mashau *et al*., 2021).
Ash (g)	1.12- 2.10	(Khomola *et al*., 2021; Mashau *et al*., 2021)
Moisture (%)	65.50- 67.25	(Khomola *et al*., 2021; Mashau *et al*., 2021)
Energy (Kcal)	122- 524	(Sainsbury *et al*., 2011; Ahmad *et al*., 2018)
Vitamin B_{12} (mcg)	2.0- 2.37	(Sainsbury *et al*., 2011; Ahmad *et al*., 2018)
Vitamin B_1 (mg)	0.04- 0.14	(Sainsbury *et al*., 2011; Ahmad *et al*., 2018)
Vitamin B_2 (mg)	0.04- 0.24	(Sainsbury *et al*., 2011; Ahmad *et al*., 2018)
Niacin (mg)	4.96- 4.99	(Sainsbury *et al*., 2011; Ahmad *et al*., 2018)
Pantothenic acid (mg)	0.6	(Ahmad *et al*., 2018)
Vitamin B_6 (mg)	0.2- 0.3	(Sainsbury *et al*., 2011; Ahmad *et al*., 2018)
sodium (mg)	63 -83	(Sainsbury *et al*., 2011; Ahmad *et al*., 2018)
Zinc (mg)	3.56- 3.6	(Sainsbury *et al*., 2011; Ahmad *et al*., 2018)
Iron (mg)	1.9- 2.97	(Sainsbury *et al*., 2011; Ahmad *et al*., 2018)
Phosphorus (mg)	174- 221	(Sainsbury *et al*., 2011; Ahmad *et al*., 2018)
Copper (mg)	0.15	(Ahmad *et al*., 2018)
Potassium (mg)	244- 275	(Sainsbury *et al*., 2011; Ahmad *et al*., 2018)
Magnesium (mg)	18.8- 22.7	(Sainsbury *et al*., 2011; Ahmad *et al*., 2018)
Calcium (mg)	12.5	(Ahmad *et al*., 2018)

2.9.1.2 Zinc and Selenium

Zinc is also a part of superoxide dismutase, which is an antioxidant enzyme required for the body immune system, having role in cell division, growth, and wound healing (Adeyeye *et al*., 2020; Chafik *et al*., 2021). An inadequate consumption of zinc results in exhaustion, deprived development, rickets and weakened mental function of an individual (Ahmad *et al*., 2018). Consumption of red meat can prevent such disorders due to the availability of zinc. Selenium is a crucial mineral required in a significant amount by individuals. Selenium is most utilised antioxidant in food supplements to prevent oxidation of fat in meat. It is a key part of an enzyme glutathione peroxidase, which along with vitamin E protects the cells from free radicals (Habibian *et al*., 2016; Xiao *et al*., 2021). Via its integration into selenoproteins, it plays an important part in sustaining well-being of an individual (Mojadadi *et al*., 2021)

2.9.1.3 Vitamins

Red meat such as mutton comprises of large quantities of vitamins that the body requires for better health (Libera *et al*., 2021). It comprises of huge amount of B vitamins (B_6 and B_{12}). Vitamin B_6 is required for proper operational of about 99 enzymes which catalyses crucial chemical reactions in individual's bodies. Also, it is crucial in creation of heme iron, which is constituent of haemoglobin, and it aids in the production of neurotransmitters (Juárez *et al*., 2021). Vitamin B_{12} is crucial for synthesis of Deoxyribonucleic acid that is essential for individual body's healthy growth and development. Vitamins found in mutton meat are required by all age groups (Ahmad *et al*., 2018). Red meat also contains vitamin A, C, D and E (Juárez *et al*., 2021). Vitamin A helps to strengthen and develop bones, as well as improving eyesight (Balami *et al*., 2019). Vitamin D is crucial for formation and maintaining bones, as well as separation and variation of cells. Vitamin E protects cells against effects from free radicals as it is an antioxidant that acts as free radical terminator. Vitamin C is necessary for integrity of bone and collagen, which assist in maintaining skin (Ahmad *et al*., 2018; Ahmad *et al*., 2022).

2.10. Mutton patties

Mutton patties is basically meat that has been finely chopped or grounded by a chopping knife or meat mincer and flattened, usually round using patty maker, manually or petri dish (Alakali *et al*., 2010; Bakieva *et al*., 2019). The process of grinding makes the meat cuts which are tougher to become tender, and grinding fatty cuts in with lean cuts assist in reducing the dryness. Minced meat is highly perishable as compared to the whole cuts of mutton meat and must be carried or handled with particular care (Cauchi, 2020). Throughout process of grinding most of ground meat are prone to oxidation of fat. This is because grinding opens up channels of meat being susceptible to oxygen, as well as disrupting and exposing phospholipids of meat to pro-oxidants such as copper and iron (Wang *et al*., 2021).

2.10.1 Shelf-life of mutton meat

Shelf-life refers to the time from when the products are packaged until their end utilisation date, whereby their attributes are still suitable for consumer's consumption. Shelf-life attributes may encompass the colour, flavour, texture, nutritional value (Meijer *et al*., 2020; Shivakumar *et* *al*., 2022). However, meat products made from minced meat such as mutton patties is likely to have short shelf life as the large, exposed channels or surface area of meat may result in spoilage. The speed of degradation relies on nutritional content of meat, proper sanitary practices when slaughtering, mincing, and preparing and during storage temperatures or environment. Microbiological contamination is the leading cause of meat deterioration, and it has detrimental impact on safety and colour of meat (Fang *et al*., 2017). Oxidation of fat and myoglobin results in colour deterioration, rancidity, and contributes to secondary defects of undesirable flavours and odours (Han *et al*., 2018; Domínguez *et al*., 2019). Minced meat products including meat patties are typically sold refrigerated at temperature ranging from 2- 5 ºC. Main solutions of extending shelf-life of fresh meat and ensuring consumers safety is to prevent or reduce product contamination and retard or hinder growth of pathogenic and spoilage microorganisms (Kumar *et al*., 2017; Santiesteban-López *et al*., 2022).

2.11 Physical properties of mutton meat

2.11.1 Colour of meat

Consumers view colour as indication of freshness and healthiness of the product; therefore, colour has greater impact on meat buying choices than all other quality criterion (Neethling *et al*., 2017; Ardeshiri and Rose, 2018). A link among colour liking and willingness to buy was observed, with consumers selecting against non-red beef and mutton (meat that is purple or brown) (Hughes *et al*., 2019). Colour is initial quality attribute that attract consumers, and it can be quantified both subjectively and objectively. The red colour in meat is widely recommended by consumers, whereas brown, discoloured meat is not (Silvestri *et al*., 2020; Xiong *et al*., 2020). Consumers' viewpoint is to blame for these disparities in liking. When compared to discoloured meat, individuals view red meat to be healthier, fresher, and of higher consuming quality (Hastie *et al*., 2020).

A prevalent misunderstanding between consumers is that meat colour signifies freshness, healthiness, and consuming quality (Liu *et al*., 2022). Even though discolouration in meat can reflect its good value, it is not always the issue. Discoloured meat can be of higher-grade meat as compared to red meat. Meat colour is impacted by a variety of inherent and external influences; therefore, it is not always a reliable indicator of meat quality (Suman *et al*., 2014; Poveda-Arteaga *et al*., 2023). Nevertheless, consumers will continue to utilise meat colour to determine quality of the meat because is merely quality criterion they can examine at the moment of buying (Testa *et al*., 2021). As a result, on-going investigation is required to determine the elements that affect meat colour and stability of colour to guarantee that fresh meat have the best possible colour and shelf-life.

2.12 Lipid oxidation in meat

Lipid oxidation linked with formation of free radicals is an impulsive interaction of ambient oxygen with double bond of polyunsaturated fatty acid of meat. This results to oxidative damage and degradation of the quality of meat and meat products by decreasing the durability (Chaijan and Panpipat, 2017; Aminzare *et al*., 2019), and development of unwanted sensory attributes, including as colour, nutritional value, texture, aroma, and taste resulting to rancidity. It is also accountable for off-flavours and bad taste, which are the most common causes for consumers to reject the products (Torrico *et al*., 2018; Dominguez *et al*., 2019). Lipid oxidation occurs as a three-stage radical chain reaction, with initiation, propagation, and termination respectively (Cardoso-Ugarte and Sosa-Morales, 2022)

2.13 Mechanisms of lipid oxidation in meat

2.13.1 Initiation stage

A hydrogen atom is extracted from the carbon nearest to the dual bond of an unsaturated fatty acid resulting to formation of alkyl radical (R•) and free hydrogen atom (H•) at the initial phase of lipid oxidation, as indicated in equation one (E1) (Bumbadiya *et al*., 2023). In the initial phase, a lag stage is usually detected when development fat oxidation in foods is gradual. This is owing to the sluggish generation of free radicals before build-up of hydroperoxides, as well as the fact that free radicals favourably attack or oxidise naturally antioxidants that shields fatty acids during early phases of oxidation (Cheng, 2016). Catalysts that speed up the reaction includes, metal ions, temperature (heating), and ultra-violet light (Amaral *et al*., 2018; Hazrat *et al*., 2021).

$$\mathbf{RH} \longrightarrow \mathbf{R\bullet + H\bullet} \quad \text{(Equation 1).}$$

2.13.2 Propagation stage

Propagation stage is the second step of lipid oxidation that takes place between the reaction of free alkyl radical (R•) formed throughout the initiation stage and molecular oxygen leading to the very reactive peroxy radical (Radical interacting with oxygen- ROO•) (Equation 2), which is able to react with unsaturated fatty acids and extract hydrogen atom, leading to formation of hydroperoxides (ROOH•) and alkyl radical (R•) (Equation 3) (Chaijan and Panpipat, 2017;

Hazrat *et al*., 2021). Later as hydroperoxides decompose, volatile aromatic compounds are formed, which give meat its rancid odour and off-flavour (Flores *et al*., 2021; Hazrat *et al*., 2021).

R• + O_2 → **ROO•**.......................... (Equation 2).

ROO• + RH → **ROOH + R•**........... (Equation 3).

2.13.3 Termination stage

Termination is the final stage of lipid oxidation which occurs between reaction of peroxy and alkyl radicals leading to development of non-radicals relatively stable products like alkanes, conjugated dienes, and ketones, which are produced when level of free radicals is adequately high (Equation 4, 5, and 6) (Karademir, 2019). Aldehydes production is assessed as being directly proportionate to degradation of meat colour and flavour, as well as functionality and stability of protein (Amaral *et al*., 2018; Hussain *et al*., 2021). Aldehydes can also cause malignancy, atherosclerosis, and purative mutagens (Ganesan and Xu, 2020).

R• + R• → **R- R**.............................. (Equation 4).

R• + ROO• → **ROOR**..................... (Equation 5).

ROO• + ROO• → **ROOR + O_2**....... (Equation 6).

CHAPTER 3: MATERIAL AND METHODS

3.1. Study design

The following figure summarises the processing of the samples and analysis conducted throughout the experiment.

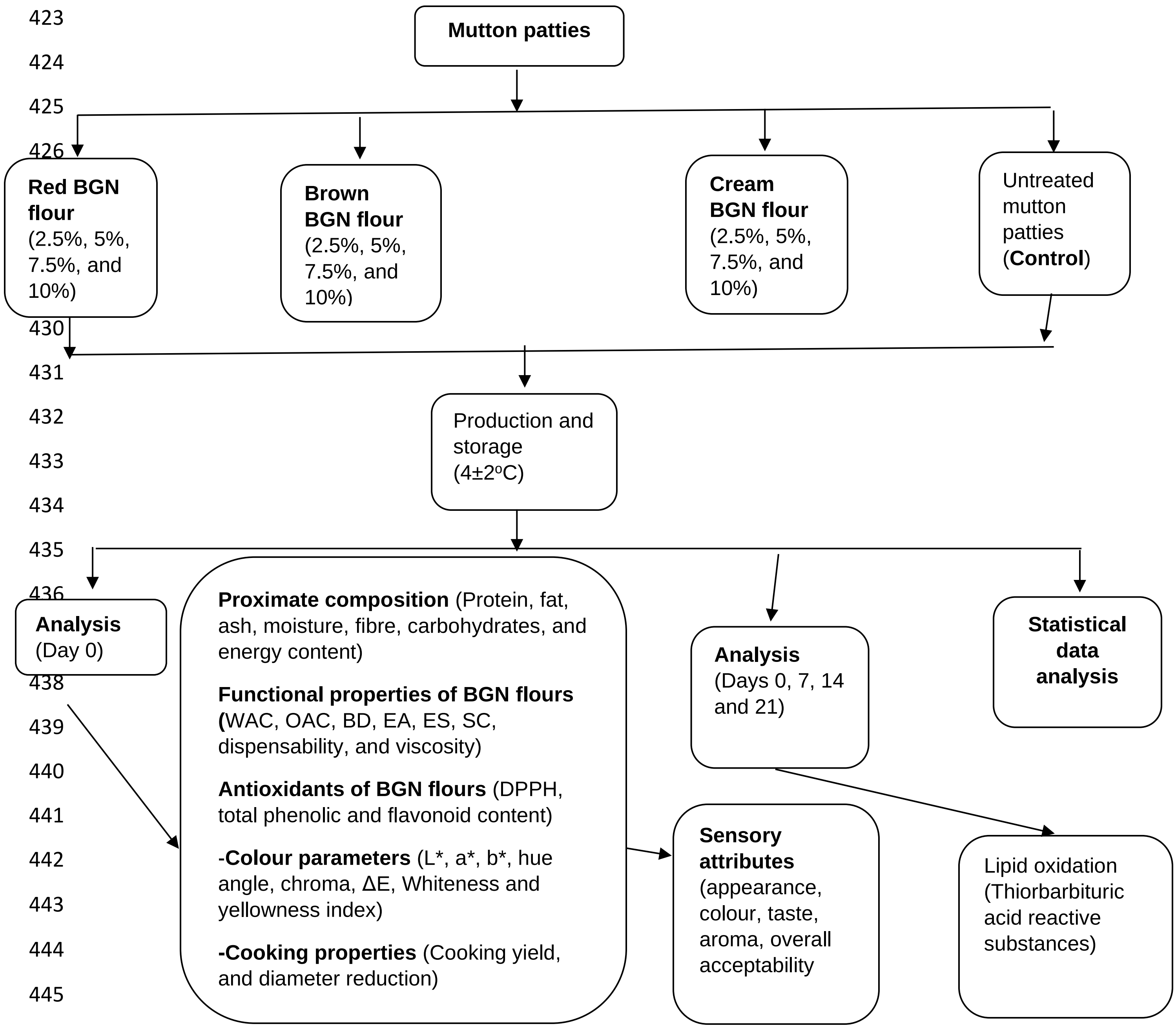


Figure 4: Schematic diagram of the research project utilising factorial design. L*= lightness; a= redness; b*= yellowness; WAC= water absorption capacity; OAC= oil absorption capacity; EA= emulsion activity; ES= emulsion stability; BD= bulk density; SC= swelling capacity; DPPH= 2,2 Diphenyl-1-pycryl-hydrazyl

3.2 Raw materials, chemicals, and reagents

Ten (10) kilogram of mixed BGN (brown, cream, and red-coated) grains was purchased from a supermarket in Thohoyandou, Limpopo Province, South Africa. The reagents acetone, acetic acid, methanol, ethanol, Folin-Ciocalteau, Hydrochloric and Thiorbarbituric acid were purchased from Merck (Pty, Ltd., Midrand, Gauteng province, South Africa). All the chemicals utilised were of analytical grade.

3.3 Preparation of Bambara groundnut flour

The BGN grains were grouped according to their colour (brown, cream, and red) separately and washed properly with tap water to remove dirt, small branches, and premature grains were physically discarded. The grains were then oven-dried at 37°C for 48 hours. The dried grains were ground utilising Retsch miller (ultra-centrifugal mill ZM 200, Germany) and sieved using a 212 µm sieve size to produce the final finer powder and packaged inside vacuum plastic bags and stored in a dry, cool area until utilisation (Alakali *et al*., 2010).

3.4 Preparation of mutton patties

Ten (10) kilogram of deboned mutton meat was bought at Newco meat butchery in Shayandima, Limpopo Province, South Africa. Every ounce of subcutaneous and intramuscular fat as well as connective tissues were manually trimmed off and then the meat was chopped into small pieces and ground utilising meat mincer (P-22, Tallers Ramon, Barcelona, Spain) through 5 mm plates. Throughout the mincing process, cold water with ice was added. Four (4) blends (for each BGN variety) were formulated by combining minced mutton meat with 2.5%, 5.0%, 7.5%, and 10% of BGN flours and 100% mutton patties was used as a control. To get a uniform mixture, each part was quietly mixed manually in a container for approximately 5 minutes. A petri-dish was utilised to shape the mix to form the patties (75 mm x 15 mm), two batches were produced and packaged in low-density polyethylene bags. For analysis of lipid oxidation, the patties were stored at refrigerator at 4 ± 2°C and analysed at day 0, 7, 14, and 21 (Argel *et al*., 2020).

3.5 Determination of functional properties of Bambara groundnut flour

3.5.1 Water absorption capacity and oil absorption capacity

Water absorption capacity (WAC) and oil absorption capacity (OAC) were obtained in triplicate where one gram of sample was measured into 25 mL centrifuge tubes. A small amount of distilled and refined sunflower oil was added and stirred till the samples became separated with water or oil. The flours were centrifuged for 20 minutes at 3000 rpm and allowed to rest for 30 minutes at ambient condition. The water or oil that was released as result of centrifugation was emptied (Ferreira *et al*., 2018). The OAC and WAC were calculated as follows in equation 1 and 2:

Water absorption capacity (%) = $\frac{weight\ of\ water\ absorbed}{weight\ of\ the\ sample} x\ 100$ (Equation 1)

Oil absorption capacity (%) = $\frac{weight\ of\ oil\ absorbed}{weight\ of\ the\ sample} x\ 100$ (Equation 2)

3.5.2 Emulsifying activity

Emulsifying activity was obtained following the procedure outlined by Arise *et al*. (2015). One (1) gram of flour was put in 15 mL of water in centrifuge tubes and centrifuged at 20000 rpm for 30 s for homogenisation; then sunflower oil (15 mL) was poured, emulsified for 1.5 minutes, and centrifuged at 750 rpm for 5 min. Emulsifying activity was computed using equation 3:

Emulsifying activity (%) = $\frac{Height\ of\ the\ remaining\ emuslfied\ layer}{Height\ of\ the\ whole\ tube\ content}\ x100$ (Equation 3)

3.5.3 Emulsion stability

Emulsion stability was obtained similarly as the emulsifying activity and heated at 80^{o}C for 30 minutes and then cooled in tap water for 15 min and centrifuged at 750 rpm for 5 min. Emulsion stability was computed using the equation 4:

Emulsion stability (%) = $\frac{Height\ of\ the\ remaing\ emulsifying\ layer}{Height\ of\ the\ whole\ tube\ content}\ x100$ (Equation 4)

3.5.4 Bulk density

Bulk density was measured using the procedure outlined by Jenfa and Akinrinde (2019). Twenty (20) grams of the powder was put in a 100 mL measuring cylinder and hit at the base with a hand. The ultimate volume was measured after the cylinder was put on a flat surface. The bulk density was determined using equation 5:

Bulk density = $\frac{Weight\ of\ sample\ g/ml}{Volume\ of\ the\ sample}$ (Equation 5)

3.5.5 Swelling capacity

Swelling capacity was determined using the procedure explained by Arise *et al*. (2019). Ten grams of BGN flour was put in a 300 mL measuring cylinder, and the volume covered was measured. The powder was then poured with 150 mL of distilled water and set aside for 4 hours. Following swelling, the ultimate volume was measured. The swelling percentage was determined using equation 6:

$$\text{Swelling capacity (\%)} = \frac{Final\ volume - Initial\ volume}{Initial\ volume} x100 \quad \text{(Equation 6)}$$

3.5.6 Dispensability

Dispensability was obtained using a procedure outlined by Jenfa and Akinrinde (2019). In a 100 mL measuring cylinder, 10 g of BGN flour was added, and 100 mL of distilled water was then poured. The mixture was aggressively agitated and let to rest for 3 h, then the volume of settled particles was recorded. The dispensability was determined using equation 7:

Dispensability (%) = 100 – The volume of settled particles (Equation 7)

3.5.7 Viscosity

The viscosity of the sample was obtained utilising the Brookfield viscometer (RUVDE230, USA). Three point five grams (3.5 g) of the sample (adjusted to 14 % moisture content) and distilled water was poured to get a mass of the sample of about 25 g. The sample was heated at $50^{o}C$ for one (1) minutes while stirring to enable complete dispersion. The resistance of the flour mixture to the mixing paddles of the viscometer was utilised to measure the viscosity (cP) (Mudau *et al*., 2022).

3.6 Determination of antioxidants properties of Bambara groundnut flour

3.6.1 DPPH Radical Scavenging Activity of mutton patties

DPPH assay was determined using a procedure outlined by Ofosu *et al*. (2020) with slight modifications. Two (2) grams of each flour was measured and placed inside beakers and 20 mL of methanol (30%) was poured and sornicated for 10 minutes in an ultrasonic bath. Afterwards, the samples were then centrifuged (Rotina 380R-Labotec Ecotherm, Midrand, South Africa) at 3000 rpm for 10 min and filtered into beakers utilising Whatman filter paper. Two (2) millimeters of the sample extract was added to 2 mL of 0.1 Mm DPPH in 10 mL test tubes. The mixture was shaken vigorously, kept at ambient condition for 30 minutes, and absorbance was analysed at 517 nm utilising UV-spectrophotometer (Shimadzu UV-1800, Japan). The DPPH content was computed using the following equation 8:

$$\text{DPPH (\%)} = \frac{Absorbance\ of\ the\ control\ (methanol\ with\ DPPH\ solution) - Absorbance\ of\ the\ flour\ sample}{Absorbance\ of\ the\ control\ (methanol\ with\ DPPH\ solution)} x\ 100$$

(Equation 8)

3.6.2 Total phenolic content

Total phenolic content was analysed using a procedure outlined by Mahmoud *et al*. (2017) with slight modification. Two (2) grams of each flour was measured and deposited into the beakers and 20 mL of methanol (30%) was then poured and sornicated for 10 minutes in an ultrasonic bath. The mixture was centrifuged at 3000 rpm for 10 min and filtered into beakers. Thereafter, 0.5 mL of the sample was poured into test tubes and 1.5 mL of Folin-Ciocalteau reagent was also poured and let to stand for 5 minutes at ambient condition (25 ± 2^{o}C). After 5 minutes, 2 mL of sodium carbonate (7%) was poured and placed in an incubator for 50 minutes in a dim place with intermittent shake. The absorbance of the samples was determined utilising UV-spectrophotometer (Shimadzu UV- 1800, Japan) at 725 nm. The total phenolic content was computed using the standard curve and reported as gallic acid (mg GAE/g).

3.6.3 Flavonoids content

Total flavonoids content was analysed using a colorimetric procedure. Two grams of each flour was measured and placed into beakers and 20 mL of methanol (30%) was then poured and sornicated for 10 minutes in an ultrasonic bath. Afterwards, the mixture was centrifuged at 5000 rpm for 10 min and filtered using Whatman paper. Then, 0.3 mL of sample extracts was added into a test tube and 3.4 mL of 30% methanol was added, and 0.15 mL of sodium nitrite ($NaNo_2$) was also added. Thereafter, 0.15 mL of Aluminum chloride hexahydrate ($AlCl_3.6H_2O$) was introduced to the mixture and let to rest for 5 minutes and 1 mL of NaOH was introduced. After that the absorbance was measured at 506 nm utilising UV-spectrophotometer (Mashau *et al*., 2021a). The total flavonoids content was computed using the standard curve and reported as catechin (mg CE/g).

3.7 Determination of proximate composition of mutton meat

3.7.1 Moisture content

Moisture content was obtained succeeding the procedure described in AOAC (2007) method 945.32 where 10 g of the sample was weighed and transferred into a blank crucible which was placed in an oven dryer at 105 ± 5^{o}C for 16-18 hours. Then the crucibles were placed in the desiccator to cool for an hour. After cooling, the weight loss was measured, and the moisture content was calculated in percentage using equation 9:

$$\text{Moisture (\%)} = \frac{fresh\ weight - dry\ weight}{fresh\ weight} x100 \qquad \text{(Equation 9)}$$

3.7.2 Ash content

Ash content was analysed according to AOAC (2007) method no. 923.03. Ten grams (10 g) of sample was put into the empty crucibles which were put into a muffle furnace for 3 hours at 550^{o}C. Therefore, the crucibles were placed in a desiccator to cool. After cooling, the weight loss was measured to determine ash content expressed in percentages using equation 10:

Ash content = $\frac{Weight\ of\ crucible+ash(g)-Weight\ of\ empty\ crucible(g)}{Weight\ of\ crucible+sample(g)-Weight\ of\ empty\ crucible(g)}\ x\ 100$ (Equation 10)

3.7.3 Protein content

Protein content was obtained using the Dumas procedure described in AOAC (2007) method no. 992.15. One gram (1.0 g) of the meat sample was put into a 528-203 ceramic combustion utilising a 604-494 plunger with a 502-210 tube. The boats containing samples were then transferred into the appropriate position in the autoloader. The analysis sequence was initiated to analyse the protein content.

3.7.4 Fat content

The fat content was determined utilising the Ankom technology described in AOCS (1989) official method no. 2. Two grams (2 g) of the sample was transferred into the filter bag and weighed. After that, the bag was sealed, followed by drying the sample in an oven drier at 102 ^{o}C for 3 hours. Then the samples were placed in a desiccator for cooling and measured. The automated extraction was then performed using petroleum ether for 90 minutes at 60^{o}C. Afterwards, the samples were dried at 105^{o}C for 30 minutes in an oven drier, followed by cooling in a desiccator and measured. The fat content was calculated using equation 11:

Fat (%) = $\frac{Weight\ of\ pre-dried\ smple\ -Weight\ of\ dried\ sample\ after\ extraction}{Weight\ of\ the\ sample}\ x\ 100$ (Equation 11)

3.7.5 Crude fibre

Crude fibre of the samples was determined following AOAC (2007) method no. 985.33. One gram 1 g of each sample was measured in triplicates into 400 ml beakers. Therefore, the samples were heated for 30 minutes with 100 mL solution of Sulphuric acid (H_2SO_4) (1.25 %) using reflux. The mixture was filtered through filter paper and then rinsed with hot water to clear the base remains completely. Therefore, the filtrate was transferred into the clean conical flask by washing it with 100 mL of NaOH (1.25 %), and then boiled again for 30 minutes. After boiling the mixture was filtered again and then washed again with hot water to completely remove the acidic residues. The residue was left on filter paper and transferred into crucibles and placed on the hot plate to evaporate excess water and measured. The remains were burnt in the muffle furnace for 3 hours at 550 ^{o}C, and then cooled in a desiccator for an hour and then measured. The fibre content was then calculated using equation 12:

Crude fibre= $\frac{Weight\ of\ crucible\ with\ fibre-Weight\ of\ crucible\ with\ ash}{Weight\ of\ sample}$ (Equation 12)

3.7.6 Carbohydrates content

Carbohydrates amount was obtained by calculating the difference of percentage of moisture, fat, protein, ash, and crude fibre, using equation 13 (Sultana, 2020):

Carbohydrates (%) = 100- (moisture + fat + protein + Crude fibre). (Equation 13)

3.7.7 Energy content

The total energy was calculated using equation 14: (Kinyuru, 2021).

Energy value (Kcal) = g/ 100 g carbohydrate x 4 + g/ 100 g fat x 9 + g/ 100 g protein x 4 (Equation 14)

3..8 Determination of physical properties of mutton patties

3.8.1 Cooking yield

Raw mutton patties were weighed, then cooked and surface-dried with a filter and measured once more utilising an analytical scale balance (Ali *et al*., 2022). The cooking yield was calculated using equation 15:

$$\text{Cooking yield} = \frac{Weight\ of\ cooked\ mutton\ patties}{Weight\ of\ raw\ mutton\ patties} x100 \qquad \text{(Equation 15)}$$

3.8.2 Diameter reduction of patties during cooking

Diameter was determined following a method described by Kilincceker (2018) using equation 16:

$$\text{Diameter Reduction (\%)} = \frac{(Diameter\ of\ cooked\ raw\ patties - Diameter\ of\ cooked\ patties}{Diameter\ of\ raw\ patties} x100$$

(Equation 16)

3.9 Colour attributes

Colour attributes were determined at three randomly chosen spots of the samples through a method outlined by Neethling *et al*. (2016) using Hunter Lab colourflex (Reston VA, U.S.A, D65). The instrument was initially calibrated using white and black tiles to determine the colour parameters such as L* (lightness), a* (redness), b* (yellowness). The whiteness index (WI), and yellowness index (YI) were determined using the equations (Mehdizadeh *et al*., 2020):

$\text{Hue} = \tan^{-1} (b^*/a^*)$ (Equation 17)

$\text{Chroma} = (a^{*2} + b^{*2})^{1/2}$ (Equation 18)

$\Delta E = \sqrt{(\Delta L)2 + (\Delta a)2 + (\Delta b)2}$ (Equation 19)

WI= 100- $\sqrt{(100 - L*)2 + (a)2 + (b)2}$ (Equation 20)

YI = $\frac{142.86b}{L*}$ (Equation 21)

3.10 Texture profile analysis

The texture characteristics of grilled patties were carried out using a method outlined by Andrés *et al*. (2011). The patties were pressed two times to 30% of their initial height amongst levelled plates. The texture analyser (Stable Micro Systems, London, UK) with a 75 mm diameter probe mms^{-1} (SMSP/75), linked up with a PC, and software provided by texture operating system corporation (New York, United States) was used. Hardness (maximum power of first compression phase, N), springiness (length of the discovered height of the sample on the succeeding (2nd) pressing split by the initial pressing length, mm/mm), cohesiveness (proportion of opposite of negative areas of the number two cycle to an area of the first cycle, J/J), chewiness (hardness × cohesiveness × springiness, N), and resilience (area through the removal of the initial pressing split by the area of the initial pressing, J/J) were obtained.

3.11 Determination of lipid oxidation

Thiorbarbituric acid reactive substance (TBARS) values were obtained following the procedure described by Mashau *et al*. (2021b) for 21 days (0, 7, 14 & 21) where standard solution of TBA was prepared in glacial acetic acid by dissolving 57.66 mg of TBA in 100 mL of glacial acetic acid. TBA solution was prepared on each day of the analysis. One gram of each raw patties sample was put in 25 mL test tube and 50% glacial acetic acid (solvent). BHT (0.01 %) was utilised to prevent the sample from oxidising. The samples mixture was centrifuged (Rotina 380R-Labotec Ecotherm, Midrand, South Africa) at 3000 rpm for 15 minutes and filtered into test tubes using Whatman papers. The mixture was boiled in water bath at 95 ^{o}C for 60 min, and test tubes were allowed to cool at ambient temperature (25 ± 2 ^{o}C) and absorbance was read at 532 nm using UV-visible spectrophotometer (Shimadzu UV-1800, Japan).

3.12 Sensory analysis

Sensory evaluation was undertaken by 60 consumer panellists with an age range of 18 to 50 years, encompassing university students and staff members who had previous knowledge with sensory analysis of meat. The formed patties were cooked by grilling in a Hobart CN85-19 convection oven (Hobart Corp., Troy, Ohio, USA) for 20 min at 160^{o}C to a core temperature of 80^{o}C as measured at the geometrical centre. To obtain homogeneous cooking, the patties were flipped over every 10 min. The prepared mutton patties were kept on warm trays in sealed plates for less than 10 min. Warmed portions (10 g) of each of the patties were placed in the white polystyrene plates and given to every participant with 3-digit numbers in a random and consistent way for analysis. The panellists were given tap water to rinse their mouth after tasting every sample. Sensory testing was carried out in a well-lit and well-designed environment. To evaluate appearance, taste, texture, colour, and total acceptability, analysis was undertaken using a 9-point hedonic scale (9= extremely like; 5= indifferent; 1= extremely dislike). All participants were given written information about the study and the products to be tasted before giving their informed consent (Argel *et al*., 2020).

3.13 Statistical analysis

The experiment and analyses were duplicated to validate the results. The data obtained was analysed by one way analysis of variance (ANOVA) utilising Statistical Package for the Social Sciences (SPSS) version 28 for Bambara groundnut flours. Two-way analysis of variance was used for mutton patties. The disparity between the mean of each analysis done in triplicates was determined utilising Duncan's multiple range test and Ryan-Einot-Gabriel-Welsch (REGWQ) test for BGN flours, and mutton patties, respectively. The acceptable significant difference was at $p \leq 0.05$ level. The spearman rank order correlation test was utilised to determine the correlation between cooking yield and diameter reduction. Primary sensory evaluation data were subjected to statistical calculations and on their bases, regression analysis was performed for each of the tested mutton patties samples.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Bambara groundnut flour characteristics

The nutritional, functional and physical properties of BGN flours are indicated in Table 8. The moisture content of red BGN flour (7.13%) was significantly lower ($p < 0.05$) than that of cream BGN flour (8.85%), whereas brown BGN flour was not significantly ($p < 0.05$) different from cream and red BGN flours. However, the moisture content of all BGN flours was typically less and between the anticipated range (0-14%) in pulse flours (Shanono and Muhammed, 2015; Buckman *et al*., 2018; Skřivan *et al*., 2021).

Table 8. Bambara groundnut flours properties.

Properties	Cream	Red	Brown
Moisture (%)	8.85 ± 0.92^{b}	7.13 ± 0.10^{a}	8.17 ± 0.58^{ab}
Ash (%)	2.89 ± 0.42^{a}	3.14 ± 0.35^{a}	3.39 ± 0.10^{a}
Protein (%)	19.67 ± 0.21^{a}	19.03 ± 0.70^{a}	21.07 ± 0.98^{b}
Fat (%)	6.67 ± 0.07^{b}	6.70 ± 0.27^{b}	6.42 ± 0.07^{a}
Fibre (%)	4.76 ± 0.03^{a}	7.73 ± 0.07^{c}	5.89 ± 0.05^{b}
Carbohydrates (%)	57.45 ± 0.11^{c}	56.27 ± 0.08^{b}	55.06 ± 0.47^{a}
Energy (kcal/100g)	368.48 ± 1.17^{b}	361.50 ± 4.43^{a}	362.29 ± 2.89^{ab}
L*	88.07 ± 0.08^{c}	81.82 ± 0.59^{a}	83.43 ± 0.12^{b}
a*	1.27 ± 0.02^{a}	2.95 ± 0.08^{b}	2.91 ± 0.05^{b}
b*	10.48 ± 0.06^{c}	7.18 ± 0.05^{a}	8.39 ± 0.12^{b}
Hue angle	82.78 ± 0.66^{c}	67.01 ± 0.81^{a}	70.79 ± 0.62^{b}
Chroma	10.56 ± 0.06^{c}	7.77 ± 0.07^{a}	8.70 ± 0.34^{b}
WI	84.07 ± 0.09^{c}	80.23 ± 0.57^{a}	81.20 ± 0.12^{b}
YI	17.00 ± 0.10^{c}	12.54 ± 0.18^{a}	14.37 ± 0.21^{b}
WAC (%)	182.49 ± 1.03^{a}	204.38 ± 2.24^{b}	201.91 ± 3.23^{b}
OAC (%)	166.87 ± 1.11^{a}	169.03 ± 3.72^{ab}	174.21 ± 3.50^{b}
EA (%)	49.64 ± 0.31^{a}	51.73 ± 1.35^{b}	52.83 ± 1.05^{b}
ES (%)	51.37 ± 1.05^{a}	49.32 ± 1.18^{a}	51.26 ± 0.79^{a}
BD (g/ml)	0.66 ± 0.01^{a}	0.68 ± 0.01^{b}	0.70 ± 0.00^{c}
SC (g/g)	0.41 ± 0.03^{b}	0.24 ± 0.05^{a}	0.18 ± 0.13^{a}
Dispensability (%)	57.33 ± 2.31^{b}	52.00 ± 2.00^{a}	48.00 ± 2.00^{a}
Viscosity (cP)	2666 ± 5.57^{a}	3402 ± 7.21^{b}	3464.67 ± 4.51^{b}
DPPH (%)	95.15 ± 3.67^{b}	87.19 ± 0.87^{a}	87.54 ± 0.74^{a}
TPC (mg GAE/g)	0.79 ± 0.01^{a}	0.98 ± 0.01^{b}	0.91 ± 0.06^{b}
TFC (mg CE/g)	0.06 ± 0.00^{ab}	0.05 ± 0.00^{a}	0.07 ± 0.01^{b}

Distinct small letters (superscripts) on the same row display that mean values are significantly different ($P < 0.05$). BGN= Bambara groundnut; L*= lightness; a= redness; b*= yellowness; WI= whiteness index; YI= yellowness index; WAC= water absorption capacity; OAC= oil absorption capacity; EA= emulsion activity; ES= emulsion stability; BD= bulk density; SC= swelling capacity; DPPH= 2,2 Diphenyl-1-pycryl-hydrazyl; TPC= Total phenolic content; TFC= Total flavonoids content.

The low moisture content suggested that BGN flours would have an extended shelf-life and be less susceptible to the proliferation of microorganisms during storage if they are packaged and stored appropriately (Sruthi and Rao, 2021; Mashau *et al*., 2022). Similarly, Oyeyinka *et al*. (2021) found higher moisture in cream BGN flour than in red and brown BGN flours. The ash content of all BGN flours was not significantly ($p < 0.05$) different from each other with values varying from 2.89 to 3.39%.

The protein content of brown BGN flour (21.07%) was significantly ($p < 0.05$) higher than that of cream (19.67%) and red BGN (19.03%) flours. Differences in the amount of protein of BGN flours might be due to variations in the type of the cultivar or unique genetic characteristics if cultivated in comparable conditions (Adeleke *et al*., 2018; Ikegwu *et al*., 2023). Oyeyinka *et al*. (2017) found significantly higher protein content in brown than red BGN flour. High protein content makes BGN flour suitable for inclusion in protein-rich diets or as a supplement for diets that lack adequate protein (Adeleke *et al*., 2017).

The fat content of brown BGN flour (6.42%) was less than that of cream (6.67%) and red BGN (6.70%) flours. The low-fat content in BGN flours was anticipated given that BGNs are dry grains and typically have lower than 10% fat when compared to oily grains like groundnuts and soybeans (Nwadi *et al*., 2020). Kaptso *et al*. (2015) stated that the low amount of fat of BGN flours might be because of their respective great amount of protein content, as supported by results in Table 8. A low amount of fat suggested that BGN flour could be preserved with minimal loss of quality until future use (Deepa and Umesh Hebbar, 2017).

The crude fibre of red BGN flour (7.73%) was significantly higher ($p < 0.05$) than that of brown (5.89%), and cream BGN (4.76%) flours, respectively. Variations in the amount of crude fibre of BGN flours might be because of the type of the cultivar (Ikegwu *et al*., 2023). Similarly, Shanono and Muhammad (2015) found higher crude fibre content in red BGN flour than in brown BGN flour. Significant crude fibre content in BGN flours is important in reducing hypertension and serum cholesterol levels and providing protection from cardiovascular conditions. It also promotes healthy bowel function and increases faecal bulk (Tan *et al*., 2021; Aremu *et al*., 2022).

The carbohydrate content of cream BGN flour (57.45%) was significantly higher ($p < 0.05$) than that of red (56.27%) and brown BGN (55.06%) flours. Regardless of the type of cultivar, carbohydrate was the most predominant component in all BGN flours. Adeleke *et al*. (2017) found higher carbohydrate in white (cream) BGN flour than in red BGN flour. Consuming BGNs can supply the body with enough energy due to their high carbohydrate content (Schulz and Slavin *et al*., 2021). The energy content of red BGN (361.50 kcal/100g) flour was less than that of cream BGN (368.48 kcal/100g) flour but not significantly different ($p < 0.05$) from brown BGN flour

(362.29 kcal/100g). Generally, the energy content of all BGN flours was high. The high-energy content of cream BGN flour was due to its respective high carbohydrate (Bunmee *et al*., 2022).

The BGN flour's colour properties are indicated in Table 8. The cream BGN (88.07) flour was significantly higher ($p < 0.05$) in lightness (L*) value than brown (83.43) and red BGN (81.82) flours. Therefore, BGN flours with less L* values, displayed significantly higher ($p < 0.05$) a* values, probably due to their relatively higher total phenolic content (Table 8) which is responsible for the red colour (Bamshaiye *et al*., 2011; Parikh and Patel, 2018). The two BGN flour (red and brown) varieties were significantly higher ($p < 0.05$) in a* values than cream BGN flour. The higher the total phenolic content of the grain the higher the a* value and less L* value (Tsamo *et al*., 2018). Oyeyinka *et al*. (2017) reported similar trends in the colour of red, brown, and cream BGN flours with respect to their phenolic content. The yellowness (b*) value of cream BGN (10.48) flour was significantly higher ($p < 0.05$) than that of brown and red BGN flours which had values of 8.39 and 7.18, respectively. The higher b* value of the flour might be due to greater amount of flavonoid content as shown in Table 8 which is responsible for the yellow colour in the grain (Khatun, 2021).

The chroma values of cream BGN flour was significantly higher ($p < 0.05$) than that of brown and red BGN flours, varying from 7.77 to 10.56. The high chroma values of cream BGN flour was probably because of its relatively high b* value since it depends on it (Falade and Akeem, 2020; Ramashia *et al*., 2021). The higher chroma value of the flour displays the highly intense colour of the sample as perceived by consumers (Mubaiwa *et al*., 2018; Falade and Akeem, 2020). A similar trend of chroma and b* values was reported by Falade and Akeem (2020) in African mesquite bean powders. The hue angle of cream BGN flour was significantly higher ($p < 0.05$) than that of red and brown BGN flours.

The WI of cream BGN flour was significantly higher ($p < 0.05$) than that of brown and red BGN flours ranging from 80.23 to 84.07. The greater WI value of cream BGN flour was probably because of its relatively high L* value (Suliman *et al*., 2023). The higher WI value of cream BGN flour might also be due to its relatively lower phenolic content as well as genetic differences in the grain varieties (Mang *et al*., 2015; Uchechukwu-Agua *et al*., 2015). Falade and Akeem (2020) found a higher WI of African mesquite bean flour due to its relatively high L* value. The YI of cream BGN flour was significantly higher ($p < 0.05$) than that of brown and red BGN flours. The higher YI value of cream BGN flour was probably due its correspondingly high b* value (Uchechukwu *et al*., 2015). A comparable pattern of YI and b* was also reported by Uchechukwu-Agua *et al*. (2015) in different cassava flour varieties.

The functional properties of BGN flours are indicated in Table 8. The WAC of brown and red BGN flours was significantly higher ($p < 0.05$) than that of the cream BGN flour ranging from 182.49 to 204.38%. The greater polar amino acid residues of protein which are water-loving might be the reason for the higher WAC of brown and cream BGN flours (Adeleke *et al*., 2017; Arise *et al*., 2017). Thus, BGN flour with higher protein levels (Table 8) might have drawn up more water than those with lower protein content (Marikkar *et al*., 2021). Iwe *et al*. (2016) stated that the disparity in WAC of various flours might be because of variations in their protein content, structural properties, and ability to absorb water. Furthermore, Adeleke *et al*. (2017) found higher WAC in brown than in white BGN flour. The OAC of brown BGN flour was significantly higher ($p < 0.05$) than that of red and cream BGN flours, with values varying from 166.89 to 174.21%. The disparity in the OAC of BGN flours might be due to the difference in the availability of non-polar side chains that might have attached to the hydrocarbon side chain of the oil amongst the BGNs flours (Chandra *et al*., 2015; Awuchi *et al*., 2019).

The emulsion activity (EA) of cream BGN flour was significantly lower ($p < 0.05$) than that of red and brown BGN flours. The lower EA of cream BGN flour might be because of its respective less protein content in comparison to other BGN flours (Argel *et al*., 2020). In addition, proteins with higher solubility and less surface hydrophobicity levels result in weaker interconnection surface covering lipid droplets (low EA) (Argel *et al*., 2020; Abiala *et al*., 2022). This result might also be due to the variety of the sample (Iwe *et al*., 2016). The EAs of BGN flours are higher than the EAs of cowpea, soya bean, and peanut (Abiala *et al*., 2022).

The bulk density (BD) of brown BGN flour was significantly higher ($p < 0.05$) than that of red and cream BGN flours with values varying from 0.66 to 0.70 g/mL. The disparity in BD might be because of the presence of starch content (Iwe *et al*., 2016), therefore a large amount of carbohydrate might account for a greater amount of BD in BGN flours (Adeleke *et al*., 2017). The greater the BD, the smaller packing volume and the stiffer the packaging material is needed, and vice versa (Mi and Ejeh, 2018; Awuchi *et al*., 2019). Adeleke *et al*. (2018) found higher BD in brown than white BGN flour. The BDs of BGN flours were comparable to the BD of soya bean and cowpea flours (Abiala *et al*., 2022).

The swelling capacity (SC) of cream BGN flour was significantly higher ($p < 0.05$) than that of red and brown BGN flours varying from 0.18 to 0.41 g/g. Higher SC of cream BGN flour might be caused by high starch content which is indicated by high carbohydrates (Table 8), particularly in starches that contain more branches of amylopectin (Iwe *et al*., 2016). The dispensability of cream BGN flour was significantly higher ($p < 0.05$) than red and brown BGN flours. The high dispensability of BGN flours might be due to their relatively low WAC (Table 8) and higher gelling ability of flours (Nzuta *et al*., 2022). The dispensability of BGN flour was less than that of the cowpea powder found by Jenfa *et al*. (2019).

The viscosity of brown and red BGN was significantly higher ($p < 0.05$) than that of cream BGN flours ranging from 2666 to 3464.67 cP. The variation in viscosity may be caused by the intermolecular network's fragility which might have led to the disintegration of BGN flours granules when gelatinised in hot water, resulting in a paste with a relatively less viscosity (Nzuta *et al*., 2022). Similarly, Falade and Nwajei (2015) reported higher viscosity in the brown variety than in the cream variety.

The antioxidant properties of BGN flours are indicated in Table 8. The DPPH content of cream BGN flour was significantly ($p < 0.05$) higher than brown and red BGN flours varying from 87.19 to 95.15%. The high DPPH of cream BGN flour followed by the red BGN flour might be due to their relatively high flavonoid content than brown BGN flour (Table 8) (Ahmed et at., 2015). Additionally, differences in BGN composition might have an impact on how hydrogen atoms were donated to DPPH, therefore affecting the DPPH content of BGN flour (Klompong and Benjakul, 2015; Ramatsetse *et al*., 2023). Oyeyinka *et al*. (2021) reported higher DPPH content in maroon BGN than in black and brown BGN flours with their respective high flavonoid content. Nyau *et al*. (2015) reported higher DPPH content in red BGN than in brown BGN flour.

The total phenolic content (TPC) of red and brown BGN flours was significantly higher ($p < 0.05$) than that of cream BGN flour ranging from 0.79 to 0.98 mg GAE/g. The difference in BGN coat colours might account for the disparity in TPC (Oyeyinka *et al*., 2021). Therefore, BGN grains that are darker in coat colours possess higher TPC than those with lighter coat colours (Parikh *et al*., 2018; Adedayo *et al*., 2021). Oyeyinka *et al*. (2017) found greater TPC in red BGN than in brown BGN flour. Tsamo *et al*. (2018) also reported higher TPC in red BGN than in brown and cream BGN flours, respectively. Therefore, consuming BGN grains may assist in fighting the negative effects caused by free radicals by functioning as free radical scavengers (Moyo *et al*., 2018; Adedayo *et al*., 2021). The total flavonoids content of brown and cream BGN flour was significantly higher ($p < 0.05$) than that of red BGN flour ranging from 0.05 to 0.07 mg/g CE. The differences in total flavonoids content of BGN flours might possibly be caused by differences in grain cultivars, assay procedure and conditions of extracting (Ramatsetse *et al*., 2023).

4.2 Proximate composition of mutton patties

The proximate composition of raw mutton patties is shown in Table 9. The increase in percentage of BGN flours decreased the moisture content of patties compared to the control sample ranging from 69.86 to 67.66%.

Table 9. Proximate composition of mutton patties incorporated with different levels of Bambara groundnut flour.

Samples	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fiber (%)	CHO (%)	Energy (kcal/100g)
Control	69.86 ± 0.10^{iD}	1.16 ± 0.05^{Aa}	19.64 ± 0.06^{cC}	7.20 ± 0.02^{eB}	0 ± 0.00^{aA}	2.14 ± 0.11^{aA}	151.92 ± 0.39^{bcdefAB}
Brown 2.5%	69.35 ± 0.10^{h}	1.45 ± 0.03^{c}	19.57 ± 0.02^{b}	7.11 ± 0.02^{cd}	0.15 ± 0.01^{bc}	2.37 ± 0.15^{abc}	151.74 ± 0.42^{bcde}
Brown 5%	69.11 ± 0.06^{fg}	1.78 ± 0.00^{de}	19.53 ± 0.01^{ab}	7.06 ± 0.03^{bc}	0.31 ± 0.01^{def}	2.21 ± 0.08^{ab}	150.50 ± 0.05^{a}
Brown 7.5%	68.72 ± 0.23^{d}	1.85 ± 0.01^{f}	19.53 ± 0.01^{ab}	6.94 ± 0.02^{ab}	0.42 ± 0.01^{fg}	2.49 ± 0.24^{bcd}	150.95 ± 0.75^{ab}
Brown 10%	68.25 ± 0.04^{bc}	1.99 ± 0.00^{g}	19.51 ± 0.02^{a}	6.89 ± 0.12^{a}	0.52 ± 0.01^{gh}	2.79 ± 0.04^{de}	151.68 ± 0.12^{bcd}
Mean brown	68.86 ± 0.44^{C}	1.77 ± 0.21^{D}	19.54 ± 0.03^{A}	7.02 ± 0.07^{A}	0.35 ± 0.14^{C}	2.47 ± 0.26^{B}	151.22 ± 0.66^{A}
Red 2.5%	69.19 ± 0.06^{fgh}	1.41 ± 0.03^{bc}	19.59 ± 0.02^{bc}	7.12 ± 0.03^{cd}	0.19 ± 0.00^{bcd}	2.50 ± 0.08^{bdc}	152.41 ± 0.42^{cdefg}
Red 5%	68.77 ± 0.11^{de}	1.77 ± 0.00^{d}	19.56 ± 0.00^{ab}	7.08 ± 0.04^{cd}	0.40 ± 0.01^{f}	2.43 ± 0.15^{abc}	151.65 ± 0.33^{bcd}
Red 7.5%	68.14 ± 0.03^{b}	1.81 ± 0.01^{ef}	19.55 ± 0.02^{ab}	6.99 ± 0.03^{ab}	0.55 ± 0.01^{h}	2.95 ± 0.07^{ef}	152.91 ± 0.12^{fg}
Red 10%	67.66 ± 0.06^{a}	1.98 ± 0.01^{g}	19.54 ± 0.01^{ab}	6.94 ± 0.02^{a}	0.79 ± 0.18^{i}	3.10 ± 0.18^{f}	153.03 ± 0.80^{g}
Mean red	68.44 ± 0.61^{A}	1.74 ± 0.21^{C}	19.56 ± 0.02^{B}	7.03 ± 0.08^{A}	0.48 ± 0.24^{D}	2.74 ± 0.32^{C}	152.50 ± 0.70^{B}
Cream 2.5%	69.21 ± 0.10^{gh}	1.38 ± 0.01^{b}	19.56 ± 0.02^{ab}	7.14 ± 0.03^{de}	0.12 ± 0.00^{b}	2.59 ± 0.06^{cd}	152.84 ± 0.53^{fg}
Cream 5%	68.98 ± 0.02^{gh}	1.75 ± 0.00^{d}	19.55 ± 0.02^{ab}	7.08 ± 0.04^{cd}	0.24 ± 0.01^{cde}	2.39 ± 0.04^{abc}	151.43 ± 0.20^{abc}
Cream 7.5%	68.40 ± 0.02^{c}	1.78 ± 0.01^{de}	19.54 ± 0.01^{ab}	6.98 ± 0.03^{ab}	0.35 ± 0.01^{ef}	2.95 ± 0.06^{ef}	152.77 ± 0.09^{efg}
Cream 10%	68.12 ± 0.02^{b}	1.95 ± 0.01^{g}	19.53 ± 0.04^{ab}	6.92 ± 0.03^{a}	0.42 ± 0.01^{ef}	3.06 ± 0.03^{ef}	152.68 ± 0.25^{defg}
Mean cream	68.67 ± 0.46^{B}	1.72 ± 0.21^{B}	19.55 ± 0.02^{AB}	7.03 ± 0.09^{A}	0.28 ± 0.12^{B}	2.75 ± 0.28^{C}	152.45 ± 0.62^{B}

Values expressed as mean ± standard deviation. Means in the same column with distinct lowercases (superscripts) indicate a significant difference ($p < 0.05$). Brown, red, and cream (2.5%, 5%, 7.5%, and 10%) indicate different concentrations of different cultivars of Bambara groundnut flours. Whereas means in the same column with distinct uppercases (superscripts) indicate a significant difference ($p < 0.05$) of the type of varieties. CHO = carbohydrate

The brown BGN variety significantly decreased ($p < 0.05$) the moisture content of patties than the cream and red BGN varieties, respectively. The reduction in the amount of moisture of formulated patties may be because of the low moisture content of BGN flours as shown in Table 8. Correspondingly, Kasaiyan *et al*. (2023) observed the reduction of moisture content in lamb sausage due to the inclusion of chickpea powders.

The ash content of formulated patties significantly increased ($p < 0.05$) with the increase in percentage of BGN flours varying from 1.16 to 1.99%. The brown BGN flour significantly increased the ash content than the red and cream BGN flours, respectively. The increased in ash content of patties with BGN substitution might be due to the high amount of ash in BGN flours as shown in Table 8. Similarly, Novello *et al*. (2019) reported an increase in the ash content of beef patties due to the inclusion of golden flaxseed powder. Furthermore, Alakali *et al*. (2010) found comparable data in beef patties added with BGN flour.

The protein content of formulated patties significantly decreased ($p<0.05$) with the increase in the percentage of BGN flours ranging from 19.64 to 19.51%. The brown BGN flour decreased the protein content of the mutton patties than the red BGN variety, respectively. The decreased in protein content of formulated patties might be due to substitution of meat fat by BGN flours since meat fat holds a substantial amount of protein (Vargas-Ramella *et al*., 2020). However, the low protein was still around the expected protein content (19%) of meat (Rama *et al*., 2019). Saikia *et al*. (2019) found a decrease in the protein content of duck meat patties as the amount of black gram powder increased. Jamaly *et al*. (2017) observed low protein content of beef meatballs due to the addition of wheat powder.

The fat content of formulated patties significantly decreased ($p < 0.05$) with an increase in the percentage of BGN flours with values ranging from 7.20 to 6.89%. Overall, all BGN varieties decreased the fat content of mutton patties equally. The control sample had a higher fat content of 7.20%. Gao *et al*. (2020) stated that the low-fat content of meat patties might be due to the low-fat of legumes incorporated, as supported by the low-fat content of BGN flours in Table 8. Morbos *et al*. (2019) found a decrease in the amount of fat of pork patties with an increase in the inclusion of Mung bean powder.

The fibre content of formulated patties significantly increased ($p < 0.05$) with an increase in the percentage of BGN flours compared to the control samples varying from 0.00 to 3.10%. The red BGN variety increased the fibre content of the mutton patties than the brown and cream BGN varieties, respectively. The improvement in the amount of fibre of formulated patties might be due to the amount of fibre content in BGN flours as shown in Table 8. Similarly, Kahraman *et al*. (2023) found an increase in the amount of fibre of kirklareli meatballs incorporated with cowpea powder.

The carbohydrate content (CHO) of control sample (2.14%) was significantly less ($p < 0.05$) than that of formulated samples, except for the sample added with 5% brown BGN flour. The red and cream BGN varieties increased the CHO content of the mutton patties than the brown BGN variety. This was due to high CHO content in BGN flours as shown in Table 8. However, there was inconsistency trend of CHO in patties with the inclusion of BGN flours because CHO content is calculated by the difference (Sousa *et al*., 2023). Therefore, samples with higher sums of proximate composition (protein, ash, moisture, and fibre) had lower CHO content, and vice versa. Embaby *et al*. (2016) found a similar trend in beef burgers added with lentil coat powder.

There was no consistent trend in energy content of patties with the inclusion of BGN flours with values ranging from 150.50 to 153.03 kcal/100g. This is because the energy relies mostly on fat (9 kal/100g), carbohydrate (4kcal/100g), and protein (4kcal/100g) (Kwon *et al*., 2020) and there was no effective difference in fat content, therefore the sample with higher sum of multiplication factor yielded higher energy content. The red and cream BGN varieties improved the energy content of the patties than the brown BGN variety. However, the control sample was not significantly ($p < 0.05$) different from samples formulated with brown 2.5% and 10%, and red 5% BGN flours. Öztürk-Kerimoğlu *et al*. (2020) reported similar results in low-fat sausages incorporated with quinoa flour.

4.3 Cooking yield and diameter reduction of mutton patties

The cooking yield and diameter reduction of mutton patties are indicated in Table 10. The cooking yield of mutton patties increased ($p < 0.05$) with an increase in the percentage of BGN flours with values ranging from 76.39% for control and 86.78% for patties added with 10% cream flour variety. Overall, all BGN varieties increased the cooking yield of the mutton patties equally. The improvement of cooking yield in formulated patties might be due to the availability of dietary fibre, WAC, and OAC in BGN flours that absorbed or retained the fat and water throughout cooking, thereby forming a firmer component of the ton patties matrix (Xu, 2017., Essa and Elsebaie, 2018; Mashau *et al*., 2021b). Similarly, Chandler and McSweeney (2022) reported an increase in cooking yield of chicken patties incorporated with yellow pea powder.

The increase in the percentage of BGN flours limited the diameter reduction of mutton patties with values ranging from 17.73 to 13.89%. All BGN varieties significantly decreased ($p < 0.05$) the diameter reduction of the mutton patties equally. The decrease in diameter reduction of formulated patties might be because of greater water-holding and swelling ability of BGN flours as shown in Table 8 (Younis and Ahmad, 2018). Additionally, the decrease in diameter reduction might be attributed to the BGN flour's ability to bind thereby keeping the meat components intact and preventing the patties dimensions from changing (Bunmee *et al*., 2022).

Table 10. The cooking yield and diameter reduction of mutton patties incorporated with different levels of Bambara groundnut flours and their correlation.

Samples	Cooking yield (%)	Diameter reduction (%)	R
Control	76.39 ± 0.03^{Aa}	17.73 ± 0.03^{eB}	-0.985
Brown 2.5%	81.28 ± 0.06^{b}	16.49 ± 0.03^{d}	
Brown 5%	83.21 ± 0.03^{d}	15.54 ± 0.02^{c}	
Brown 7.5%	84.03 ± 0.04^{e}	15.04 ± 0.03^{b}	
Brown 10%	86.75 ± 0.03^{g}	13.99 ± 0.58^{a}	
Mean brown	83.82 ± 2.27^{B}	15.28 ± 0.94^{A}	
Red 2.5%	81.39 ± 0.03^{c}	16.25 ± 0.04^{d}	
Red 5%	83.23 ± 0.02^{d}	15.56 ± 0.04^{c}	
Red 7.5%	84.12 ± 0.04^{ef}	15.06 ± 0.02^{b}	
Red 10%	86.80 ± 0.03^{g}	13.94 ± 0.04^{a}	
Mean red	83.89 ± 2.25^{B}	15.20 ± 0.91^{A}	
Cream 2.5%	81.31 ± 0.02^{bc}	16.48 ± 0.02^{d}	
Cream 5%	83.31 ± 0.03^{d}	15.42 ± 0.03^{bc}	
Cream 7.5%	84.12 ± 0.03^{f}	15.10 ± 0.02^{b}	
Cream 10%	86.78 ± 0.16^{g}	13.89 ± 0.03^{a}	
Mean cream	83.88 ± 2.27^{B}	15.22 ± 0.97^{A}	

Values expressed at mean ± standard deviation. Mean in the same column with distinct lowercases (superscripts) indicates a significant difference ($p < 0.05$). Brown, red, and cream (2.5%, 5%, 7.5%, and 10%) indicate different concentrations of different cultivars of Bambara groundnut flours. Whereas means in the same column with distinct uppercases (superscripts) indicate a significant difference ($p < 0.05$) of the type of varieties. R, is correlation coefficient of cooking yield and diameter reduction.

High diameter reduction value of the control sample was probably due to the point that during cooking, the protein denatured, water evaporated, and fat drips leading to weight loss and shrinkage of the patties (Chandler and McSweeney, 2022). Park *et al*. (2017) reported the decrease in diameter reduction in pork patties formulated with black rice powder. Furthermore, there was negative correlation (r= -0.985) between the diameter reduction and cooking yield of the patties. This was anticipated since BGN flours has the ability to absorb water thereby improving cooking yield and limiting the diameter reduction of mutton patties during cooking.

4.4 Colour properties of mutton patties

The colour properties of raw mutton patties are depicted in Table 11 while Figure 5 shows images of mutton patties incorporated with different BGN flours varieties. The L* values of muton patties significantly increased ($p < 0.05$) with the addition of BGN flours ranging from 54.04 to

58.59. The cream and brown BGN varieties significantly increased ($p < 0.05$) the L* value of the patties than red BGN variety. However, patties added with 2.5% brown and red BGN flours did not differ with the control sample. The patties sample with the most increased L* value was the one added with 10% cream BGN flour. The a* values of formulated patties significantly decreased ($p < 0.05$) with an addition of BGN flours compared to control. The cream BGN variety decreased the a* values of the patties than the red and brown BGN varieties, respectively. Therefore, the increase in L* values and reduction in a* values might be attributed to the dominant light colour of BGN flours that diluted the red colour of mutton patties causing reduction in meat myoglobin (Saikia *et al*., 2019). Da Silva Felix *et al*. (2021) found an improvement in lightness and a reduction in redness of lamb patties with the inclusion of cassava flour. The b* values of mutton patties decreased with the inclusion of BGN flours ranging from 18.38 to 15.49. All BGN varieties decreased the b* values of patties equally. However, patties added with 2.5% BGN flours did not significantly differ with the control sample. The decrease in b* values might be due to the low-fat content of formulated patties as shown in Table 9. Similarly, Salarkarimi *et al*. (2019) found a decrease in b* values of beef burgers incorporated with chestnut powder.

Chroma of mutton patties significantly decreased ($p < 0.05$) with an increase in the percentage of BGN flours with values ranging from 23.66 to 17.82. All BGN varieties decreased the chroma values of patties equally. The reduction in chroma values might be attributed to the reduction in a* values of formulated mutton patties (Mashau *et al*., 2021b). Thus, the inclusion of BGN flours did not boost the colour intensity of patties since chroma decreased. However, the values obtained are tolerable, since the acceptable chroma value by consumers is 3 and above (King *et al*., 2023). Ball *et al*. (2021) found the reduction in chroma values of ground beef with an inclusion of pea protein. The hue angle of the control sample was lower than that of the formulated samples ranging from 50.98 to 60.39°. The brown, and cream BGN varieties increased the hue angle of patties than the red BGN variety. The increase in hue angle was due to decrease in a* values of formulated patties, as higher hue angle represents lower redness of meat products (Ball *et al*., 2021). Furthermore, lower a* and chroma values with high hue angle denote the browning of meat because of their strong correlation with metmyoglobin concentration (Mashau *et al*., 2021a; Khomola *et al*., 2021).

The colour difference of formulated patties significantly increased ($p < 0.05$) with the addition of BGN flours varying from 0.00 to 8.21. The cream BGN variety increased the colour difference of patties than the brown and red varieties. The noticed disparities in the colour of formulated mutton patties might be due to the presence of colour pigments of BGN flours (Adewumi *et al*., 2022). Since the colour differences of formulated patties are above 2, it indicates that they are noticeable (Moarefian *et al*., 2013; Mashau *et al*., 2021a). Similarly, Argel *et al*. (2020) found an increase in colour difference of low-fat pork burgers with an increase in lentil flour concentration.

Table 11. Colour properties of mutton patties incorporated with different levels of Bambara groundnut flour.

Samples	L*	a*	b*	Chroma	Hue angle	∆E	WI	YI
Control	$54.04±0.96^{Aa}$	$14.90±0.46^{dC}$	$18.38±0.43^{dB}$	$23.66±0.63^{eB}$	$50.98±0.24^{aA}$	$0.00±0.00^{aA}$	$48.31±1.14^{aA}$	$48.61±2.03^{eB}$
Brown 2.5%	$55.47±1.11^{abc}$	$11.17±1.35^{bc}$	$17.68±0.15^{cd}$	$20.93±0.86^{cd}$	$57.79±2.87^{bc}$	$4.26±1.51^{bc}$	$50.79±0.73^{bc}$	$45.54±0.59^{de}$
Brown 5%	$55.93±1.67^{abcd}$	$11.18±1.43^{bc}$	$16.72±0.89^{abc}$	$20.12±1.53^{bcd}$	$56.33±1.98^{b}$	$4.85±1.42^{bc}$	$51.52±0.95^{bcd}$	$42.70±1.10^{bcd}$
Brown 7.5%	$56.99±0.10^{bcde}$	$10.70±0.45^{bc}$	$16.30±0.99^{abc}$	$19.51±0.63^{abcd}$	$56.67±2.60^{b}$	$5.65±1.10^{bcd}$	$52.77±0.32^{de}$	$40.85±2.53^{abc}$
Brown 10%	$57.72±0.37^{cde}$	$9.97±0.42^{ab}$	$16.13±0.68^{abc}$	$18.96±0.79^{ab}$	$58.26±0.29^{bc}$	$6.57±1.34^{cd}$	$53.66±0.02^{ef}$	$39.91±1.44^{abc}$
Brown mean	$56.53±1.27^{B}$	$10.76±1.02^{B}$	$16.71±0.90^{A}$	$19.88±1.15^{A}$	57.27±2.03C	$5.33±1.46^{BC}$	$52.18±1.27^{C}$	$42.25±2.62^{A}$
Red 2.5%	$54.96±0.71^{ab}$	$12.05±0.39^{c}$	$17.54±0.45^{cd}$	$21.29±0.31^{d}$	$55.50±1.36^{b}$	$3.17±0.90^{b}$	$50.38±0.48^{b}$	$45.61±1.54^{de}$
Red 5%	$55.07±0.67^{ab}$	$11.25±0.64^{bc}$	$16.42±0.21^{abc}$	$19.91±0.54^{bcd}$	$55.62±1.14^{b}$	$4.06±1.12^{bc}$	$51.22±0.58^{bcd}$	$42.61±0.05^{bcd}$
Red 7.5%	$55.41±0.41^{abc}$	$10.82±0.33^{bc}$	$15.72±0.10^{ab}$	$19.08±0.18^{abc}$	$55.46±0.90^{b}$	$5.10±0.90^{bc}$	$51.34±0.48^{bcd}$	$40.52±0.43^{abc}$
Red 10%	$56.21±0.66^{abcde}$	$10.22±0.29^{abc}$	$15.26±0.32^{a}$	$18.37±0.37^{ab}$	$56.17±0.28^{b}$	$6.03±0.37^{cd}$	$52.16±0.62^{bcde}$	$38.78±1.21^{ab}$
Red mean	$55.21±0.74^{A}$	$11.09±0.78^{B}$	$16.24±0.94^{A}$	$19.66±1.18^{A}$	$55.69±0.91^{B}$	$4.59±1.34^{B}$	$51.27±0.80^{B}$	$41.88±2.79^{A}$
Cream 2.5%	$56.11±0.42^{abcd}$	$10.79±0.77^{bc}$	$17.03±0.42^{bcd}$	$20.17±0.45^{bcd}$	$57.67±2.14^{bc}$	$4.89±0.30^{bc}$	$51.74±0.34^{bcd}$	$43.36±0.73^{cd}$
Cream 5%	$56.65±0.05^{bcde}$	$10.24±0.11^{abc}$	$16.66±0.35^{abc}$	$19.55±0.35^{abcd}$	$58.41±0.38^{bc}$	$5.64±0.85^{bcd}$	$52.32±0.21^{cde}$	$42.01±0.86^{bcd}$
Cream 7.5%	$57.97±1.03^{de}$	$10.13±0.17^{ab}$	$16.37±0.36^{abc}$	$19.25±0.34^{abcd}$	$58.25±0.64^{bc}$	$6.57±1.57^{cd}$	$53.79±1.00^{ef}$	$40.34±0.33^{abc}$
Cream 10%	$58.59±1.35^{e}$	$8.79±0.34^{a}$	$15.49±0.80^{ab}$	$17.82±0.71^{a}$	$60.39±1.63^{c}$	$8.21±1.76^{d}$	$54.84±1.83^{f}$	$37.82±2.79^{a}$
Cream mean	$57.33±1.28^{B}$	$9.99±0.85^{A}$	$16.39±0.74^{A}$	$19.20±0.99^{A}$	$58.68±1.60^{C}$	$6.33±1.69^{C}$	$51.27±0.80^{D}$	$40.88±1.21^{A}$

Values expressed as the mean± standard deviation. Means in the same column with distinct lowercases (superscripts) indicate a significant difference ($p < 0.05$). L*= lightness; a*= redness; b*= yellowness; ∆E= colour difference; WI= whiteness index; YI= yellowness index. Brown, red, and cream (2.5%, 5%, 7.5%, and 10%) indicate different concentrations of different cultivars of Bambara groundnut flours. Whereas means in the same column with distinct uppercases (superscripts) indicate a significant difference ($p < 0.05$) of the type of varieties

The WI of formulated patties significantly increased ($p < 0.05$) with the inclusion of BGN flours with values ranging from 48.31 to 54.84. Overall, the cream BGN variety decreased the WI of the patties than the brown, red BGN variety, and control, respectively. The increase in WI might be due to an increase in L* values caused by the inclusion of BGN flours which diluted the myoglobin of meat thereby increasing WI (Saikia *et al*., 2019). Saricoban and Yilmaz (2010) found an improvement in WI of beef meatballs with an increase in lightness. However, the YI of formulated patties significantly decreased ($p < 0.05$) with the inclusion of BGN flours ranging from 48.61 to 37.82. All BGN varieties decreased YI of patties equally. The decrease in YI might be because of the reduction in b* values and fat content of the patties, as well as dilution of myoglobin content (Kumar and Kumar., 2020). A similar trend was reported by Saricoban and Yilmaz (2010) in beef meatballs.

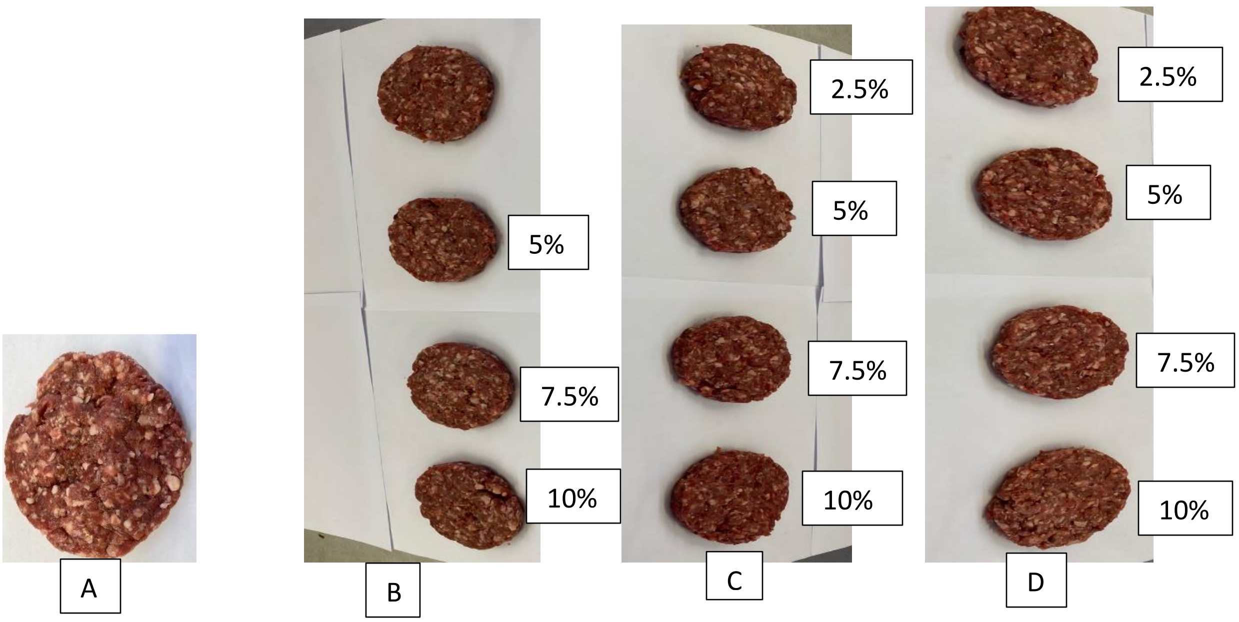


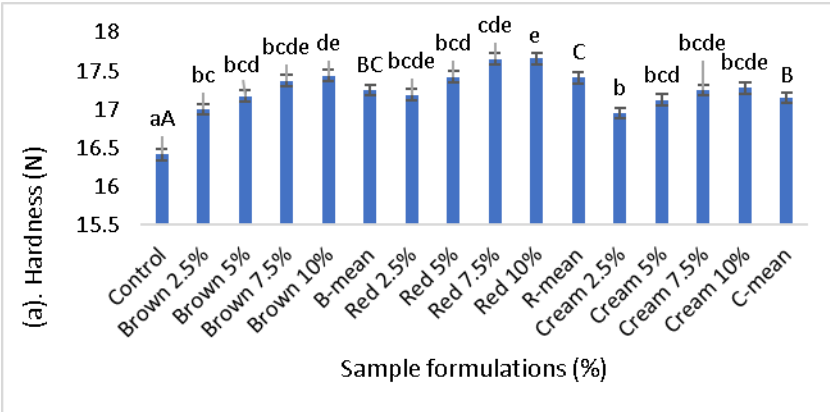
Figure 5. Mutton patties formulated with BGN flours (2.5%, 5%, 7.5%, and 10%). A = 100% mutton patties, B = mutton patties added with brown BGN flour, C = mutton patties added with cream BGN flour and D = mutton patties added with red BGN flour, BGN = Bambara groundnut

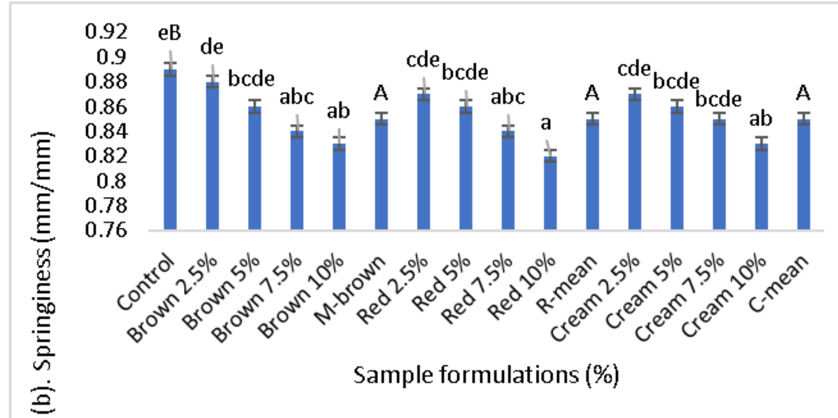
4.5 Textural properties of mutton patties

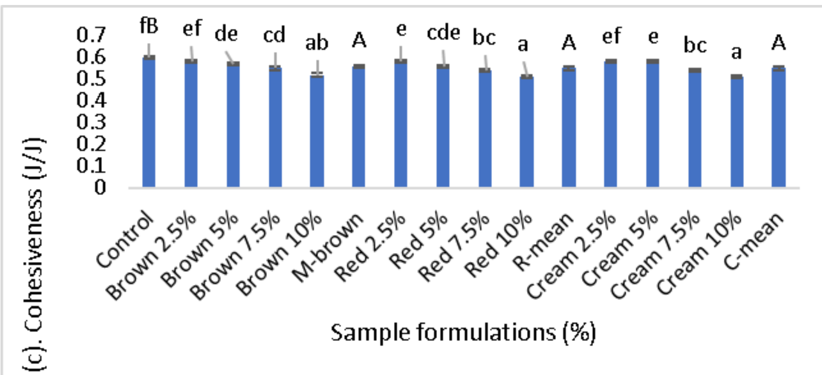
The textural properties of raw mutton patties are indicated in Figure 6. The increase in the percentage of all BGN flours significantly increased ($p < 0.05$) the hardness (a) and resilience (e) of patties compared to the control sample ranging from 16.41 to 17.66 N, and from 0.35 to 0.48 J/J, respectively. However, the resilience of the control was not different from sample added with 2.5% of brown and cream BGN flours. The red and brown BGN varieties increased the hardness of the patties than the cream BGN variety, respectively. On the other hand, the red and cream BGN varieties increased the resilience of the patties than brown BGN variety. The significant increase ($p < 0.05$) in hardness and resilience might be due to high WAC and dry matter of BGN flours (Table 8) that absorbed water in meat patties, thereby decreasing the moisture content of patties (Table 9) making them harder (Siddiq *et al*., 2009; Nuhriawangsa *et al*., 2023).

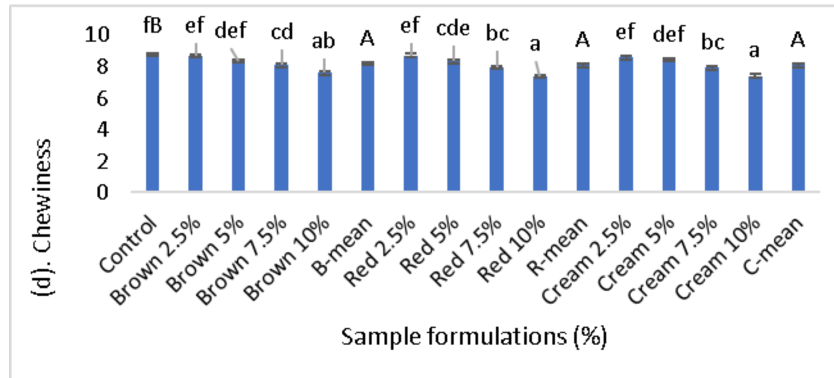
Moreover, the improvement of dietary fibre due to the addition of BGN flours might have improved water holding and binding abilities of patties, thereby improving hardness and resilience (Choi *et al*., 2010; Lopez-Vargas *et al*., 2014; Younis and Ahmad., 2018). Tahmasebi *et al*. (2016) found an increase in the hardness of sausages because of the inclusion of pigeon pea powder. Younis and Ahmad (2018) reported an increase in hardness and resilience of buffalo patties with an increase of apple pomace flour. The addition of BGN flours significantly decreased ($p < 0.05$) springiness (b) of mutton patties with values ranging from 0.89 to 0.82 mm/mm. All BGN varieties decreased the springiness of patties equally. The decrease in springiness might be due to the inclusion of BGN flours which increased the fibre content of patties, thereby reducing the speed of deformed patties to spring back after initial compression (Hautrive *et al*., 2019).

The increase in the percentage BGN flours significantly decreased ($p < 0.05$) the cohesiveness (c) of patties compared to control sample ranging from 0.60 to 0.51 J/J. Overall, all BGN varieties decreased the cohesiveness of patties equally. The decrease in cohesiveness (c) of patties might be due to the inclusion of BGN flours which led to weakening of inner bond structure of patties by reducing the stronger bonds formed between meat particles, resulting in less dense and homogeneous structure of meat (Chandler and McSweeney, 2022; Argel *et al*., 2022). Similarly, Ghribi *et al*. (2018) reported a reduction in cohesiveness of sausages incorporated with chickpea protein isolates. Varma *et al*. (2019) reported a reduction in cohesiveness of goat nuggets due to incorporation of amaranth seed powder.

1 
(a). Hardness (N)
18
17.5
17
16.5
16
15.5
aA bc bcd bcde de BC bcde bcd cde e C b bcd bcde bcde B
Control
Brown 2.5%
Brown 5%
Brown 7.5%
Brown 10%
B-mean
Red 2.5%
Red 5%
Red 7.5%
Red 10%
R-mean
Cream 2.5%
Cream 5%
Cream 7.5%
Cream 10%
C-mean
Sample formulations (%)


(b). Springiness (mm/mm)
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0.78
0.76
eB de bcde abc ab A cde bcde abc a A cde bcde bcde ab A
Control
Brown 2.5%
Brown 5%
Brown 7.5%
Brown 10%
M-brown
Red 2.5%
Red 5%
Red 7.5%
Red 10%
R-mean
Cream 2.5%
Cream 5%
Cream 7.5%
Cream 10%
C-mean
Sample formulations (%)

2 
(c). Cohesiveness (J/J)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
fB ef de cd ab A e cde bc a A ef e bc a A
Control
Brown 2.5%
Brown 5%
Brown 7.5%
Brown 10%
M-brown
Red 2.5%
Red 5%
Red 7.5%
Red 10%
R-mean
Cream 2.5%
Cream 5%
Cream 7.5%
Cream 10%
C-mean
Sample formulations (%)


(d). Chewiness
10
8
6
4
2
0
fB ef def cd ab A ef cde bc a A ef def bc a A
Control
Brown 2.5%
Brown 5%
Brown 7.5%
Brown 10%
B-mean
Red 2.5%
Red 5%
Red 7.5%
Red 10%
R-mean
Cream 2.5%
Cream 5%
Cream 7.5%
Cream 10%
C-mean
Sample formulations (%)

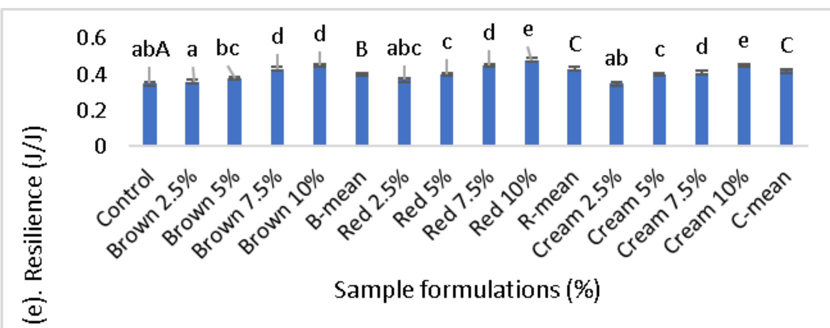
3 
(e). Resilience (J/J)
0.6
0.4
0.2
0
abA a bc d d B abc c d e C ab c d e C
Control
Brown 2.5%
Brown 5%
Brown 7.5%
Brown 10%
B-mean
Red 2.5%
Red 5%
Red 7.5%
Red 10%
R-mean
Cream 2.5%
Cream 5%
Cream 7.5%
Cream 10%
C-mean
Sample formulations (%)

Figure 6. The texture properties of mutton patties incorporated with different levels of Bambara groundnut flour based on their colours. (a) Hardness, (b) Springiness, (c) cohesiveness, (d) Chewiness, and (e) Resilience, respectively. Means with distinct lowercases (Superscripts) indicates significant difference ($p < 0.05$). Whereas means in the same column with distinct uppercases (superscripts) indicate a significant difference ($p < 0.05$) of the type of the varieties

The increase in the addition of BGN flours led to a significantly decrease ($p < 0.05$) in chewiness (d) of patties with values varying from 8.77 to 7.38. However, there was no significant variation among the control and patties added with 2.5% brown and red BGN flours. All BGN varieties decreased the chewiness of patties equally. The decrease in chewiness might be due to less difficult and more effective integration of BGN flours in meat matrix (Sayas-Barbera *et al*., 2021). Correspondingly, Öztürk-Kerimoğlu *et al*. (2020) found a reduction in the chewiness of beef sausages with the incorporation of teff powder. Moreover, Sayas-Barbera *et al*. (2021) found a reduction in the chewiness of beef patties with the incorporation of black quinoa powder.

4.6 Lipid oxidation of mutton patties

Thiobarbituric acid reactive substances (TBARS) values of raw mutton patties are indicated in Table 12. There was no significant difference ($p < 0.05$) in all samples on day zero.

Table 12. Lipid oxidation of mutton patties incorporated with different levels of Bambara groundnut flour (mg MDA/kg).

	Storage days			
Samples	**0**	**7**	**14**	**21**
Control	0.06 ± 0.00^{a}	0.20 ± 0.00^{g}	0.63 ± 0.00^{p}	0.88 ± 0.00^{w}
Control mean				0.44 ± 0.34^{C}
Brown 2.5%	0.05 ± 0.00^{a}	0.14 ± 0.00^{f}	0.53 ± 0.01^{mn}	0.77 ± 0.01^{tu}
Brown 5%	0.06 ± 0.00^{a}	0.12 ± 0.00^{cdef}	0.49 ± 0.02^{l}	0.76 ± 0.01^{t}
Brown 7.5%	0.06 ± 0.00^{a}	0.12 ± 0.00^{cdef}	0.45 ± 0.02^{j}	0.70 ± 0.01^{r}
Brown 10%	0.05 ± 0.00^{a}	0.10 ± 0.00^{abc}	0.39 ± 0.02^{i}	0.60 ± 0.00^{o}
Brown mean				0.38 ± 0.27^{B}
Red 2.5%	0.05 ± 0.00^{a}	0.13 ± 0.00^{ef}	0.51 ± 0.01^{lm}	0.78 ± 0.02^{u}
Red 5%	0.05 ± 0.00^{a}	0.12 ± 0.00^{cdef}	0.50 ± 0.01^{l}	0.74 ± 0.01^{s}
Red 7.5%	0.05 ± 0.00^{a}	0.11 ± 0.00^{cde}	0.44 ± 0.02^{j}	0.65 ± 0.02^{q}
Red 10%	0.06 ± 0.00^{a}	0.08 ± 0.01^{b}	0.35 ± 0.02^{h}	0.54 ± 0.01^{n}
Red mean				0.36 ± 0.26^{A}
Cream 2.5%	0.05 ± 0.00^{a}	0.14 ± 0.00^{f}	0.54 ± 0.01^{n}	0.79 ± 0.01^{v}
Cream 5%	0.06 ± 0.00^{a}	0.13 ± 0.00^{ef}	0.50 ± 0.01^{l}	0.77 ± 0.00^{tu}
Cream 7.5%	0.05 ± 0.00^{a}	0.11 ± 0.00^{cde}	0.47 ± 0.01^{k}	0.70 ± 0.01^{r}
Cream 10%	0.06 ± 0.00^{a}	0.10 ± 0.00^{abc}	0.40 ± 0.02^{i}	0.63 ± 0.00^{p}
Cream mean				0.38 ± 0.27^{B}

Values expressed as mean ± standard deviation. Means in the same column with distinct lowercases (superscripts) indicate significant difference ($p < 0.05$) within that day. Means in the same row with distinct lowercases (superscripts) indicate a significant difference ($p < 0.05$). TBARS = Thiobarbituric acid reactive substances. Brown, red, and cream (2.5%, 5%, 7.5%, and 10%) indicate different concentrations of different cultivars of Bambara groundnut flours. Whereas means in the same column with distinct uppercases (superscripts) indicate a significant difference ($p < 0.05$) of the type of varieties

However, from day 7 to 21 the TBARS values of formulated mutton patties increased but was still less than that of the control sample within storage days which had values varying from 0.08 to 0.88 mgMDA/kg. The red BGN variety significantly ($p < 0.05$) delayed the lipid oxidation of the patties effectively than the brown and cream BGN varieties. Mutton patties incorporated with 10% red BGN flour delayed lipid oxidation more effectively than the samples added with brown and cream BGN flours from day 7 to 21. The low TBARS values of formulated patties within storage days compared to control might be due to the decrease in the amount of fat in formulated patties samples as shown in Table 9 with the increase of BGN flours (Faid, 2019). Furthermore, low TBARS values might be because of the greater amount of polyphenolic compound in BGN flours (Table 8) which acted as free radical terminators and oxygen scavengers, thereby slowing down the process of lipid oxidation in mutton patties (Al-Juhaimi *et al*., 2017; Bing *et al*., 2022).

The significant increase ($p < 0.05$) in TBARS values during the storage period might influence oxidation of double bonds of polyunsaturated fatty acid as well as the production of volatile compounds in meat (Dilnawaz *et al*., 2017; Mashau *et al*., 2021a). Although TBARS values increased in all samples during the storage days, the values were still within the permissible limits of less than 1 MDA/kg (Dilnawaz *et al*., 2017; Cerón-Guevara *et al*., 2020). Comparable data were found by Dilnawaz *et al*. (2017) in mutton blocks incorporated with green coffee bean powder. Furthermore, Alakali *et al*. (2010) found a delay in lipid oxidation of beef patties incorporated with BGN flour.

4.7 Sensory properties of mutton patties

Sensory properties of mutton patties formulated with BGN flours are indicated in Table 13. There was no significant difference ($p < 0.05$) in the appearance, aroma, texture, and overall acceptability scores of formulated patties compared to the control sample. Furthermore, there was no noticeable difference in the taste of formulated patties (except 10% brown and 7.5% cream BGN flours) compared to the control sample. The liked sensory attributes of formulated patties by panellists might be due to high OAC of BGN flours as shown in Table 8 which improves the sensation of chewing, the taste, and preserves the flavour in meat (Arise *et al*., 2019; Adewumi *et al*., 2022). The taste scores of mutton patties samples formulated with 10% brown BGN flour (6.45), and 7.5% cream BGN flour (6.27) were less than that of the control sample. The lower taste score might be due to the stronger flavour of BGNs which panellists disliked, this dominated the flavour of formulated mutton patties (Motamedi *et al*., 2015; Novikasari *et al*., 2022). Nevertheless, the sensory properties of all samples scored above the acceptable level of 5 in the 9-hedonic scale.

Table 13. Sensory properties of mutton patties incorporated with different levels of Bambara groundnut flour.

Samples	Appearance	Aroma	Taste	Texture	Overall acceptability
Control	7.05 ± 1.61^{abc}	6.66 ± 1.83^{ab}	7.53 ± 1.93^{b}	7.23 ± 1.31^{a}	7.31 ± 1.62^{a}
Brown 2.5%	7.60 ± 1.42^{abc}	7.02 ± 1.56^{ab}	7.55 ± 1.31^{b}	7.45 ± 1.48^{a}	7.47 ± 1.32^{a}
Brown 5%	7.06 ± 1.84^{abc}	6.85 ± 1.49^{ab}	6.87 ± 1.42^{ab}	6.98 ± 1.73^{a}	6.81 ± 1.77^{a}
Brown 7.5%	6.79 ± 1.99^{ab}	6.63 ± 1.67^{ab}	6.79 ± 1.85^{ab}	6.87 ± 1.65^{a}	6.74 ± 1.86^{a}
Brown 10%	6.92 ± 1.86^{c}	6.77 ± 1.82^{ab}	6.45 ± 2.23^{a}	6.81 ± 2.02^{a}	6.76 ± 1.84^{a}
Red 2.5%	6.87 ± 1.48^{abc}	6.76 ± 1.75^{ab}	6.79 ± 1.77^{ab}	6.97 ± 1.64^{a}	7.05 ± 1.47^{a}
Red 5%	7.46 ± 1.32^{ab}	7.23 ± 1.56^{b}	6.95 ± 1.83^{ab}	7.28 ± 1.40^{a}	7.25 ± 1.52^{a}
Red 7.5%	7.24 ± 1.74^{abc}	6.73 ± 1.71^{ab}	6.79 ± 2.11^{ab}	7.23 ± 1.48^{a}	7.00 ± 1.82^{a}
Red 10%	6.89 ± 1.96^{abc}	7.03 ± 1.85^{ab}	6.77 ± 2.20^{ab}	7.13 ± 152^{a}	6.76 ± 2.13^{a}
Cream 2.5%	7.18 ± 1.82^{abc}	6.94 ± 1.88^{ab}	7.03 ± 2.40^{ab}	7.19 ± 1.84^{a}	7.02 ± 1.92^{a}
Cream 5%	6.61 ± 2.26^{a}	6.81 ± 1.61^{ab}	6.77 ± 2.15^{ab}	6.95 ± 1.87^{a}	6.90 ± 1.91^{a}
Cream 7.5%	7.00 ± 1.70^{abc}	6.40 ± 2.04^{a}	6.27 ± 2.35^{a}	7.00 ± 1.98^{a}	6.73 ± 2.09^{a}
Cream 10%	7.29 ± 1.63^{abc}	6.90 ± 1.58^{ab}	6.79 ± 2.07^{ab}	7.18 ± 1.47^{a}	7.03 ± 1.75^{a}

Values expressed as mean ± standard deviation. Mean in the same column with distinct lowercases (superscripts) indicates a significant difference ($p < 0.05$). Brown, red, and cream (2.5%, 5%, 7.5%, and 10%) indicate different concentrations of different cultivars of Bambara groundnut flours.

Therefore, the findings of the study imply that BGN flours may be utilised as a fat substitute in low-fat mutton patties without causing drastic changes in the sensory attributes of the meat. Similar results were reported by Argel *et al*. (2020) in low-fat pork patties incorporated with lentil powder. Furthermore, Alakali *et al*. (2010) found comparable results in beef patties incorporated with 5% BGN powder.

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

The inclusion of BGN flour varieties in mutton patties can be utilised as natural preservative, fat substitute, ash, and fibre booster. The increase in percentages of BGN flours decreased the protein content of mutton patties, but it was still within expected protein content (19%) of meat. The cooking yield and diameter reduction of mutton patties were also improved due to the increase in percentage of BGN flours up to 10%. Furthermore, the inclusion of BGN flour from 2.5 to 10% was successful in delaying the lipid oxidation, indicating that it may be utilised to improve the shelf-life of mutton patties because of its antioxidant's properties.

The sensory properties (appearance, taste, texture, colour, and overall acceptability) of formulated patties were not significantly different from the control sample; however, they were above the acceptable score of 5. All BGN varieties had positive effects on the mutton patties, more especially red BGN variety followed by brown, and cream BGN varieties, respectively. Furthermore, the inclusion of 10% red BGN flour in mutton patties is highly recommended since it retains the colour, reduces the moisture content, delays lipid oxidation, increases the ash, fibre, carbohydrates, and energy contents, as well as hardness, and resilience than other BGN varieties. The results of the study show that Bambara groundnut can be used as an additive in mutton patties without detrimental effects on the quality parameters. However, difficult to cook and mill phenomena of BGN are major constraints for its utilization, therefore, it is recommended to utilise biological and physical procedures to minimize cooking time and advanced milling equipment should be implemented. Furthermore, extensive research on advanced processing technologies such as high-pressure processing should be explored.

Meat industries can utilise BGN flours as fat-substitute and natural preservative to meet the demands of consumers for healthy meat products. The current study will open new opportunities to use Bambara groundnut flours low-fat for processed meat in meat or food industry. Further research should be conducted to discover the effect of different BGN flour varieties on other meat products and their potential influence on pH, antioxidants, microbiological properties, vitamins, and minerals of such products. Modern technologies such three-dimensional (3D) food printing should also be used in the production of mutton patties incorporated with bambara flours. Since BGN is rich in nutritional composition and has high oil absorption capacity, further research is also warranted to manufacture plant-based meat analogue from BGN flours using 3D printing and analysed for nutritional composition, lipid oxidation, sensory attributes, and textural properties.

Gas chromatography-mass spectrometry (GC-MS) should also be used to extract the volatile organic compounds which contributes to the flavour and aroma such as aldehydes (2-Methylpropanal, Hexanal, and Nonanal), ketones (2,3-Butanedione and 2,3-pentanedione) that will also determine the quality and shelf-life of the mutton patties added with different varieties of BGN flours. Nevertheless, future research is necessary to ascertain the influence of incorporating distinct types of legumes in low-fat meat products.

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References

Abdelnabi, F.R.A. (2022). Food Culture and Its Sources for Gifted Students in The Intermediate Stage In Najran Region, Kingdom Of Saudi Arabia. *Journal of Positive School Psychology*, 4331-4348.

Abiala, O., Abiala, M., and Omojola, B. (2022). Quality attributes of chicken nuggets extended with different legume flours. *Food Production, Processing and Nutrition*, 4(1), 1-11.

Adebiyi, J.A., Kayitesi, E., Adebo, O.A., Changwa, R., and Njobeh, P.B. (2019). Food fermentation and mycotoxin detoxification: An African perspective. *Food Control*, 106, 106731.

Adebiyi, J.A., Njobeh, P.B., and Kayitesi, E. (2019). Assessment of nutritional and phytochemical quality of Dawadawa (an African fermented condiment) produced from Bambara groundnut (*Vigna subterranea*). *Microchemical Journal*, 149, 104034.

Adedayo, B.C., Anyasi, T.A., Taylor, M.J., Rautenbauch, F., Le Roes-Hill, M., and Jideani, V.A. (2021). Phytochemical composition and antioxidant properties of methanolic extracts of whole and dehulled Bambara groundnut (*Vigna subterranea)* seeds. *Scientific Reports*, 11(1), 14116.

Adeleke, O.R., Adiamo, O.Q., and Fawale, O.S. (2018). Nutritional, physicochemical, and functional properties of protein concentrate and isolate of newly-developed Bambara groundnut (*Vigna subterrenea* L.) cultivars. *Food Science and Nutrition*, 6(1), 229-242.

Adeleke, O.R., Adiamo, O.Q., Fawale, O.S., and Olamiti G. (2017). Effect of processing methods on antinutrients and oligosaccharides contents and protein digestibility of the flours of two newly developed Bambara groundnut cultivars. *International Food Research Journal*, 24(5), 1948–1955.

Adewumi, O.O., Felix-Minnaar, J.V., and Jideani, V.A. (2022). Functional properties and amino acid profile of Bambara groundnut and *Moringa oleifera* leaf protein complex. *Processes*, 10(2), 205.

Adeyeye, E.I., Adesina, A.J., Olaleye, A.A., Olagboye, S.A., and Olatunya, M.A. (2020). Proximate, vitamins, minerals compositions together with mineral ratios and mineral safety index of Kilishi (beef jerky meat). *Haya the Saudi Journal of Life Sciences*, 5(5), 79-89.

Adeyeye, E.I., and Olaleye, A.A. (2012). Amino acid composition of Bambara groundnut (*Vigna subterranea*) seeds: dietary implications. *International Journal of Chemical Sciences*, 5(2), 152-156.

Adu-Dapaah, H., Berchie, J.N., Amoah, S., Addo, S.K., and Boateng, M. (2016) Progress in Bambara groundnut research in Ghana: breeding, agronomy and utilization. In: Onus N, Currie A (eds) Acta Horticulture 1127, *ISHS* 2016. XXIX IHC. Proceedings of international symposium on plant breeding in horticulture. (Accessed 13 June 2022)

Aguilera, J., and Rivera, R. (1992). Hard-to-cook defect in black beans: hardening rates, water imbibition and multiple mechanism hypothesis. *Food Research International*, 25(2), 101-108.

Ahmad, M.H., Afzal, M.F., Imran, M., Khan, M.K., and Ahmad, N. (2022). Nutrition: A Strategy for Curtailing the Impact of COVID-19 Through Immunity Booster Foods. In *Handbook of Research on Pathophysiology and Strategies for the Management of COVID-19* (pp. 253-269). IGI Global.

Ahmad, R.S., Imran, A., and Hussain, M.B. (2018). Nutritional Composition of Meat. In: M.S. Arshad (ed), Meat Science and Nutrition, (IntechOpen, Pakistan), pp. 61–77.

Ahmed, D., Khan, M.M., and Saeed, R. (2015). Comparative analysis of phenolics, flavonoids, and antioxidant and antibacterial potential of methanolic, hexanic and aqueous extracts from *Adiantum caudatum* leaves. *Antioxidants, 4*(2), 394-409.

Ahmmed, T., Rahman, A., Salma, U., Akter, Z., Ansary, M.M.U., Khalil, M.I., Karim, N., and Bari, L. (2020). Nutritional, phytochemicals, and antioxidant properties of some popular pulse varieties of Bangladesh. *Journal of Agricultural Chemistry and Environment*, 9(04), 343.

Aina, T.A., Joseph, O.A., Inyang, K.O., and Temitope, O.O. (2017). The importance and efficacy of epigallocatechin and epicatechin. *European Pharmaceutical Review*, 22(5), 42-44.

Ajiboye, A.A., and Oyejobi, G.K. (2017). In vitro antimicrobial activities of Vigna subterranea. *Journal of Antimicrobial agents*, 3 (12), 1-4.

Alakali, J.S., Irtwange, S.V., and Mzer, M.T. (2010). Quality evaluation of beef patties formulated with Bambara groundnut (*Vigna subterranean* L.) seed flour. *Meat Science*, 85(2), 215-223.

Alake, C.O., and Alake, O.O. (2016). Genetic diversity for agro-nutritional traits in African landraces of Vigna subterranean Germplasm. *Journal of Crop Improvement*, 30(4), 378-398.

Alam, W., Khan, H., Shah, M.A., Cauli, O., and Saso, L. (2020). Kaempferol as a dietary anti-inflammatory agent: current therapeutic standing. *Molecules*, 25(18), 4073.

Ali, M.I., Ibrahim, R.M., and Mostafa, A.G. (2022). Production of chicken patties supplemented with cantaloupe by-products: Impact on the quality, storage stability, and antioxidant activity. *International Journal of Food Science*, 2020, 1-21.

Al-Juhaimi, F., Adiamo, O.Q., Alsawmahi, O.N., Gahfoor, K., Islam Sarker, M.Z., Mohamed Ahmed, I.A., and Babiker, E.E. (2017). Effect of pistachio seed hull extracts on quality attributes of chicken burger. *CyTA-Journal of Food*, 15(1), 9-14.

Al-Juhaimi, F., Ghafoor, K., Hawashin, M.D., Alsawmahi, O.N., and Babiker, E.E. (2016). Effects of different levels of Moringa (*Moringa oleifera*) seed flour on quality attributes of beef burgers. *CyTA - Journal of Food*, 14, 1911– 1919.

Alves, L.A.A.S., Lorenzo, J.M., Gonçalves, C.A.A., Santos, B.A., Heck, R.T, Cichoski, A.J., and Campagnol, P.C.B. (2016). Production of healthier bologna type sausages using pork skin and green banana flour as a fat replacers. *Meat Science*, 121, 73–78.

Amadi, A.O. (2020). Nutritional effects of full-fat soy flour as an extender on cooked beef sausage quality. *Asian Food Science Journal*, 17(3), 44-53.

Amaral, A.B., da Silva, M.V., and da Lannes, S.C.S. (2018). Lipid oxidation in meat: Mechanisms and protective factors—A review. *Food Science and Technology*, *38*, 1–15.

Amarteifio, J.O., Tibe, O., and Njogu, R.M. (2006). The mineral composition of Bambara groundnut (*Vigna subterranea* (L) Verdc) grown in Southern Africa. *African Journal of Biotechnology*, 5(23), 2408-2411.

Aminzare, M., Hashemi, M., Ansarian, E., Bimkar, M. Azar, H.H. Mehrasbi, M.R., Daneshamooz, S., and Raeisi, M., Jannat, B., and Afshari, A. (2019). *Using natural antioxidants in meat and meat products as preservatives: A review. Advances in Animal and Veterinary Sciences*, 7(5), 417-426.

Andrés, S.C., Pennisi Forell, S.C., Ranalli, N., Zaritzky, N.E., and Califano, A.N. (2011). Healthier functional beef burgers, in Agricultural Research Updates: Volume 2, ed. by Hendriks BP. Nova Science Publishers, Hauppauge, New York, United State of America, 2, pp 185–211.

Annan, N.T., Plahar, W.A., and Nti, C.A. (2003). Dissemination of improved Bambara groundnut processing technologies through a new coalition arrangement to enhance rural livelihoods in northern Ghana, in training of trainee's workshop: Tamale Ghana.

Ardeshiri, A., and Rose, J.M. (2018). How Australian consumers value intrinsic and extrinsic attributes of beef products. *Food Quality and Preference*, *65*,146-163.

Aremu, M.O., Yashim, T.C., Ibrahim, H., Adeyeye, E.I., Omosebi, M.O., and Ablaku, B.E. (2022). Nutritional quality assessment of commonly sold steamed Bambara groundnut (*Vigna subterranea* L. Verdc) pastes in Lafia motor parks, Nasarawa state, Nigeria. *Bangladesh Journal of Scientific and Industrial Research*, 57(1), 27-40.

Argel, N.S., Lorenzo, G., Domínguez, R., Fraqueza, M.J., Fernández-López, J., Sosa, M.E., Campagnol, P.C.B., Lorenzo, J.M., and Andrés, S.C. (2022). Hybrid meat products: Incorporation of white bean Flour in lean pork burgers. *Applied Sciences*, 12(15), 7571.

Argel, N.S., Ranalli, N., Califano, A.N., and Andrés, S.C. (2020). Influence of partial pork meat replacement by pulse flour on physicochemical and sensory characteristics of low-fat burgers. *Journal of the Science of Food and Agriculture,* 100(10), 3932-3941.

Arise, A.K., Akintayo, O.O., Dauda, A.O., and Adeleke, B.A. (2019). Chemical, functional, and sensory qualities of abari (maize-based pudding) nutritionally improved with Bambara groundnut (*Vigna subterranea*). *Ife Journal of Science*, 21(1), 165-173.

Arise, A.K., Alashi, A.M., Nwachukwu, I.D., Malomo, S.A., Aluko, R.E., and Amonsou, E.O. (2017). Inhibitory properties of Bambara groundnut protein hydrolysate and peptide fractions against angiotensin-converting enzymes, renin, and free radicals. *Journal of the Science of Food and Agriculture*, 97(9), 2834-2841.

Arise, A.K., Amonsou, E.O., and Ijabadeniyi, O.A. (2015): Influence of extraction methods on functional properties of protein concentrates prepared from South African Bambara groundnut landraces. *International Journal of Food Science and Technology,* 50(5), 1095-1101.

Arise, A.K., Dauda, A.O., Awolola, G.V., and Akinlolu-ojo, T.V. (2017). Physico-chemical, functional and pasting properties of composite flour made from wheat, plantain, and Bambara for biscuit production. *Annals: Food Science and Technology*, 18(4), 616-624.

Arise, A.K., Nwachukwu, I.D., Aluko, R.E., and Amonsou, E.O. (2017). Structure, composition and functional properties of storage proteins extracted from Bambara groundnut (*Vigna subterranea*) landraces. *International Journal of Food Science and Technology*, 52(5), 1211-1220.

Arulpandi, I., and Sangeetha, R. (2012). Antibacterial activity of fistulin: a protease inhibitor purified from the leaves of *Cassia fistula*. *International Scholarly Research Notices*, 2012, 1-4.

Aslinah, L.N.F., Mat, M., and Ismail-Fitry, M.R. (2018). Simultaneous use of Adzuki beans (*Vigna Angularis*) Flour as meat extender and fat replacer in reduced-fat beef meatballs (*Bebola Daging*). *Journal of Food Science and Technology*, 55, 3241–3248.

Association of Official Analytical Chemists AOAC. (2007). Official Methods of Analysis of AOAC International, 18th ed.; AOAC: Washington, DC, United State of America.

Atoyebi, J.O., Osilesi, O., Adebawo, O., and Abberton, M. (2017). Evaluation of nutrient parameters of selected African accessions of Bambara groundnut (*Vigna subterranea* (L.) Verdc.). *American Journal of Food and Nutrition*, 5, 83–89.

Awuchi, C.G., Igwe, V.S., and Echeta, C.K. (2019). The functional properties of foods and flours. *International Journal of Advanced Academic Research*, 5(11), 139-160

Ayandipe, D.O., Adebowale, A.A., Obadina, O., Sanwo, K., Kosoko, S.B., and Omohimi, C.I. (2020). Optimization of high-quality cassava and coconut composite flour combination as filler in chicken sausages. *Journal of Culinary Science and Technology,* 20(1), 1-32.

Azam-Ali, S.N., Sesay, A., Karikari, S.K., Massawe, F.J., Aguilar-Manjarrez, J., Bannayan, M., and Hampson, K.J. (2001). Assessing the Potential of an Underutilized Crop–a Case Study Using Bambara Groundnut. *Experimental Agriculture*, 37(04), 433-472.

Bag, B.B., Panigrahi, C., Gupta, S., and Mishra, H.N. (2022). Efficacy of plant-based natural preservatives in extending shelf life of sugarcane juice: Formulation optimization by MOGA and correlation study by principal component analysis. *Applied Food Research*, 2(2), 100164.

Bagdatli, A. (2018). The influence of quinoa (*Chenopodium quinoa* Willd.) flour on the physicochemical, textural, and sensorial properties of beef meatball. *Italian Journal of Food Science,* 30 (2), 280–288.

Bakieva, A., Akimov, M., Abdilova, G., Ibragimov, N., and Bekeshova, G. (2019). Developing new type of disk plate for meat chopper and its effect to water-binding capacity and yield stress of minced meat. *International Journal of Mechanical and Production Engineering Research and Development*, 9(6), 377-390.

Balami, S., Sharma, A., and Karn, R. (2019). Significance of nutritional value of fish for human health. *Malaysian Journal of Halal Research*, 2(2), 32-34.

Ball, J.J., Wyatt, R.P., Lambert, B.D., Smith, H.R., Reyes, T.M., and Sawyer, J.T. (2021). Influence of plant-based proteins on the fresh and cooked characteristics of ground beef patties. *Foods*, 10(9), 1971.

Bamshaiye, O.M., Adegbola, J.A., and Bamishaiye, E.I. (2011). Bambara groundnut: an under-utilized nut in Africa. *Advances in Agricultural Biotechnology*, 1 (1), 60-72.

Bamshaiye, O.M., Adegbola, J.A., and Bamishaiye, E.I. (2011). Bambara groundnut: an under-utilized nut in Africa. *Advances in Agricultural Biotechnology*, 1(1), 60-72.

Baptista, A., Pinho, O., Pinto, E., Casal, S., Mota, C., and Ferreira, I.M.P.L.V.O. (2016). Characterization of protein and fat composition of seeds from common beans (*Phaseolus *vulgaris* L.), cowpea (*Vigna unguiculata* L. Walp) and Bambara groundnuts (*Vigna subterranea* L. Verdc) from Mozambique. *Journal of Food Measurements and Characteristics*, 11, 442- 450.

Barker, S., and McSweeney, M.B. (2022). Sensory characterization of yellow pea and ground chicken hybrid meat burgers using static and dynamic methodologies. *Journal of Food Science*, 87(12), 5390-5401.

Berchie, J.N., Adu-Dapaah, H.K., Dankyi, A.A., Plahar, W.A., Nelson-Quartey, F., Haleegoah, J., Asafu-Agyei, J.N., and Addo, J.K. (2010). Practices and constraints in Bambara groundnuts production, marketing, and consumption in the Brong Ahafo and Upper-East Regions of Ghana. *Journal of Agronomy*, 9(3), 111-118.

Beriain, M.J., Gómez, I., Ibáñez, F.C., Sarriés, M.V., and Ordóñez, A.I. (2018). Improvement of the functional and healthy properties of meat products. In *Food quality: Balancing Health and Disease* (pp. 1-74). Academic Press.

Bhatia, A., Bharti, S.K., Tripathi, T., Mishra, A., Sidhu, O.P., Roy, R., and Nautiyal, C.S. (2015). Metabolic profiling of *Commiphora wightii* (*guggul*) reveals a potential source for pharmaceuticals and nutraceuticals. *Phytochemistry*, 110, 29-36.

Bing, S., Zang, Y., Li, Y., Zhang, B., Mo, Q., Zhao, X., and Yang, C. (2022). A combined approach using slightly acidic electrolyzed water and tea polyphenols to inhibit lipid oxidation and ensure microbiological safety during beef preservation. *Meat Science*, 183, 108643.

Borghi, S.M., Mizokami, S.S., Pinho-Ribeiro, F.A., Fattori, V., Crespigio, J., Clemente-Napimoga, J. T., Pitol, D.L., Issa, J.P., Fukada, S.Y. and Casagrande, R., and Verri Jr, W.A. (2018). The flavonoid quercetin inhibits titanium dioxide (TiO_2)-induced chronic arthritis in mice. *The Journal of Nutritional Biochemistry*, 53, 81-95.

Brink, M., Belay, G., and De Wet, J.M.J. (2006). *Plant resources of tropical Africa 1: Cereals and pulses* (pp. 54-57). Wageningen, The Netherlands: PROTA Foundation.

Buckman, E.S., Oduro, I., Plahar, W.A., and Tortoe, C. (2018). Determination of the chemical and functional properties of yam bean (*Pachyrhizus erosus* (L.) Urban) flour for food systems. *Food Science and Nutrition*, 6(2), 457-463.

Bujang, A., and Taib, N.A. (2014). Changes on amino acids content in soybean, garbanzo bean and groundnut during pre-treatments and *tempe* making. *Sains Malaysiana*, 43(4), 551–557.

Bumbadiya, M.R., Maji, S., Sao, K., and Ranvir, S.G. (2023). Butter Oil (Ghee): Composition, Processing, and Physicochemical Changes during Storage. In *The Chemistry of Milk and Milk Products*, Apple Academic Press. pp. 159-184.

Bunmee, T., Setthaya, P., Chaiwang, N., and Sansawat, T. (2022). Effect of purple eggplant flour on physicochemical, lipid oxidation, and sensory properties of low-fat beef patties. *International Journal of Food Science*, *2022*, 9753201.

Calvo, L., Toldrá, F., Rodríguez, A.I., López-Bote, C., and Rey, A.I. (2016). Effect of dietary selenium source (organic vs. mineral) and muscle pH on meat quality characteristics of pigs. *Food Science and Nutrition*, 5(1), 94–102.

Câmara, A.K.F.I., Vidal, V.A.S., Santos, M., Bernardinelli, O.D., Sabadini, E., and Pollonio, M.A.R. (2020). Reducing phosphate in emulsified meat products by adding chia (*Salvia hispanica* L.) mucilage in powder or gel format: A clean label technological strategy. *Meat science*, 163, 108085.

Cardoso-Ugarte, G.A., and Sosa-Morales, M.E. (2022). Essential oils from herbs and spices as natural antioxidants: Diversity of promising food applications in the past decade. *Food Reviews International*, 38(1), 403-433.

Cauchi, E. (2020). Development of a modelling approach for characterization and prediction of bacterial spoilage microbiota dynamics in perishable foodstuffs. PhD thesis, Université de Liège, Liège, Belgique. *Département de Sciences des Denrées Alimentaires (DDA),* pp. 382

Cerón-Guevara, M.I., Rangel-Vargas, E., Lorenzo, J.M., Bermúdez, R., Pateiro, M., Rodríguez, J. A., Sánchez-Ortega I., and Santos, E.M. (2020). Reduction of salt and fat in frankfurter sausages by addition of *agaricus bisporus* and *pleurotus ostreatus* flour. *Foods*, 9(6), 760.

Chafik, A., Essamadi, A., Çelik, S.Y., and Mavi, A. (2019). Purification and biochemical characterization of a novel copper, zinc superoxide dismutase from liver of camel (*Camelus dromedarius*): An antioxidant enzyme with unique properties. *Bioorganic Chemistry*, 86, 428-436.

Chai, H.H., Massawe, F., and Mayes, S. (2016) Effects of mild drought stress on the morpho-physiological characteristics of a Bambara groundnut segregating population. *Euphytica*, 208(2), 225–236.

Chaijan, M., Panpipat, W. (2017). Mechanism of oxidation in foods of animal origin. In *Natural Antioxidants. Applications in Foods of Animal Origin*; Banerjee, R., Verma, A.K., Siddiqui, M.W., Eds.; Apple Academic Press, Inc.: Boca Raton, Florida, United State of America, pp. 1–38.

Chandler, S.L., and McSweeney, M.B. (2022). Characterizing the properties of hybrid meat burgers made with pulses and chicken. *International Journal of Gastronomy and Food Science*, 27, 100492.

Chandra, S., Singh, S., and Kumari, D. (2015). Evaluation of functional properties of composite flours and sensorial attributes of composite flour biscuits. *Journal of Food Science and Technology*, 52, 3681-3688.

Chazovachii, B., Chitongo, L., and Ndava, J. (2013). Reducing urban poverty through fuel wood business in Masvingo city, Zimbabwe: A Myth or Reality. *Bangladesh e-journal of sociology*, 10(1), 59.

Chen, A.Y., and Chen, Y.C. (2013). A review of the dietary flavonoid, kaempferol on human health and cancer chemoprevention. *Food chemistry*, 138(4), 2099-2107.

Cheng, J. (2016). Lipid oxidation in meat. *Journal of Nutrition in Food Science,* 6, 1-3.

Chigwedere, C.M., Njoroge, D.M., Van Loey, A.M., and Hendrickx, M.E. (2019). Understanding the relations among the storage, soaking, and cooking behaviour of pulses: A scientific basis for innovations in sustainable foods for the future. *Comprehensive Reviews in Food Science and Food Safety*, 18(4), 1135-1165.

Chinnapun, D., and Sakorn, N. (2022). Structural characterization and antioxidant and anti-inflammatory activities of new chemical constituent from the seeds of bambara groundnut (*Vigna subterranea* (L.) Verdc.). *CyTA-Journal of Food*, 20(1), 93-101.

Choi, J.H., Kim, N., Kim, G.W., and Choi, H.Y. (2019). Effect of cacao nip extracts on quality characteristics of pork patties during cold storage period. *Food Science of Animal Resources*, 39(6), 918–933.

Choi, Y.S., Choi, J.H., Han, D.J., Kim, H.Y., Lee, M.A., Kim, H.W., Lee, J.W., Ching, H.J., and Kim, C.J. (2010). Optimization of replacing pork back fat with grape seed oil and rice bran fiber for reduced-fat meat emulsion systems. *Meat Science*, 84(1), 212-218.

Chon, S.U. (2013). Total polyphenols and bioactivity of seeds and sprouts in several legumes. *Current Pharmaceutical Design*, 19 (34), 6112-6124.

Cizmarova, B., Hubkova, B., Bolerazska, B., Marekova, M., and Birkova, A. (2020). Caffeic Acid: A Brief Overview of Its Presence, Metabolism, and Bioactivity. *Bioactive Compounds in Health and Disease*, 3 (4), 74-81.

Cook, D. (2017). Small scale farmers utilization and perceptions of Bambara groundnut production in South Africa: *a case study in a semi-arid region of Limpopo* (Master's dissertation, University of Cape Town, Cape Town, South Africa).

da Silva Felix, T.M., de Carvalho, F.A.L., Ramos, E.J.N., Ferreira, B.J.M., de Souza Rodrigues, R.T., and Queiroz, M.A.Á. (2021). Replacement meat by commercial flours on physicochemical and sensory properties of low-fat lamb burgers. *Research, Society and Development*, 10(14), e560101421792-e560101421792.

Daglia, M. (2012). Polyphenols as antimicrobial agents. *Current Opinion in Biotechnology*, *23*(2), 174-181.

Damfami, A., and Namo, O.A.T. (2020). Bambara groundnut (*Vigna subterranea* (L.) Verd.): A review of its past, present and future role in human nutrition. *Journal of Agriculture and Forest Meteorology Research*, 3(1), 274-281.

de Florio Almeida, J., dos Reis, A.S., Heldt, L.F.S., Pereira, D., Bianchin, M., de Moura., Plata-Oviedo, M.V., Haminiuk, C.W.I., Ribeiro, I.S., and da Luz, C.F.P. (2017). Lyophilized bee pollen extract: A natural antioxidant source to prevent lipid oxidation in refrigerated sausages. *LWT-Food Science and Technology*, 76, 299-305.

De Kock, C. (2013). Bambara groundnut. Speciality Foods of Africa Pvt Ltd, Harare, Zimbabwe undated.

De Oliveira Fagundes, D.T., Lorenzo, J.M., Dos Santos, B.A., Fagundes, M.B., Heck, R.T., Cichoski, A.J., and Campagnol, P.C.B. (2017). Pork skin and canola oil as strategy to confer technological and nutritional advantages to burgers. *Czech Journal of Food Sciences*, 35(4), 352–359.

Deepa, C., and Umesh Hebbar, H. (2017). Effect of micronization of maize grains on shelf-life of flour. *Journal of Food Processing and Preservation*, 41(5), e13195.

Department of Agriculture, Forestry & Fisheries. (2011). Production guideline for Bambara groundnuts: Pretoria, South Africa. Pp. 1-10. Published by Directorate Agricultural Information Services & Department of Agriculture, Forestry and Fisheries. URL www.nda.agri.za/docs/Brochures/ProguideBambara.pdf. Accessed on 14 March 2021.

Di Vita, G., Zanchini, R., Spina, D., Maesano, G., La Via, G., and D'Amico, M. (2022). Exploring purchasing determinants for a low-fat content salami: are consumers willing to pay for an additional premium. *Frontiers in Sustainable Food Systems*, 6, 794533.

Diedericks, C.F., Venema, P., Mubaiwa, J., Jideani, V.A., and Linden, E.V. (2020). Effect of processing on the microstructure and composition of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) seeds, flour, and protein isolates. *Food Hydrocolloids,* 108, 106031.

Dilnawaz, H.M., Kumar, S., and Bhat, Z.F. (2017). Effect of green coffee bean extract on the lipid oxidative stability and storage quality of restructured mutton blocks containing *Colocasia esculenta*, a novel binding agent. *Agricultural Research*, 6, 443-454.

Dominguez, R., Pateiro, M., Gagaoua, M., Barba, F.J., Zhang, W., and Lorenzo, J.M. (2019). A comprehensive review on lipid oxidation in meat and meat products. *Antioxidants*, 8(10), 429.

Dzudie, T., Scher, J., and Hardy, J. (2002). Common bean flour as an extender in beef sausages. *Journal of Food Engineering*, 52(2), 143-147.

Embaby, H., Mokhtar, S., Mostafa, A., and Gaballah, A. (2016). Effect of Lentil (*Lens culinaris*) coat powder addition on lipid oxidation and quality characteristics of beef burgers stored at 4ºC. *Suez Canal University Journal of Food Sciences*, *3*(1), 35-44.

Esho, E.O., George, O.O., and Olagoke, O.V. (2018) Isolation and identification of moulds from "Moi-Moi" a locally prepared porridge from Bambara groundnut (*Vigna subterranea*). *Microbiology Research Journal International,* 24(2), 1-4.

Essa, R.Y., and Elsebaie, E. (2018). Effect of using date pits powder as a fat replacer and anti-oxidative agent on beef burger quality. *Journal of Food Dairy Science, Mansoura University*, 9(2), 91-96.

Faid, S. (2019). Utilization of amaranth as a fat replacer and germinated red beans to prepare low-fat beef burgers with a long shelf-life storage period. *African Journal of Biological Sciences*, 15(1), 253-268.

Falade, K.O., and Akeem, S.A. (2020). Physicochemical properties, protein digestibility and thermal stability of processed African mesquite bean (*Prosopis africana*) flours and protein isolates. *Journal of Food Measurement and Characterization*, 14(3), 1481-1496.

Falade, K.O., and Nwajei, C.P. (2015). Physical, proximate, functional, and pasting properties of four non-and γ-irradiated Bambara groundnut (*Vigna subterranean*) cultivars. *International Journal of Food Science and Technology*, 50(3), 640-651.

Fang, Z., Zhao, Y., Warner, R.D., and Johnson, S.K. (2017). Active and intelligent packaging in meat industry. *Trends in Food Science and Technology*, 61, 60– 71.

FAOSTAT—Food and Agriculture Organization of the United Nations. Statistical Databases (2020). *International Journal of Humanities and Social Science,* 2013, 3, 234-245. FAOSTAT: Rome, Italy.

Fasoyiro, S., Widodo, Y., and Kehinde, T. (2012). Processing and Utilization of Legumes in the Tropics. In: Eissa AA ed. Trends in Vital Food and Control Engineering. InTech. Available: http://www.intechopen.com/books/trends-in-vital-food-andcontrolengineering/processing-and-utilization-of-legumes-in-the-tropics (accessed 01 February 2021)

Ferreira D.C., Ziegler, V., da Silva Lindemann, I., Hoffmann, J.F., Levien Vanier, N., and de Oliveira, M. (2018). Quality of black beans as a function of long-term storage and moldy development: chemical and functional properties of flour and isolated protein. *Food Chemistry*, 246, 473–480.

Flores, M., Avendaño, V., Bravo, J., Valdés, C., Forero-Doria, O., Quitral, V., Vilcanqui, Y., and Ortiz-Viedma, J. (2021). Edible oil parameters during deterioration processes. *International Journal of Food Science*, 2021, 1-16.

Fowler, S.M., Morris, S., and Hopkins, D.L. (2019). Nutritional composition of lamb retail cuts from carcases of extensively finished lambs. *Meat Science*, 154, 126– 132.

Ganesan, K., and Xu, B. (2020). Deep frying cooking oils promote the high risk of metastases in the breast-A critical review. *Food and Chemical Toxicology*, 144, 111648.

Gao, Z., Shen, P., Lan, Y., Cui, L., Ohm, J.B., Chen, B., and Rao, J. (2020). Effect of alkaline extraction pH on structure properties, solubility, and beany flavor of yellow pea protein isolate. *Food Research International*, 131, 109045.

Garcia, E., Filisetti, T.M., Udaeta, J.E., and Lajolo, F.M. (1998). Hard-to-cook beans (Phaseolus vulgaris): involvement of phenolic compounds and pectates. *Journal of Agricultural and Food Chemistry*, 46(6), 2110-2116.

Gbaguidi, A.A., Dansi, A., Dossou-Aminon, I., Gbemavo, D.S.J.C., Orobiyi, A., Sanoussi, F., and Yedomonhan, H. (2018). Agromorphological diversity of local Bambara groundnut (*Vigna subterranea* (L.) Verdc.) collected in Benin. *Genetic Resources and Crop evolution*, *65*, 1159-1171.

Geletu, U.S., Usmael, M.A., Mummed, Y.Y., and Ibrahim, A.M. (2021). Quality of cattle meat and its compositional constituents. *Veterinary Medicine International*, 1-9.

Ghribi, A.M., Amira, A.B., Gafsi, I.M., Lahiani, M., Bejar, M., Triki, M., Zouari, A., Attia, H., and Besbes, S. (2018). Toward the enhancement of sensory profile of sausage "Merguez" with chickpea protein concentrate. *Meat Science*, 143, 74-80.

Giacalone, D., and Jaeger, S.R. (2023). Consumer acceptance of novel sustainable food technologies: A multi-country survey. *Journal of Cleaner Production*, 408, 137119.

Glodde, F., Günal. M., Kinsel, M.E., and Abughazeleh, A. (2018). Effects of natural antioxidants on the stability of omega-3 fatty acids in dog food. *Journal of Veterinary Research*, 62(1), 103-108.

Gómez, I., Janardhanan, R., Ibañez, F.C., and Beriain, M.J. (2020). The effects of processing and preservation technologies on meat quality: Sensory and nutritional aspects. *Foods*, 9(10), 1416.

Gonçalves, A.C., Nunes, A.R., Falcão, A., Alves, G., and Silva, L.R. (2021). Dietary effects of anthocyanins in human health: A Comprehensive Review. *Pharmaceuticals*, 14(7), 690.

Grosso, G., La Vignera, S., Condorelli, R.A., Godos, J., Marventano, S., Tieri, M., Ghelfi, F., Titta, L., Lafronconi, A., Gambera, A., and Galvano, F. (2022). Total, red and processed meat consumption and human health: An umbrella review of observational studies. *International Journal of Food Sciences and Nutrition*, 73(6), 726-737.

Gwala, S., Wainana, I., Pallares, A.P., Kyomugasho, C., Hendrickx, M., and Grauwet, T. (2019). Texture and interlinked post-process microstructures determine the in vitro starch digestibility of Bambara groundnuts with distinct hard-to-cook levels. *Food Research International*, 120, 1-11.

Habibian, M., Ghazi, S., and Moeini, M.M. (2016). Effects of dietary selenium and vitamin e on growth performance, meat yield, and selenium content and lipid oxidation of breast meat of broilers reared under heat stress. *Biological Trace Element Research*, 169(1), 142- 152.

Halimi, R.A., Barkla, B.J., Mayes, S., and King, G.J. (2019). The potential of the underutilized pulse bambara groundnut (*Vigna subterranea* (L.) Verdc.) for nutritional food security. *Journal of Food Composition and Analysis*, 77, 47-59.

Han, J.W., Ruiz-Garcia, L., Qian, J.P., and Yang, X.T. (2018). Food packaging: A comprehensive review and future trends. *Comprehensive Reviews in Food Science and Food Safety,* 17(4), 860–877.

Hardy, Z. (2016). Functional and nutritional characteristics of Bambara groundnut milk powder as an ingredient in yoghurt (Doctoral thesis, Cape Peninsula University of Technology, Bellville South Africa).

Harris, T. (2017). Bambara groundnut (*Vigna subterranean*) from Mpumalanga province of South Africa: phytochemical and antimicrobial properties of seeds and product extracts (Doctoral thesis, Cape Peninsula University of Technology, Bellville, South Africa).

Hastie, M., Ashman, H., Torrico, D., Ha, M., and Warner, R. (2020). A mixed method approach for the investigation of consumer responses to sheep meat and beef. *Foods*, 9, 126.

Hautrive, T.P., Piccolo, J., Rodrigues, A.S., Campagnol, P.C.B., and Kubota, E.H. (2019). Effect of fat replacement by chitosan and golden flaxseed flour (wholemeal and defatted) on the quality of hamburgers. *Food Science and Technology*, 102, 403-410.

Hazrat, M. A., Rasul, M. G., Khan, M. M. K., Mofijur, M., Ahmed, S. F., Ong, H. C., and Show, P. L. (2021). Techniques to improve the stability of biodiesel: a review. *Environmental Chemistry Letters*, 19, 2209-2236.

Heck, R.T., Saldaña, E., Lorenzo, J.M., Correa, L.P., Fagundes, M.B., Cichoski, A.J., de Menezes, C.R., Wagner, R., and Campagnol, P.C.B. (2019). Hydrogelled emulsion from chia and linseed oils: A promising strategy to produce low-fat burgers with a healthier lipid profile. *Meat Science*, 156, 174-182.

Heinonen, M. (2007). Antioxidant activity and antimicrobial effect of berry phenolics–a Finnish perspective. *Molecular Nutrition and Food Research*, 51(6), 684-691.

Hillocks, R., Bennett, C., and Mponda, O. (2012). Bambara nut: A review of utilisation, market potential and crop improvement. *African Crop Science Journal*, 20(1), 1-16.

Hlanga, N.C., Modi, A.T., and Mathew, I. (2021). Evaluating nutritional content among Bambara groundnut lines. *Journal of Food Composition and Analysis*, 102, 104053.

https://www.innovationbridge.info/ibportal/sites/default/files/bambara-tia-brochure-2019.pdf (innovationbridge.info). (Accessed 19 March 2022).

https://www.murgaca.com/en/products/mutton-trunks-8020.html

Hughes, J.M., Clarke, F.M., Purslow, P.P., and Warner, R.D. (2019). Meat colour is determined not only by chromatic heme pigments but also by the physical structure and achromatic light scattering properties of the muscle. *Comprehensive Reviews in Food Science and Food Safety,* 19(1), 44-63

Hussain, M.A., Sumon, T.A., Mazumder, S.K., Ali, M.M., Jang, W.J., Abualreesh, M.H., Sharifuzzaman, S.M., Jang, W.J., Brown, C.L., Lee., H.T., Lee, E.W., and Hasan, M.T. (2021). Essential oils and chitosan as alternatives to chemical preservatives for fish and fisheries products: A review. *Food Control*, 129, 108244.

Hussin, H., Gregory, P.J., Julkifle, A.L., Sethuraman, G., Tan, X.L., Razi, F., and Azam-Ali, S.N. (2020). Enhancing the nutritional profile of noodles with bambara groundnut (*Vigna subterranea*) and moringa (*Moringa oleifera*): A food system approach. *Frontiers in Sustainable Food Systems*, 4, 59.

Hwang, H.J., Yoon, J.A., and Shin, K.O. (2018). Chemical properties of lignans, their effects on human health, and the enhancement of milk function of lignans. *Journal of Dairy Science and Biotechnology*, 36(2), 81-94.

Ibny, F.Y.I., Jaiswal, S.K., Mohammed, M., and Dakora, F.D. (2019). Symbiotic effectiveness and ecologically adaptive traits of native rhizobial symbionts of Bambara groundnut (*Vigna subterranea* L. Verdc.) in Africa and their relationship with phylogeny. *Scientific Reports*, 9(1), 1-17.

Ikegwu, T.M., Nkama, I.R.O., and Okafor, I.G. (2023). Comparative studies of the proximate, microscopic, and thermal properties of processed maize, wheat, millet, cassava, and Bambara nut flours. *Acta Scientific Nutritional Health,* 7(2), 38-47.

Imran, M., Saeed, F., Hussain, G., Imran, A., Mehmood, Z., Gondal, T.A., El-Ghorab, A., Ahmad, I., Pezzani, R., Arshad, M.U. and Bacha, U., and Islam, S. (2021). Myricetin: A comprehensive review on its biological potentials. *Food Science and Nutrition*, 9(10), 5854-5868.

Isemura, M. (2019). Catechin in human health and disease. *Molecules*, 24(3), 528.

Iwe, M.O., Onyeukwu, U., and Agiriga, A.N. (2016). Proximate, functional, and pasting properties of FARO 44 rice, African yam bean and brown cowpea seeds composite flour. *Cogent Food & Agriculture*, *2* (1), 1142409.

Jamaly, S.I., Hashem, M.A., Akhter, S., and Hossain, M.A. (2017). Wheat flour as dietary fiber on fresh and preserved beef meatballs. *Bangladesh Journal of Animal Science*, 46(1), 35-43.

Jenfa, D.M., and Akinrinde, I.M. (2019). *Functional Properties and Sensory Quality OF Bambara Groundnut and Cowpea Flour for Ekuru Production.* In: 1st National Conference of WITED, Ilaro Chapter, August 13-16, 2019, The Federal Polytechnic, Ilaro. Nigeria.

Jideani, V.A., and Diedericks, C.F. (2014). Nutritional, therapeutic, and prophylactic properties of *Vigna subterranea* and *Moringa oleifera*, in: O. Oguntibe (Ed.), *Antioxidant-Antidiabetic Agents and Human Health*, Janeza Trdine, Rijeka, Croatia, 9, 187-201.

Jideani, V.A., and Jideani, A.I. (2021). Current and Future Bambara groundnut Research Directions. *Bambara groundnut: Utilization and Future Prospects*, 15, 217-229.

Jin, S., Li, W., Naab, F.Z., Coles, D., and Frewer, L.J. (2023). Consumer attitudes toward novel agrifood technologies: a critical review on genetic modification and synthetic biology. *Present Knowledge in Food Safety*, 1004-1014.

Juárez, M., Lam, S., Bohrer, B.M., Dugan, M.E., Vahmani, P., Aalhus, J., Juárez, A., López-Campos, O., Prieto, N., and Segura, J. (2021). Enhancing the nutritional value of red meat through genetic and feeding strategies. *Foods*, 10(4), 872.

Kahkeshani, N., Farzaei, F., Fotouhi, M., Alavi, S.S., Bahramsoltani, R., Naseri, R., Momtaz, S., Abbasabadi, Z., Rahimi, R., Farzaei, M.H. and Bishayee, A. (2019). Pharmacological effects of gallic acid in health and diseases: A mechanistic review. *Iranian Journal of Basic Medical Sciences*, 22(3), 225.

Kahraman, E., Dağlioğlu, O., and Yilmaz, İ. (2023). Physicochemical and sensory characteristics of traditional Kırklareli meatballs with added cowpea (*Vigna unguiculata*) flour. *Food Production, Processing and Nutrition,* 5(1), 1-5.

Kamei, Y., Hatazawa, Y., Uchitomi, R., Yoshimura, R., and Miura, S. (2020). Regulation of skeletal muscle function by amino acids. *Nutrients*, 12(1), 261.

Kanatt, S.R., Arjun, K., and Sharma, A. (2011). Antioxidant and antimicrobial activity of legume hulls. *Food Research International*, 44(10), 3182-3187.

Kaptso, K.G., Njintang, Y.N., Nguemtchouin, M.M.G., Scher, J., Hounhouigan, J., and Mbofung, C.M. (2015). Physicochemical and micro-structural properties of flours, starch, and proteins from two varieties of legumes: Bambara groundnut (*Vigna subterranea*). *Journal of Food Science and Technology*, 52, 4915-4924.

Karademir, Y. (2019). Investigation of amino acid modifications derived from lipid oxidation in foods (Doctoral thesis, Middle East Technical University).

Karak, P. (2019). Biological activities of flavonoids: An overview. *International Journal of Pharmaceutical Sciences and Research*, 10(4), 1567-1574.

Kasaiyan, S.A., Caro, I., Ramos, D.D., Salvá, B.K., Carhuallanqui, A., Dehnavi, M., and Mateo, J. (2023). Effects of the use of raw or cooked chickpeas and the sausage cooking time on the quality of a lamb-meat, olive-oil emulsion-type sausage. *Meat Science*, 202, 109217.

Khan, F., Azman, R., Chai, H.H., Mayes, S., and Lu, C. (2016). Genomic and transcriptomic approaches towards the genetic improvement of an underutilised crops: The case of Bambara groundnut. *African Crop Science Journal*, 24(4), 429-458.

Khan, M.M.H., Rafii, M.Y., Ramlee, S.I., Jusoh, M., and Al-Mamun, M. (2021). Bambara groundnut (*Vigna subterranea* L. Verdc): A crop for the new millennium, its genetic diversity, and improvements to mitigate future food and nutritional challenges. *Sustainability*, 13(10), 5530.

Khatun, S., and Kim, T. (2021). Phenolic compound, antioxidant activity and nutritional components of five legume seeds. *American Journal of Biomedical Science and Research*, 12(4), 328-334.

Khomola, G.T., Ramatsetse, K.E., Ramashia, S.E., and Mashau, M.E. (2021). The incorporation of *Moringa oleifera* leaves powder in mutton patties: Influence on nutritional value, technological quality, and sensory acceptability. *Open Agriculture*, 6(1), 738-748

Kilincceker, O. (2018). Effects of different starches on some of the frying and storage properties of meat patties. *Advances in Food Sciences*, 40(1), 35-41.

Kim, J.M., and Heo, H.J. (2022). The roles of catechins in regulation of systemic inflammation. *Food Science and Biotechnology*, 31(8), 957-970.

King, D.A., Hunt, M.C., Barbut, S., Claus, J.R., Cornforth, D.P., Joseph, P., and Weber, M. (2023). American Meat Science Association guidelines for meat color measurement. *Meat and Muscle Biology*, 6(4), 1-89.

Kinyuru, J. N. (2021). Nutrient content and lipid characteristics of desert locust (*Schistoscerca gregaria*) swarm in Kenya. *International Journal of Tropical Insect Science*, 41(3), 1993-1999.

Klompong, V., and Benjakul, S. (2015). Antioxidative and antimicrobial activities of the extracts from the seed coat of Bambara groundnut (*Voandzeia subterranea*). *RSC Advances*, 5(13), 9973-9985.

Koné, M., Patat-Ochatt, E.M., Conreux, C., Sangwan, R.S., and Ochatt, S.J. (2007). In vitro morphogenesis from cotyledon and epicotyl explants and flow cytometry distinction between landraces of Bambara groundnut [*Vigna subterranea* (L.) Verdc], an under-utilised grain legume. *Plant Cell, Tissue, and Organ Culture*, *88*, 61-75.

Kumar, P., Chatli, M.K., Singh, P., Malav, O.P., and Verma A.K. (2016). Meat analogues: Health promising sustainable meat substitutes. *Critical Reviews in Food Science and Nutrition*. 57(5), 923-932.

Kumar, P., Chatli, M.K., Verma, A.K., Mehta, N., Malav, O.P., Kumar, D., and Sharma, N. (2017). Quality, functionality, and shelf life of fermented meat and meat products: a review. *Critical Reviews in Food Science and Nutrition*, 57(13), 2844–2856.

Kumar, Y. (2021). Development of low-fat/reduced-fat processed meat products using fat replacers and analogues. *Food Reviews International*, 37(3), 296-312.

Kumar, Y., Kumar, V., and Sangeeta. (2020). Comparative antioxidant capacity of plant leaves and herbs with their antioxidative potential in meat system under accelerated oxidation conditions. *Journal of Food Measurement and Characterization*, 14, 3250-3262.

Kwon, Y.J., Lee, H.S., Park, J.Y., and Lee, J.W. (2020). Associating intake proportion of carbohydrate, fat, and protein with all-cause mortality in Korean adults. *Nutrients*, 12(10), 3208.

Laura, A., Moreno-Escamilla, J.O., Rodrigo-García, J., Alvarez-Parrilla, E. (2019). Phenolic Compounds. *In Postharvest Physiology and Biochemistry of Fruits and Vegetables*. *Woodhead Publishing*, pp. 253–271.

Libera, J., Iłowiecka, K., and Stasiak, D. (2021). Consumption of processed red meat and its impact on human health: A review. *International Journal of Food Science and Technology*, 56(12), 6115-6123.

Liu, J., Ellies-Oury, M.P., Stoyanchev, T., and Hocquette, J.F. (2022). Consumer perception of beef quality and how to control, improve and predict it? Focus on eating quality. *Foods*, 11(12), 1732.

Lopes, N.A., and Brandelli, A. (2018). Nanostructures for delivery of natural antimicrobials in food. *Critical Reviews in Food Science and Nutrition*, 58(13), 2202-2212.

López-Vargas, J.H., Fernández-López, J., Pérez-Álvarez, J.Á., and Viuda-Martos, M. (2014). Quality characteristics of pork burger added with albedo-fiber powder obtained from yellow passion fruit (*Passiflora edulis var. flavicarpa*) co-products. *Meat Science*, 97(2), 270-276.

Magnani, C., Isaac, V.L.B., Correa, M.A., and Salgado, H.R.N. (2014). Caffeic acid: a review of its potential use in medications and cosmetics. *Analytical Methods*, 6(10), 3203-3210.

Mahmoud, M.H., Abou-Arab, A.A., and Abu-Salem, F.M. (2017). Quality characteristics of beef burger as influenced by different levels of orange peel powder. *American Journal of Food Technology,* 12(4), 262-270.

Majola, N.G., Gerrano, A.S., and Shimelis, H. (2021). Bambara groundnut (*Vigna subterranea* [L.] Verdc.) production, utilisation, and genetic improvement in Sub-Saharan Africa. *Agronomy*, 11(7), 1345.

Malik, P., and Kapoor, S. (2015). Antioxidant potential of diverse Indian cultivars of lentils (*Lens culinaris* L.). *Research Article Biological Sciences*, 5(1), 123-129.

Manessis, G., Kalogianni, A.I., Lazou, T., Moschovas, M., Bossis, I., and Gelasakis, A.I. (2020). Plant-derived natural antioxidants in meat and meat products. *Antioxidants*, 9(12), 1215.

Mang, D.Y., Abdou, A.B., Njintang, N.Y., Djiogue, E.M., Bernard, C., Scher, J., and Mbofung, M.C. (2015). Effect of dehulling and boiling on the physico-chemical, functional and pasting properties of two varieties of Mucuna bean (*Mucuna pruriens* L.) flours. *Journal of Food Measurement and Characterization*, 9, 435-447.

Maphosa, Y., and Jideani, V.A. (2017). The role of legumes in human nutrition. *Functional Food-Improve Health Through Adequate Food*, pp 13.

Marikkar, N., Marasinghe, S., Yalegama, C., and Hewapathirana, D. (2021). The physical and functional properties of partially defatted coconut testa flour. *CORD*, 37, 11-22.

Masek, A., Latos, M., Piotrowska, M., and Zaborski, M. (2018). The potential of quercetin as an effective natural antioxidant and indicator for packaging materials. *Food Packaging and Shelf-Life*, 16, 51-58.

Mashau, M.E., Mabodze, T., Tshiakhatho, O.J., Silungwe, H., and Ramashia, S.E. (2020). Evaluation of the content of polyphenols, antioxidant activity and physicochemical properties of tortillas added with Bambara groundnut flour. *Molecules*, 25(13), 3035.

Mashau, M.E., Mukwevho, T.A., Ramashia, S.E., and Siwela, M. (2022). The influence of Bambara groundnut (*Vigna subterranean*) flour on the nutritional, physical and antioxidant properties of steamed bread. *CyTA-Journal of Food*, 20(1), 259-270.

Mashau, M.E., Munandi, M., and Ramashia, S.E. (2021b). Exploring the influence of *Moringa oleifera* leaves extract on the nutritional properties and shelf life of mutton patties during refrigerated storage. *CyTA-Journal of Food*, 19(1), 389-398.

Mashau, M.E., Ramatsetse, K.E., and Ramashia, S.E. (2021a). Effects of adding *Moringa oleifera* leaves powder on the nutritional properties, lipid oxidation and microbial growth in ground beef during cold storage. *Applied Sciences*, 11(7), 2944.

Massawe, F.J., Mwale, S.S., Azam-Ali, S.N., and Roberts, J.A. (2005). Breeding in Bambara groundnut (*Vigna subterranea* (L.) Verdc.): strategic considerations. *African Journal of Biotechnology*, 4(6), 463-471.

Matsa, W., and Mukoni, M. (2013). Traditional science of seed and crop yield preservation: exploring the contributions of women to indigenous knowledge systems in Zimbabwe. *International Journal of Humanities and Social Science*, 3(4), 234-245.

Mazhangara, I.R., Festus Jaja, I., and Chivandi, E. (2022). Consumer perceptions and attitudes towards chevon and chevon-derived products: A case study of Amathole and Buffalo city municipalities in South Africa. *Journal of Culinary Science and Technology*, 1, 1-17.

Mbosso, C., Boulay, B., Padulosi, S., Meldrum, G., Mohamadou, Y., Niang, A.B., Coulibaly, H., Koreissi, Y., and Sidibe, A. (2020). Fonio and Bambara groundnut value chains in Mali: issues, needs, and opportunities for their sustainable promotion. *Sustainabilty*, 12(11), 4766.

Mehdizadeh, T., Tajik, H., Langroodi, A.M., Molaei, R., and Mahmoudian, A. (2020). Chitosan-starch film containing pomegranate peel extract and Thymus kotschyanus essential oil can prolong the shelf life of beef. *Meat Science*, 163, 108073.

Meijer, G.W., Detzel, P., Grunert, K.G., Robert, M.C., and Stancu, V. (2021). Towards effective labelling of foods. An international perspective on safety and nutrition. *Trends in Food Science and Technology*, *118*, 45-56.

Mendiratta, S.K., Shinde, A.T., and Mane, B.G. (2013). Effect of added vegetable (carrot, radish and capsicum) as functional ingredients in mutton nuggets. *Journal of Meat Science and Technology,* 1(2), 71-76.

Mi, Y., and Ejeh, D.D. (2018). Production of Bambara groundnut substituted whole wheat bread: Functional properties and quality characteristics. *Journal of Nutrition and Food Sciences*, 8(5), 1000731.

Mishra, S.K., Belur, P.D., and Iyyaswami, R. (2021). Use of antioxidants for enhancing oxidative stability of bulk edible oils: A review. *International Journal of Food Science and Technology*, 56(1), 1-12.

Moarefian, M., Barzegar, M., and Sattari, M. (2013). Cinnamomum zeylanicum essential oil as a natural antioxidant and antibacterial in cooked sausage. *Journal of Food Biochemistry*, 37(1), 62-69.

Moghtadaei, M., Soltanizadeh, N., and Goli, S.A.H. (2018). Production of sesame oil oleogels based on beeswax and application as partial substitutes of animal fat in beef burger. *Food Research International*, 108, 368–377.

Mojadadi, A., Au, A., Salah, W., Witting, P., and Ahmad, G. (2021). Role for selenium in metabolic homeostasis and human reproduction. *Nutrients*, 13(9), 3256.

Morbos, C.E., Bandalan, M., Gonzaga, J.M., Cabugawan, E.C., and Galvez, L.A. (2019). Quality and acceptability of burger patty as influenced by the levels of mung bean (*Vigna radiata*) flour as meat substitute. *Annals of Tropical Research*, 41(1), 102-117.

Motamedi, A., Vahdani, M., Baghaei, H., and Borghei, M.A. (2015). Considering the physicochemical and sensorial properties of momtaze hamburgers containing lentil and chickpea seed flour. *Nutrition and Food Sciences Research*, 2(3), 55-62.

Moyo, S.M., Mavumengwana, V., and Kayitesi, E. (2018). Effects of cooking and drying on phenolic compounds and antioxidant activity of African green leafy vegetables. *Food Reviews International*, 34(3), 248-264.

Mubaiwa, J., Fogliano, V., Chidewe, C., and Linnemann, A.R. (2017). Hard-to-cook phenomenon in bambara groundnut (*Vigna subterranea* (L.) Verdc.) processing: Options to improve its role in providing food security. *Food Reviews International*, 33(2), 167-194.

Mubaiwa, J., Fogliano, V., Chidewe, C., and Linnemann, A.R. (2018). Bambara groundnut (*Vigna subterranea* (L.) Verdc.) flour: A functional ingredient to favour the use of an unexploited sustainable protein source. *PloS One*, 13(10), e0205776.

Mubaiwa, J., Fogliano, V., Chidewe, C., Bakker, E.J., and Linnemann, A.R. (2018). Utilization of bambara groundnut (*Vigna subterranea* (L.) Verdc.) for sustainable food and nutrition security in semi-arid regions of Zimbabwe. *PloS one*, 13(10), e0204817.

Muchekeza, J.T., Jombo, T.Z., Magogo, C., Mugari, A., Manjeru, P., and Manhokwe, S. (2021). Proximate, physico-chemical, functional and sensory properties of quinoa and amaranth flour AS potential binders in beef sausages. *Food Chemistry*, 365, 130619.

Mudau, M., Ramashia, S.E., and Mashau, M.E. (2022). Mineral content, functional, thermo-pasting, and microstructural properties of spontaneously fermented finger millet flours. *Foods*, 11(16), 2474.

Muhammad, I., Rafii, M.Y., Ramlee, S.I., Nazli, M.H., Harun, A.R., Oladosu, Y., Musa, I., Arolu, F., Chukwu, S.C., Haliru, B.S., Akos, I.S., Halidu, J., and Arolu, I.W. (2020). Exploration of bambara groundnut (*Vigna subterranea* (L.) Verdc.), an underutilized crop, to aid global food security: Varietal improvement, genetic diversity, and processing. *Agronomy*, 10(6), 766.

Murevanhema, Y.Y., and Jideani, V.A. (2013). Potential of Bambara groundnut (*Vigna subterranea* (L.) Verdc) milk as a probiotic beverage-A review. *Critical Review in Food Science and Nutrition*, 53(9), 954–967.

Musah, M., Azeh, Y., Mathew, J.T., Nwakife, N.C., Mohammed, A.I., and Saidu, F. (2021). Nutritional evaluation of bambara groundnut (*Vigna subterranea* (L.) Verdc) from Lapai, Nigeria. *African Journal of Agriculture and Food Science*, 4, 32–39.

Ndamitso, M.M., Mustapha, S., Etsuyankpa, M.B., Ajai, A.I., and Mathew, J.T. (2017). Evaluation of chemical composition of *Acacia nilotica* seeds. *FUW Trends in Science and Technology Journal*. 2, 927–931.

Neethling, N.E., Suman, S.P., Sigge, G.O., Hoffman, L.C., and Hunt, M.C. (2017). Exogenous and endogenous factors influencing colour of fresh meat from ungulates. *Meat and Muscle Biology,* 1(1), 32.

Ninomiya, K. (2016). Food science of dashi and umami taste. *Yakugaku Zasshi*, 136, 1327–1334.

Novello, D., Schiessel, D.L., Santos, E.F., and Pollonio, M.A.R. (2019). The effect of golden flaxseed and by-product addition in beef patties: physicochemical properties and sensory acceptance. *International Food Research Journal*, 26(4), 1237-1248.

Novikasari, N.A.M., Wati, A.K., Khikmah, N., and Muflihati, I. (2020). Effect of peanut types on patties analogue characteristics. *Journal of Agri-Food Science and Technology*, 1(1), 1-11.

Nti, C.A. (2009). Effects of bambara groundnut (*Vigna subterranea*) variety and processing on the quality and consumer appeal for its products. *International Journal of Food Science and Technology*, 44(11), 2234-2242.

Nuhriawangsa, A.M.P., Swastike, W., Hertanto, B.S., Hanifa, A., and Kartikasari, L.R. (2023). Physical quality of beef sausage using porang flour as a substitute for tapioca flour. In *IOP Conference Series: Earth and Environmental Science,* 1200(1), *012021*.

Nwadi, O.M., Uchegbu, N., and Oyeyinka, S.A. (2020). Enrichment of food blends with Bambara groundnut flour: Past, present, and future trends. *Legume Science*, 2(1), e25.

Nyau, V., Prakash, S., Rodrigues, J., and Farrant, J. (2015). Antioxidant activities of Bambara groundnuts as assessed by FRAP and DPPH assays. *American Journal of Food and Nutrition*, 3(1), 7-11.

Nzuta, R.A., Elechi, J.O., Isa, I.S., Kittika'a, H.J., and Thomas, C.T. (2022). Flour and Cassava (*Manihot* spp) cultivars in Nigeria: understanding their chemical functionalities and acceptability in food systems. *International Journal of Scientific Research in Chemical,* 9(2), 20-29.

Official methods and recommended practices of the American Oil Chemist's Society, 4th edn., by D. Firestone, American Oil Chemists' Society (AOSC), Washington, DC, United State of America

Ofosu, F.K., Elahi, F., Daliri, E.B.M., Chelliah, R., Ham, H.J., Kim, J.H., Han, S.I., Hur, J.H., and Oh, D.H. (2020). Phenolic profile, antioxidant, and antidiabetic potential exerted by millet grain varieties. *Antioxidants*, 9(3), 254.

Okafor, J., Okafor, G., Leelavathi, K., Bhagya, S., and Elemo, G. (2015). Effect of roasted Bambara groundnut (*Voandzeia subterranea*) fortification on quality and acceptability of biscuits. *Pakistan Journal of Nutrition*, 14(10), 653-657.

Okafor, J.N., Jideani, V.A., Meyer, M., and Le Roes-Hill, M. (2022). Bioactive components in Bambara groundnut (*Vigna subterraenea* (L.) Verdc) as a potential source of nutraceutical ingredients. *Heliyon*, 2022, e09024.

Okafor, J.N., Rautenbauch, F., Meyer, M., Le Roes-Hill, M., Harris, T., and Jideani, V.A. (2021). Phenolic content, antioxidant, cytotoxic and antiproliferative effects of fractions of *Vigna subterraenea* (L.) verdc from Mpumalanga, South Africa. *Heliyon*, 7(11), e08397.

Okpuzor, J., Ogbunugafor, H.A., Okafor. U., and Sofidiya, M.O. (2010). Identification of Protein Types in Bambara Nut Seeds: Perspectives for Dietary Protein Supply in Developing Countries. *Experimental and Clinical Sciences International Journal*, 9, 17-28.

Okwunodulu, I.N., Peter, G.C., and Okwunodulu, F.U. (2019). Proximate quantification and sensory assessment of moi-moi prepared from Bambara nut and cowpea flour blends. *Asian Food Science Journal*, 9(2), 1-11.

Olaleke, A.M., Olorunfemi, O., and Emmanuel, A. (2006). A comparative study on the chemical and amino acid composition of some Nigerian under-utilized legume flours. *Pakistan Journal of Nutrition*, 5(1), 34-38.

Olatunde, O.O., and Benjakul, S. (2018). Natural preservatives for extending the shelf-life of seafood: a revisit. *Comprehensive Reviews in Food Science and Food Safety*, 17(6), 1595-1612.

Olatunde, S.J., Ogundele, O.M., Oyedokun, J., Chinma, C.E., Shittu, T.A., and Onoja, V. (2021). Traditional food uses of Bambara groundnut. *Food and Potential Industrial Applications of Bambara Groundnut*, 9, 153-168.

Oluwatoyin, A. (2014). Physicochemical characterization, and antioxidant properties of the seeds and oils of ginger (*Zingiber officinale*) and garlic (*Allium sativum*). *Science Journal of Chemistry*, 2(6), 44-50.

Onyilagha, J.C., Islam, S., and Ntamatungiro, S. (2009). Comparative phytochemistry of eleven species of Vigna (Fabaceae). *Biochemical Systematics and Ecology*, 37(1), 16-19.

Owusu-Ansah, P., Besiwah, E.K., Bonah, E., and Amagloh, F.K. (2022). Non-meat ingredients in meat products: A scoping review. *Applied Food Research*, 2(1), 100044.

Oyedeji, A.B., Oladunjoye, A.O., Ijabadeniyi, O.A., and Kayitesi, E. (2021). Phytochemicals in Bambara groundnut. *Food and Potential Industrial Applications of Bambara Groundnut*, 4, 137-152.

Oyeleke, G.O., Afolabi, O., and Isola, A.D. (2012). Some quality and carbohydrate fractions of Bambara groundnut (*Vigna subterranea* (L).) Seed Flour. *IOSR Journal of Applied Chemistry*, 2(4), 16-19.

Oyeyinka, A.T., Pillay, K., Tesfay, S., and Siwela, M. (2017), "Physical, nutritional and antioxidant properties of Zimbabwean Bambara groundnut and effects of processing methods on their chemical properties", *International Journal of Food Science and Technology*, 52(10), 2238-2247.

Oyeyinka, A.T., Pillay, K., Tesfay, S., and Siwela, M. (2017). Physical, nutritional and antioxidant properties of Zimbabwean bambara groundnut and effects of processing methods on their chemical properties. *International Journal of Food Science and Technology*, 52(10), 2238-2247.

Oyeyinka, S.A., Abdulsalam, A.O., Ahmed El-Imam, A.M., Oyeyinka, A.T., Olagunju, O.F., Kolawole, F.L., Arise, A.K., Adedeji, E.O., and Njobeh, P.B. (2021). Total phenolic content, antioxidant, anti-inflammatory and anti-microbial potentials of Bambara groundnut (*Vigna subterranea* L.) seed extract. *British Food Journal*, 123(11), 3421-3435.

Oyeyinka, S.A., and Oyeyinka, A.T. (2018). A review on isolation, composition, physicochemical properties, and modification of Bambara groundnut starch. *Food Hydrocolloids*, 75, 62–71.

Öztürk-Kerimoğlu, B., Kavuşan, H.S., Tabak, D., and Serdaroğlu, M. (2020). Formulating reduced-fat sausages with quinoa or teff flours: effects on emulsion characteristics and product quality. *Food Science of Animal Resources*, 40(5), 710.

Paglarini, C.S., Vidal, V.A.S., Martini, S., Cunha, R.L., Rosiane, L., and Pollonio, M.A.R. (2020). Protein-based hydrogelled emulsions and their application as fat replacers in meat products. A review. *Critical Reviews in Food Science*, 62(3), 640-655.

Parikh, B., and Patel, V.H. (2018). Total phenolic content and total antioxidant capacity of common Indian pulses and split pulses. *Journal of Food Science and Technology*, 55, 1499-1507.

Park, S.Y., Lee, J.W., Kim, G.W., and Kim, H.Y. (2017). Effect of black rice powder on the quality properties of pork patties. *Korean Journal for Food Science of Animal Resources*, 37(1), 71.

Pina-Pérez, M.C., Rivas, A., Martínez, A., and Rodrigo, D. (2017). Antimicrobial potential of macro and microalgae against pathogenic and spoilage microorganisms in food. *Food Chemistry*, 235, 34-44.

Polizer-Rocha, Y.J., Lorenzo, J.M., Pompeu, D., Rodrigues, I., Baldin, J.C., Pires, M. A., and Trindade, M.A. (2020). Physicochemical and technological properties of beef burger as influenced by the addition of pea fibre. *International Journal of Food Science and Technology*, 55(3), 1018–1024.

Ponnampalam, E.N., Bekhit, A.E.D., Bruce, H., Scollan, N.D., Muchenje, V., Silva, P., and Jacobs, L. (2019). Production Strategies and Processing Systems of Meat: Current Status and Future Outlook for Innovation – A Global Perspective. *Sustainable Meat Production and processing*, 2019, 17- 44.

Ponnampalam, E.N., Sinclair, A.J., and Holman, B.W. (2021). The sources, synthesis and biological actions of omega-3 and omega-6 fatty acids in red meat: An overview. *Foods*, 10(6), 1358.

Possidonio, C., Prada, M., Graca, J., and Piazza, J. (2021). Consumer perceptions of conventional and alternative protein sources: A mixed methods approach with meal and product framing. *Appetite,* 156, 104860.

Poveda-Arteaga, A., Krell, J., Gibis, M., Heinz, V., Terjung, N., and Tomasevic, I. (2023). Intrinsic and Extrinsic Factors Affecting the Colour of Fresh Beef Meat—Comprehensive Review. *Applied Sciences*, 13(7), 4382.

Price, A., Diaz, P., Banon, S., and Garrido, M.D. (2013). Natural extracts versus sodium ascorbate to extend the shelf life of meat-based ready-to-eat meals. *Food Science and Technology International*, 19, 427– 438.

Purohit, A.S, Reed, C., Mohan, A. (2016). Development and evaluation of quail breakfast sausage. *LWT-Food Science and Technology*, 69, 447–453.

Rama, V., Joshevska, E., and Hristova, V.K. (2019). Modern cattle slaughtering technology and its meat quality. *Knowledge-International Journal,* 34(3), 667-671.

Ramashia, S.E., Mamadisa, F.M., and Mashau, M.E. (2021). Effect of *Parinari curatellifolia* peel flour on the nutritional, physical and antioxidant properties of biscuits. *Processes*, 9(8), 1262.

Ramatsetse, K.E., Ramashia, S.E., and Mashau, M.E. A review on health benefits, antimicrobial and antioxidants properties of Bambara groundnut (*Vigna subterranea*). *International Journal of Food Properties*, 26(1), 91-107.

Ravani, A., and Sharma, H.P. (2022). Functional Food, Meat based functional foods. Book Editor(s): Navnidhi Chhikara, Anil Panghal, N. C. A. and Chaudhary, C. Wiley. pp. 235-287.

Rout, S., Tambe, S., Deshmukh, R.K., Mali, S., Cruz, J., Srivastav, P.P., Amin., P.D., Gaikwad, K.K., de Aguiar Andrade, E.H., and de Oliveira, M.S. (2022). Recent trends in the application of essential oils: The next generation of food preservation and food packaging. *Trends in Food Science and Technology*, 129, 421-439.

Saikia, K., Laskar, S.K., Hazarika, M., Das, A., Saleque, A., and Deka, N.N. (2019). Effects of Black gram flour (*Vigna mungo* L.) on the proximate composition, texture, colour profile and microbiological qualities of duck meat patties. *International Journal of Current Microbiology and Applied Science*, 8(7), 1399-1407.

Sainsbury, J., Schönfeldt, H.C., and Van Heerden, S.M. (2011). The nutrient composition of South African mutton. *Journal of Food Composition and Analysis*, 24(5), 720-726.

Salarkarimi, V., Varidi, M.J., and Varidi, M. (2019). The effect of chestnut (*Quercus brantii*) flour substitution on the physicochemical and sensory properties of burgers. *Research and Innovation in Food Science and Technology*, 8(1), 15-30.

Salawu, S.O. (2016). Comparative study of the antioxidant activities of methanolic extract and simulated gastrointestinal enzyme digest of Bambara nut (*Vigna subterranean*) *Futa*. *Journal of Research in Sciences*, 1, 107–120.

Salehi, B., Machin, L., Monzote, L., Sharifi-Rad, J., Ezzat, S.M., Salem, M.A., Merghany, R.M., El Mahdy, N.M., Kılıç, C.S., Sytar, O. and Sharifi-Rad, M., and Cho, W. C. (2020). Therapeutic potential of quercetin: New insights and perspectives for human health. *ACS Omega*, 5(20), 11849-11872.

Samad, N., and Javed, A. (2018). Therapeutic effects of gallic acid: Current scenario. *Journal of Phytochemistry and Biochemistry*, 2(113), 2.

Santiesteban-López, N.A., Gómez-Salazar, J.A., Santos, E.M., Campagnol, P.C., Teixeira, A., Lorenzo, J.M., Sosa-Morales, M.E., and Domínguez, R. (2022). Natural antimicrobials: A clean label strategy to improve the shelf life and safety of reformulated meat products. *Foods*, 11(17), 2613.

Saricoban, C., and Yilmaz, M.T. (2010). Modelling the effects of processing factors on the changes in colour parameters of cooked meatballs using response surface methodology. *World Applied Sciences Journal*, 9(1), 14-22.

Sarker, U., and Oba, S. (2018). Drought stress enhances nutritional and bioactive compounds, phenolic acids, and antioxidant capacity of Amaranthus leafy vegetable. *BMC Plant Biology*, 18(1), 1-15.

Sayas-Barberá, E., Valero-Asencio, M.M., Navarro Rodríguez-Vera, C., Fernández-López, J., Haros, C.M., Pérez-Álvarez, J.Á., and Viuda-Martos, M. (2021). Effect of different black quinoa fractions (seed, flour and wet-milling coproducts) upon quality of meat patties during freezing storage. *Foods*, 10(12), 3080.

Schulz, R., and Slavin, J. (2021). Perspective: defining carbohydrate quality for human health and environmental sustainability. *Advances in Nutrition*, 12(4), 1108-1121.

Schuster-Gajzago, I. (2004). Nutritional aspects of legumes. In: Cultivated plants, primarily as food sources. Encyclopedia of Food and Agricultural Sciences, Engineering and Technology Resources. Encyclopedia of Life Support System (EOLSS). Developed under the auspices of the UNESEO, *Eolss Publishers*, Oxford, United Kingdom, 1, 1-7.

Schwingshackl, L., Hoffmann, G., Iqbal, K., Schwedhelm, C., and Boeing, H. (2018). Food groups and intermediate disease markers: a systematic review and network meta-analysis of randomized trials. *The American Journal of Clinical Nutrition*, 108(3), 576–586.

Semwal, D.K., Semwal, R.B., Combrinck, S., and Viljoen, A. (2016). Myricetin: A dietary molecule with diverse biological activities. *Nutrients*, 8(2), 90.

Shanono, I.M., and Muhammad, Y.Y. (2015). effect of cooking on proximate and anti-nutritional content of Bambara Groundnut. *Journal of Advances in Food Science and Technology*, 2(4), 176-180.

shinyani, M., Mashau, M.E., and Jideani, A.I. (2020). Bioactive compounds, antioxidant activity and consumer acceptability of porridges of finger millet (*Eleusine coracana*) flours: Effects of spontaneous fermentation. *International Journal of Food Properties*. 23(1), 1692-710.

Shivakumar, N., Ramesh Babu, M.S., Vasudeva, S., and Akshay, H. (2022). Bio-Based Materials Used in Food Packaging to Increase the Shelf Life of Food Products. In *Biobased Materials: Recent Developments and Industrial Applications*. Singapore: Springer Nature Singapore. pp. 195-209.

Siddiq, M., Nasir, M., Ravi, R., Dolan, K.D., and Butt, M.S. (2009). Effect of defatted maize germ addition on the functional and textural properties of wheat flour. *International Journal of Food Properties*, 12(4), 860-870.

Siegrist, M., and Hartmann, C. (2020). Consumer acceptance of novel food technologies. *Nature Food*, 1(6), 343-350.

Silva dos Santos, J., Goncalves Cirino, J.P., de Oliveira Carvalho, P., and Ortega, M.M. (2021). The pharmacological action of kaempferol in central nervous system diseases: A review. *Frontiers in Pharmacology*, 11, 565700.

Silvestri, C., Aquilani, B., Piccarozzi, M., and Ruggieri, A. (2020). Beef traditional food: Consumer before purchase preferences based on quality. *Italian Journal of Food Science*, 32(1), 16-44.

Sitohy, M., Mahgoub, S., Osman, A., El-Masry, R., and Al-Gaby, A. (2013). Extent and mode of action of cationic legume proteins against *Listeria monocytogenes* and *Salmonella Enteritidis*. *Probiotics and Antimicrobial Proteins*, 5, 195-205.

Skřivan, P., Sluková, M., Jurkaninová, L., and Švec, I. (2021). Preliminary investigations on the use of a new milling technology for obtaining wholemeal flours. *Applied Sciences*, 11(13), 6138.

Sousa, R., Portmann, R., Recio, I., Dubois, S., and Egger, L. (2023). Comparison of in vitro digestibility and DIAAR between vegan and meat burgers before and after grilling. *Food Research International*, 166, 112569.

Sruthi, N.U., and Rao, P.S. (2021). Effect of processing on storage stability of millet flour: A review. *Trends in Food Science and Technology*, 112, 58-74.

Stephens, J.M. (2012). Bambara Groundnut-*Voandzeia subterranean*, (L.) Thouars, University of Florida, Gainesville, Florida. http://edis.ifas.ufl.edu/mv014. (Accessed 19 March 2021).

Suliman, G.M., Hussein, E.O., ALSagan, A.A., Alo-Waimer, A.N., Alhotan, R., Al-Baadani, H.H., Ba-Awadh, H.A., Qaid, M.M., and Swelum, A.A.A. (2023). Effects of adding nano-emulsified plant oil and probiotics to drinking water during different periods besides sex on processing characteristics, physicochemical properties, and meat quality traits of broiler chickens. *Frontiers in Veterinary Science*, 10, 151.

Sultana, S. (2020). Nutritional and functional properties of *Moringa oleifera*. *Metabolism Open*, *8*, 100061.

Suman, S.P., Hunt, M.C., Nair, M.N., and Rentfrow, G. (2014). Improving beef colour stability: Practical strategies and underlying mechanisms. *Meat Science*, 98, 490-504.

Tahmasebi, M., Labbafi, M., Emam-Djomeh, Z., and Yarmand, M.S. (2016). Manufacturing the novel sausages with reduced quantity of meat and fat: The product development, formulation optimization, emulsion stability and textural characterization. *LWT-Food Science and Technology*, 68, 76-84.

Tajik, N., Tajik, M., Mack, I., and Enck, P. (2017). The potential effects of chlorogenic acid, the main phenolic components in coffee, on health: a comprehensive review of the literature. *European Journal of Nutrition*, 56, 2215-2244.

Tan, W.C., Tan, C.H., Nyam, K.L., Tan, C.P., and Julkifle, A. (2021). Nutritive Bambara groundnut powdered drink mix: characterization and in-vivo assessment of the cholesterol-lowering effect. *Journal of Food Science and Technology*, 58, 2992-3000.

Tan, X.L., Azam-Ali, S., Goh, E.V., Mustafa, M., Chai, H.H., Ho, W.K., Mayes, S., Mabhaudhi, T., Azam-Ali, S., and Massawe, F. (2020). Bambara groundnut: An underutilized leguminous crop for global food security and nutrition. *Frontiers in Nutrition*, 7, 601496.

Tardy, A.L., Pouteau, E., Marquez, D., Yilmaz, C., and Scholey, A. (2020). Vitamins and minerals for energy, fatigue, and cognition: a narrative review of the biochemical and clinical evidence. *Nutrients*, 12(1), 228.

Temba, M.C., Njobeh, P.B., Adebo, O.A., Olugbile, A.O., and Kayitesi, E. (2016). The role of compositing cereals with legumes to alleviate protein energy malnutrition in Africa. *International Journal of Food Science and Technology,* 51(3), 543–554.

Temegne, N.C. (2018) Improvement in the performances of Voandzou (*Vigna subterranea* (L.) Verdc.) in response to phosphate deficiency through chemical and biological fertilization. Ph.D Thesis, Faculty of Science, University of Yaounde, , Yaounde, Cameroon.

Temegne, N.C., Gouertoumbo, W.F., Wakem, G.A., Nkou, F.T.D., Youmbi, E., and Ntsomboh-Ntsefong, G. (2018). Origin and ecology of Bambara groundnut (Vigna subterranea (L.) Verdc): A review. *Journal of Ecology and Natural Resources*, 2 (4), 000140.

Temudo, M.P., Cabral, A.I., and Talhinhas, P. (2020). Urban and rural household energy consumption and deforestation patterns in Zaire province, Northern Angola: A landscape approach. *Applied Geography*, 119, 102207.

Testa, M.L., Grigioni, G., Panea, B., and Pavan, E. (2021). Colour and marbling as predictors of meat quality perception of Argentinian consumers. *Foods*, 10(7), 1465.

Thakur, A., Sharma, V., and Thakur, A. (2019). An overview of anti-nutritional factors in food. *International Journal of Chemical Studies*, 7(1), 2472-2479.

Thomas, A.A., Feng, B., and Chakrabarti, S. (2017). ANRIL: a regulator of VEGF in diabetic retinopathy. *Investigative Ophthalmology and Visual Science*, 58(1), 470-480.

Torrico D.D., Hutching, S., Ha, M., Bittner, E.P., Fuentes, S., Warner, R.D., and Dunshea, F.R. (2018). Novel techniques to understand consumer responses towards food products: a review with a focus on meat. *Meat Science*, 144, 30–42.

Tsamo, A. T., Ndibewu, P.P., and Dakora, F.D. (2018). Phytochemical profile of seeds from 21 Bambara groundnut landraces via UPLC-qTOF-MS. *Food Research International*, 112, 160-168.

Tsamo, A.T., Ndibewu, P.P., and Dakora, F.D. (2018). Phytochemical profile of seeds from 21 Bambara groundnut landraces via UPLC-qTOF-MS. *Food Research International*, 112, 160-168.

Uchechukwu-Agua, A.D., Caleb, O.J., Manley, M., and Opara, U.L. (2015). Effects of storage conditions and duration on physicochemical and microbial quality of the flour of two cassava cultivars (TME 419 and UMUCASS 36). *CyTA-Journal of Food*, 13(4), 635-645.

Udeh, E.L., Nyila, M.A., and Kanu, S.A. (2020). Nutraceutical and antimicrobial potentials of Bambara groundnut (*Vigna subterranean*): A review. *Heliyon*, 6(10), e05205.

Vargas-Ramella, M., Munekata, P.E., Pateiro, M., Franco, D., Campagnol, P.C., Tomasevic, I., Domínguez, R., and Lorenzo, J.M. (2020). Physicochemical composition and nutritional properties of deer burger enhanced with healthier oils. *Foods*, 9(5), 571.

Verma, A.K., Rajkumar, V., and Kumar, S. (2019). Effect of amaranth and quinoa seed flour on rheological and physicochemical properties of goat meat nuggets. *Journal of Food Science and Technology*, 56, 5027-5035.

Vijayaraghavan, K., Rajkumar, J., and Seyed, M.A. (2018). Phytochemical screening, free radical scavenging, and antimicrobial potential of *Chromolaena odorata* leaf extracts against pathogenic bacterium in wound infections–a multispectrum perspective. *Biocatalysis and Agricultural Biotechnology*, 15, 103-112.

Wang, Y., Domínguez, R., Lorenzo, J.M., and Bohrer, B.M. (2021). The Relationship between Lipid Content in Ground Beef Patties with Rate of Discolouration and Lipid Oxidation during Simulated Retail Display. *Foods*, 10(9), 1982.

Wanyama, A.W. (2018). *Evaluation of phytoconstituents, antioxidants potential, cytotoxic, antimicrobial activities, and mineral composition of Vigna subterranea (L) Verdic. Extracts* (Doctoral thesis, JKUAT-COHES).

Wanyama, A.W., Orwa, J.A., Njenga, P.K., and Irungu, B.N. (2017). Evaluation of cytotoxicity, antimicrobial activities, and minerals composition of *Vigna subterranea* (L.) verdc. (Bambara groundnut) extracts. *African Journal of Health Sciences*, 30(2), 88-104.

Willett, W., Rockstrom, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell M., Clark, M., Gordon, L.J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J.A., De Vries, W., and Murray, C.J.L. (2019). Food in the Anthropocene: The EAT-Lancet Commission on healthy diets from sustainable food systems. *Lancet*, 393(10170), 447-492.

Xiao, J., Khan, M.Z., Ma, Y., Alugongo, G.M., Ma, J., Chen, T., Khan., A., and Cao, Z. (2021). The antioxidant properties of selenium and vitamin E; their role in periparturient dairy cattle health regulation. *Antioxidants*, 10(10), 1555.

Xiong, Y., Li, S., Warner, R.D., and Fang, Z. (2020). Effect of oregano essential oil and resveratrol nanoemulsion loaded pectin edible coating on the preservation of pork loin in modified atmosphere packaging. *Food Control*, *114*, 107226.

Xu, B., and Chang, S.K. (2008), "Effect of soaking, boiling, and steaming on total phenolic content and antioxidant activities of cool season food legumes", *Food Chemistry*, 110(1), 1-13.

Xu, R. (2017). Assessment of physicochemical and functional properties of fibre-rich fractions of yellow pea and red lentil to use in low-fat pork bologna (Doctoral dissertation, University of Saskatchewan).

Yan, Y., Zhou, X., Guo, K., Zhou, F., and Yang, H. (2020). Use of chlorogenic acid against diabetes mellitus and its complications. Journal of Immunology Research, 2020, 1-6.

Yang, T. (2019). Effects of non-allergen ingredients on functional properties and sensory acceptability of selected processed meat products. MSc Thesis, Department of Agricultural, Food and Nutritional Science University of Alberta, Edmonton, Canada.

Yao, D.N., Kouassi, K. N., Erba, D., Scazzina. F., and Pellegrini, N. (2015) Nutritive evaluation of the Bambara groundnut Ci12 landrace [*Vigna subterranea* (L.) Verdc. (*Fabaceae*)] produced in Côte d'Ivoire. *International Journal of Molecular Sciences*, 16(9), 21428-21441.

Yogesh, K. (2021). Development of low-fat/reduced-fat processed meat products using fat replacers and analogues, *Food Reviews International*, 37(3), 296-312.

Younis, K., and Ahmad, S. (2018). Quality evaluation of buffalo meat patties incorporated with apple pomace powder. *Buffalo Bulletin*, 37(3), 389-401.

Yusnawan, E., Sutrisno, K.A., and Kristiono, A. (2019). Total phenolic content and antioxidant activity of mung bean seed cultivars from optimized extraction treatment. *Buletin Palawija*, 17(1), 1-9.

Zanello, P.R., Koishi, A.C., Rezende Júnior, C.D.O., Oliveira, L.A., Pereira, A.A., de Almeida, M.V., Duarte dos Santos, C.N., and Bordignon, J. (2015). Quinic acid derivatives inhibit dengue virus replication in vitro. *Virology journal*, 12(1), 1-13.

Zerabruk, K., Retta, N., Muleta, D., and Tefera, A.T. (2019). Assessment of microbiological safety and quality of minced meat and meat contact surfaces in selected butcher shops of addis ababa, Ethiopia. *Journal of Food Quality*, 2019, 1-9.

Appendix A

ETHICS APPROVAL CERTIFICATE

RESEARCH AND INNOVATION
OFFICE OF THE DIRECTOR

NAME OF RESEARCHER/INVESTIGATOR:
Mr KE Ramatsetse

STUDENT NO:
16014230

PROJECT TITLE **Effect of partial mutton meat substitution by Bambara groundnut flour on physicochemical properties, lipid oxidation and sensory acceptability of low-fat patties.**

ETHICAL CLEARENCE NO: **FSEA/22/FST/07/1711**

SUPERVISORS/ CO-RESEARCHERS/ CO-INVESTIGATORS

NAME	INSTITUTION & DEPARTMENT	ROLE
Dr SE Ramashia	UNIVEN, Food Science and Technology	Supervisor
Mr M Mashau	UNIVEN, Food Science and Technology	Co - Supervisor
Mr. KE Ramatsetse	UNIVEN, Food Science and Technology	Investigator – Student

Type: **Masters Research**
Risk: **Minimal risk to humans, animals, or environment (Category 2)**
Approval Period: **November 2022 - November 2023**

The Human and Clinical Trails Research Ethics Committee (HCTREC) hereby approves your project as indicated above.

General Conditions
While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following.

- The project leader (principal investigator) must report in the prescribed format to the REC:
  - Annually (or as otherwise requested) on the progress of the project, and upon completion of the project.
  - Within 48hrs in case of any adverse event (or any matter that interrupts sound ethical principles) during the course of the project.
  - Annually a number of projects may be randomly selected for an external audit.
- The approval applies strictly to the protocol as stipulated in the application form. Would any changes to the protocol be deemed necessary during the course of the project, the project leader must apply for approval of these changes at the REC. Would there be deviated from the project protocol without the necessary approval of such changes, the ethics approval is immediately and automatically forfeited.
- The date of approval indicates the first date that the project may be started. Would the project have to continue after the expiry date; a new application must be made to the REC and new approval received before or on the expiry date.
- In the interest of ethical responsibility, the REC retains the right to:
  - Request access to any information or data at any time during the course or after completion of the project,
  - To ask further questions; Seek additional information; Require further modification or monitor the conduct of your research or the informed consent process.
  - withdraw or postpone approval if:
  - Any unethical principles or practices of the project are revealed or suspected.
  - It becomes apparent that any relevant information was withheld from the REC or that information has been false or misrepresented.
  - The required annual report and reporting of adverse events was not done timely and accurately,
  - New institutional rules, national legislation or international conventions deem it necessary.

ISSUED BY:
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Date Considered: November 2022

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Appendix B

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A review on health benefits, antimicrobial and antioxidant properties of Bambara groundnut (*Vigna subterranean*)

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ABSTRACT

Bambara groundnut (*Vigna subterranean*) is an African legume that belongs to the family and subfamily of *Fabaceae* and *Faboidea*, respectively. It is becoming one of the most utilized legumes after being underutilized for many years in Africa. It is the third most significant legume after groundnut (*Arachis hypogaea*) and cowpea (*Vigna hypogea*). Bambara groundnut (BGN) is a complete food because of its richness in nutritional properties such as crude fiber, iron, protein, carbohydrate, fat and minerals. Moreover, BGN possesses antioxidants properties as it contains phytochemicals, such as tannins, flavonoids and phytic acids which possess health benefits for humans such as preventing diabetes, stroke, atherosclerosis, heart disease, cancer, Alzheimer and cardiovascular diseases. In addition, these phytochemicals extend the shelf life of food products and have antimicrobial properties which can inhibit microbial growth. This paper highlights the current findings on BGN nutritional composition, health benefits, antimicrobial and antioxidant properties. Therefore, it is advisable for food industry to exploit BGN grain to its full potential to tackle challenges of food security and nutrition globally.

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Bambara groundnut; phytochemicals; nutritional; antioxidants and antimicrobial properties

Introduction

Bambara groundnut (*Vigna subterranean*) is a legume belonging to the family and subfamily of *Fabaceae* and *Faboidea*, respectively.[1] Bambara groundnut is a legume indigenous to Africa and it is believed that its origin is between west and central Africa.[2] It grows in the wild in northern Nigeria and eastwards to southern Sudan and is currently grown across tropical Africa and to a smaller range in tropical portions of America, Asia, and Australia.[3] Bambara groundnut (BGN) is the third most significant legume after groundnut (*Arachis hypogaea*) and cowpea (*Vigna hypogea*).[4,5] It plays a crucial socio-economic impact in the semi-arid regions globally and contains sufficient protein. Therefore, if combined with some native protein sources, it could help improve the nutritional issues globally.[6,7]

Bambara groundnut grain is a proper healthy food due to its high iron (4.9–48 mg/100 g) and protein contents (18.0–24.0%) when compared to other legume products, with great amount of amino acids content, fiber (5.0–12%), fat (5.0–7.0%), carbohydrate (57.43–63.09%)calcium (95.8–99 mg/100 g), potassium (1144–1935 mg/100 g), and sodium (2.9–12.0 mg/100 g).[7,8] Bambara groundnuts diverse nutritional composition suggests that it can meet dietary needs of people globally.[9] Its high protein content maintains a greater focus on improving procedures for processing its grains and expanding food applications.[9] Bambara groundnut also contains several polyphenols such as flavonoids (medioresinol, catechin, catechin

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This article has been republished with minor changes. These changes do not impact the academic content of the article.

Appendix C

10:12

Food Science & Nutrition - Manuscript ID FSN3-2023-08-1756.R1 [email ref: SE-8-a] Inbox

WOA Admin 2023/10/31

to mpho.mashau, me, s...

31-Oct-2023

Dear Mr. Mashau:

Your revised manuscript entitled "Effect of partial mutton meat substitution with Bambara groundnut (Vigna subterranea (L.) Verdc.) flour on physicochemical properties, lipid oxidation and sensory acceptability of low-fat patties" by Ramatsetse, Kgaogelo; Ramashia, Shonisani; Mashau, Mpho, has been successfully submitted online and is presently being given full consideration for publication in Food Science & Nutrition.

Co-authors: Please contact the Editorial Office as soon as possible if you disagree with being listed as a co-author for this manuscript.

Appendix D

Editing and Proofreading Report

09 July 2022

This letter serves to confirm that I, Dr I. Ndlovu of the Department of English, Media Studies and Linguistics at the University of Venda, have proofread and edited an article titled “Bambara groundnut (Vigna subterranean): Nutritional composition, health benefits, antioxidants, antimicrobial properties, and food applications” by Kgaogelo Edwin Ramatsetse, Eugenia Shonisani Ramashia and Mpho Edward Mashau.

I carefully read through the document, focusing on proofreading and editorial issues. The recommended suggestions are clearly highlighted and can either be accepted or rejected using the Microsoft Track Changes Function.

Yours Sincerely

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Appendix E

Editing and Proofreading Report

14 August 2023

This letter serves to confirm that I, Prof. I. Ndlovu of the Department of English, Media Studies and Linguistics at the University of Venda, have proofread and edited an article titled "Effect of partial mutton meat substitution with Bambara groundnut flour on physicochemical properties, lipid oxidation and sensory acceptability of low-fat patties" by Kgaogelo Edwin Ramatsetse, Shonisani Eugenia Ramashia and Mpho Edward Mashau.

I carefully read through the document, focusing on proofreading and editorial issues. The recommended suggestions are clearly highlighted and can either be accepted or rejected using the Microsoft Track Changes Function.

Yours Sincerely

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