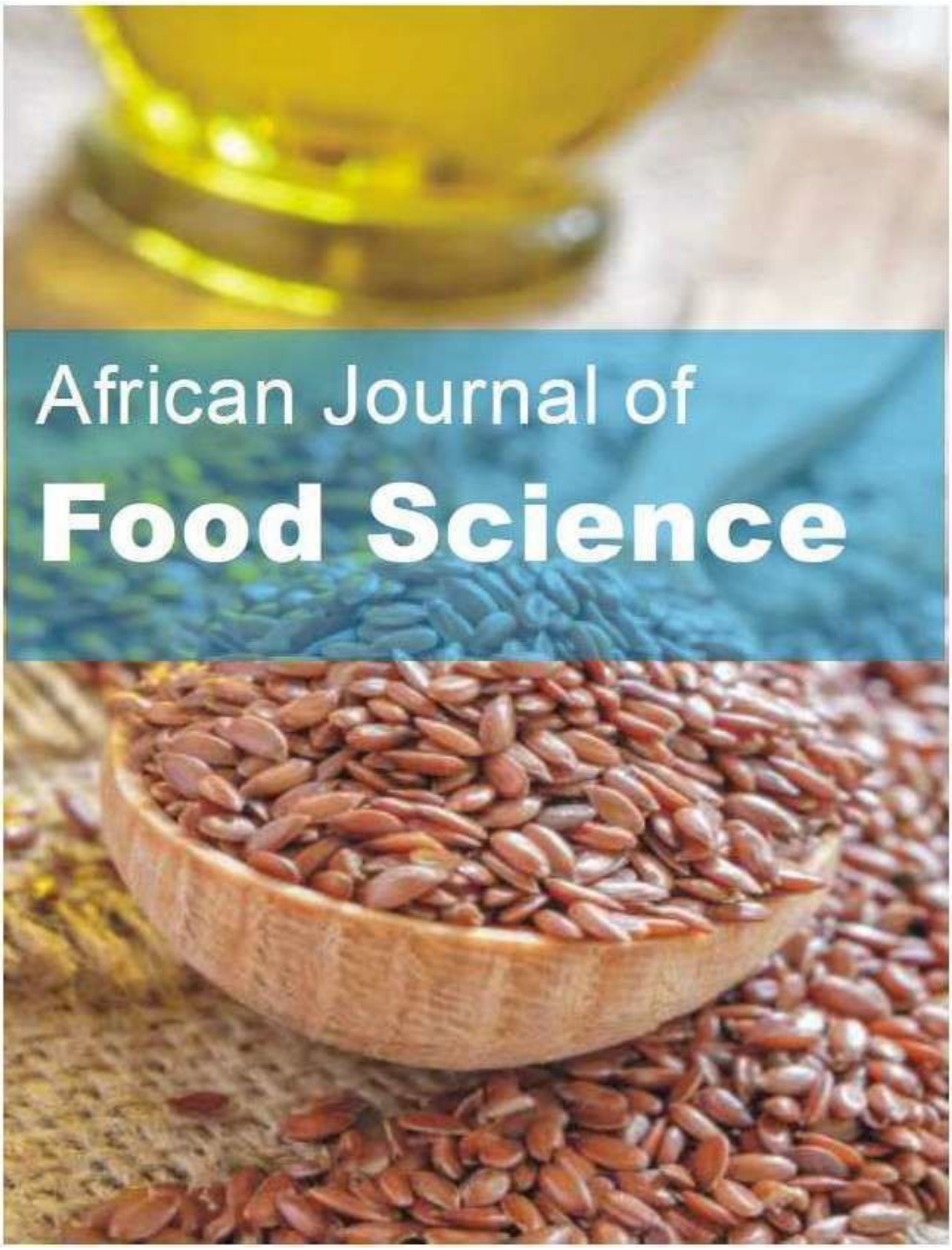
OPEN ACCESS



African Journal of Food Science

March 2022
ISSN 1996-0794
DOI: 10.5897/AJFS
www.academicjournals.org

ACADEMIC JOURNALS
expand your knowledge

About AJFS

The African Journal of Food Science (AJFS) is a peer reviewed open access journal. The journal commenced publication in September 2007. The African Journal of Food Science welcomes for publication papers that investigate and review perspectives on food engineering, handling, processing, storage, preservation, contamination and packaging; sensory analysis. Other aspects covered include food safety, microbiology, nutraceuticals, chemistry, technology and nanotechnology in addition to quality and nutritional evaluation and genetic variation of food.

Indexing

Abstracts on Hygiene and Communicable Diseases, AgBiotechNet, Agricultural Economics Database, Agricultural Engineering Abstracts, Agroforestry Abstracts, Animal Breeding Abstracts, Animal Production Database, Animal Science, Biofuels Abstracts, Botanical Pesticides, CAB Abstracts, CABI's Global Health Database, Chemical Abstracts (CAS Source Index), CNKI Scholar Crop Physiology Abstracts, Crop Science Database, Dairy Science Abstracts, Environmental Impact Environmental Science Database, Field Crop Abstracts, Forest Science, Google Scholar, Grasslands and Forage Abstracts, Horticultural Science, Horticultural Science Abstracts, Irrigation and Drainage Abstracts, Maize Abstracts, Microsoft Academic, Nutrition Abstracts and Reviews Series A: Human and Experimental, Nutrition Abstracts and Reviews Series B: Livestock Feeds and Feeding, Nutrition and Food Sciences, Ornamental Horticulture, Parasitology Database, Plant Breeding Abstracts, Plant Genetic Resources Abstracts, Plant Genetics and Breeding Database Plant Growth Regulator Abstracts, Plant Protection Database, Potato Abstracts, Poultry Abstracts Rice Abstracts, Rural Development Abstracts, Seed Abstracts, Soil Science Database, Soils and Fertilizers Abstracts, Soybean Abstracts, Sugar Industry Abstracts, Tropical Diseases Bulletin Veterinary Bulletin, Veterinary Science Database, VetMed Resource, Weed Abstracts Wheat, Barley and Triticale Abstracts, World Agricultural Economics and Rural Sociology Abstracts

Open Access Policy

Open Access is a publication model that enables the dissemination of research articles to the global community without restriction through the internet. All articles published under open access can be accessed by anyone with internet connection.

The African Journal of Food Science is an Open Access journal. Abstracts and full texts of all articles published in this journal are freely accessible to everyone immediately after publication without any form of restriction.

Digital Archiving Policy

The African Journal of Food Science is committed to the long-term preservation of its content. All articles published by the journal are preserved by Portico. In addition, the journal encourages authors to archive the published version of their articles on their institutional repositories and as well as other appropriate websites.

https://www.portico.org/publishers/ajournals/

Metadata Harvesting

The African Journal of Food Science encourages metadata harvesting of all its content. The journal fully supports and implement the OAI version 2.0, which comes in a standard XML format. See Harvesting Parameter

Memberships and Standards

Academic Journals strongly supports the Open Access initiative. Abstracts and full texts of all articles published by Academic Journals are freely accessible to everyone immediately after publication.

All articles published by Academic Journals are licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0). This permits anyone to copy, redistribute, remix, transmit and adapt the work provided the original work and source is appropriately cited.

Crossref is an association of scholarly publishers that developed Digital Object Identification (DOI) system for the unique identification published materials. Academic Journals is a member of Crossref and uses the DOI system. All articles published by Academic Journals are issued DOI.

Similarity Check powered by iThenticate is an initiative started by CrossRef to help its members actively engage in efforts to prevent scholarly and professional plagiarism. Academic Journals is a member of Similarity Check.

CrossRef Cited-by Linking (formerly Forward Linking) is a service that allows you to discover how your publications are being cited and to incorporate that information into your online publication platform. Academic Journals is a member of CrossRef Cited-by.

Academic Journals is a member of the International Digital Publishing Forum (IDPF).
The IDPF is the global trade and standards organization dedicated to the development and promotion of electronic publishing and content consumption.

Contact

Editorial Office: ajfs@academicjournals.org

Help Desk: helpdesk@academicjournals.org

Website: http://www.academicjournals.org/journal/AJFS

Submit manuscript online http://ms.academicjournals.org

Academic Journals
73023 Victoria Island, Lagos, Nigeria
ICEA Building, 17th Floor,
Kenyatta Avenue, Nairobi, Kenya.

Editors

Editorial Board Members

Table of Content

Effects of charcoal kiln and microwave oven drying techniques on the chemical and thermal characteristics of tomato and yam slices 58
Chibuzo S. Nwankwo, James T. Mbachiantim, Victor O. Olanegan, Okpomor O. Endurance, Carew E. Irene, Chigozie F. Okoyeuzu, Belay Dereje and Abebe Teshome

Effect of chitosan coatings on quality and shelf-life of chicken and quail eggs 63
Esin Derelioğlu and Özlem Turgay

Physicochemical and consumer acceptability of different particle-sized cassava strips 71
Chioma Illoh, Helen Obioma Agu, Chioke Amaefuna Okolo and Victoria Adaora Jideani

Nutritional and sensory quality of a sorghum snack supplemented with sesame and baobab fruit powder 81
David Edgar Kimani, Catherine Nkirote Kunyanga and Eliud Kahiu Ngugi

Vol. 16(3) pp. 58-62, March 2022
DOI: 10.5897/AJFS2021.2163
Article Number: AA9C2E468741
ISSN: 1996-0794

http://www.academicjournals.org/AJFS

ACADEMIC JOURNALS
expand your knowledge

African Journal of Food Science

Full Length Research Paper

Effects of charcoal kiln and microwave oven drying techniques on the chemical and thermal characteristics of tomato and yam slices

Chibuzo S. Nwankwo[1]*, James T. Mbachiantim[2], Victor O. Olanegan[1], Okpomor O. Endurance[3], Carew E. Irene[1], Chigozie F. Okoyeuzu[4], Belay Dereje[5] and Abebe Teshome[6]

[1]Department of Food Science and Technology Federal University of Agriculture Makurdi, Benue State, Nigeria.
[2]Department of Nutrition and Dietetics, College of Food Technology and Human Ecology, Federal University of Agriculture, Makurdi, Benue State, Nigeria.
[3]International Centre for Biotechnology (ICB) Under the Auspices of UNESCO, at the University of Nigeria, Nsukka, Enugu State, Nigeria.
[4]Department of Food Science and Technology, Faculty of Agriculture, University of Nigeria, Nsukka, Enugu State, Nigeria.
[5]Department Food Process Engineering, College of Engineering and Technology, Wolkite University, Ethiopia.
[6]Department of Chemical Engineering, Kombolcha Institute of Technology, Wollo University, Wollo, Ethiopia.

Received 1 December, 2021; Accepted 1 February, 2022

Most drying equipment required constant electricity, which is rarely available in Sub-Saharan African countries for local farmers. In order to reduce postharvest loss, it is important to develop and use alternative equipment that is cheap and does not require electricity. The aim of this study was to compare the charcoal kiln oven and microwave oven on the drying characteristics of tomato and yam slices, as well as the effects of these different drying techniques on the chemical parameters of tomato and yam slices. The experiment was laid out based on a completely randomized design. In the charcoal kiln, the final moisture content of dried tomato and yam slices was 16.20 and 5.70%, while in the microwave it was 12.25 and 6.60%. These differences were significant ($p<0.05$). The ash content was higher in microwave-dried tomatoes (1.35%) and kiln-dried yams (3.15%) slices. The protein and carbohydrate contents of kiln-dried tomato slices were significantly ($p<0.05$) higher than microwave-dried ones, but microwave-dried yam slices were significantly ($p<0.05$) higher than kiln-dried yam slices. The potassium and iron contents of kiln-dried yam slices were significantly ($p<0.05$) higher than microwave-dried samples. The heat transfer in microwave-dried tomato and yam slices was significantly ($p<0.05$) higher than in kiln-dried ones. The charcoal kiln oven was better at drying yam than tomato. Local farmers could benefit from charcoal kiln dryers for the drying process since they do not require power supply.

Key words: Drying, microwave, kiln, tomato, yam.

INTRODUCTION

White yam (*Dioscorea rotundata*) is an important food security crop in West Africa because it is nutritious, cost-effective, and healthy. Yam is one of the most significant sources of energy in the diet, consisting primarily of

starch but also containing some proteins, lipids, vitamin C, vital minerals, anti-aging, and fertility-promoting characteristics (Nugraheni et al., 2021). Tomato is also one of the world's most significant fruits. It is easily and widely cultivated, and can grow in a variety of soils and temperatures. Tomatoes are also high in vitamins and minerals (Arslan and Özcan, 2011; Jorge et al., 2018). Yam and tomato are perishable fruits due to their high moisture content, high respiration rates, and lack of a protective cuticle (Hattim et al., 2019; Okeke et al., 2020). Postharvest losses of yam are estimated to be more than 20%, owing primarily to fungus-caused rot during storage.

Postharvest losses have a severe impact on farmers' and dealers' income, putting food security efforts in jeopardy. As a result, yams must be consumed within a few weeks of harvesting or processed into flour by peeling, slicing, blanching, and drying (Okeke et al., 2020). Because tomatoes have such a limited shelf life, it is no surprise that a large amount of the harvest gets consumed, cooked, or processed (Jorge et al., 2018). Tomatoes, on the other hand, are highly perishable in their raw state, resulting in waste and losses during peak harvesting season (Bashir et al., 2014). It is critical to avoid these losses and wastage, especially when there is a supply and demand imbalance during the harvesting off-season (Bashir et al., 2014; Hattim et al., 2019). Tomatoes and yams can be dehydrated and sold as a substitute for fresh produce. Tomatoes and yams have been dehydrated for many years as a way of preserving them (Arslan and Özcan, 2011; Jorge et al., 2018). Drying is one of the technologies that can be utilized to generate high-quality goods while also reducing postharvest losses in tomatoes and yams. Drying, a typical food preservation technique, is an important part of food processing and can be used to create a new type of product (Mechlouch et al., 2012).

Microwaves have been widely used in food processing technologies and offered significant energy savings, with a potential reduction in drying times in addition to the inhibition of the surface temperature of the treated material (Celen and Kahveci, 2013; Figiel, 2009; Abano and Amoah, 2015), but the microwave oven is costly and required constant electricity. Electricity is rarely constant in sub-Saharan African countries, especially Nigeria. There is a need to develop and use alternative equipment, such as charcoal kiln ovens, that is cheap and cost-effective and could be accessible by farmers in rural areas in order to reduce postharvest loss (Idi et al., 2018). Charcoal kiln ovens have been used for drying all kinds of fish (Idi et al., 2018; Issa et al., 2020). However, the aim of this study was to compare the charcoal kiln oven and microwave oven on the drying characteristics of tomato and yam slices, as well as the effects of these different drying procedures on the chemical parameters of tomato and yam.

MATERIALS AND METHODS

Procurement of the sample

Fresh plum tomatoes (*Lycopersicon esculentum*) at ripe stage, uniform size, red colour and examined to exclude all virtual defects were purchased from the modern market located in Makurdi metropolis, Benue State, Nigeria. The mature white yam (*D. rotundata*) used for the study was also purchased from the modern market located in Makurdi metropolis, Benue State, Nigeria. Fresh plum tomatoes (4 kg) and white yam (10 kg) were processed for drying in the microwave and charcoal kiln oven, respectively, immediately after purchase.

Drying methods

Kiln oven drying

The charcoal kiln oven used for drying was locally fabricated with wrought iron (2 mm thickness) in the Department of Food and Technology at the Federal University of Agriculture Makurdi, Benue State, Nigeria. The charcoal kiln oven has three chambers: drying, charcoal, and fan chambers. The operation was based on heat supply by burning charcoal and air supply by a solar-powered fan. The dimensions of the charcoal kiln oven cavity were 400, 400 and 400 mm, respectively.

Microwave drying

A programmable domestic microwave oven (Arcelik ARMD 580, Turkey) with a maximum output of 700 W and 2450 MHz was used for drying experiments. The dimensions of the microwave cavity were 345, 6 340, and 6 225 mm, respectively.

Analytical methods

Sample preparation and analysis

Ripened and healthy tomatoes were sorted, washed and then sliced with a stainless steel knife to thickness of 0.005 m and area of 0.0013 m^2. The yams was peeled with a knife to separate the edible portion from the peel and then sliced uniformly to have thickness of 0.005 m and surface area of 0.0013 m^2. The tomato and yam slices were dried in charcoal kiln and microwave oven, respectively, thereafter the chemical characteristics of dried tomato and yam in both charcoal kiln and microwave oven were determined by AOAC (2010). Thermal conductivity and heat transfer of the sample was determined according to Berk (2018).

$$\text{Thermal conductivity (K)} = 0.25X_C + 0.155X_P + 0.16X_F + 0.135X_a + 0.58X_W \quad (1)$$

E-mail: toteupstar@yahoo.com. Tel: 08165444222.

Table 1. Chemical composition (dry basis) and thermal characteristics of dried tomato and yam slices.

Chemical composition (%)	Tomato			Yam		
	Fresh	Charcoal kiln dried	Microwave dried	Fresh	Charcoal kiln dried	Microwave dried
Moisture (%)	90.34^{a}±0.04	16.20^{b}±0.06	12.25^{c} ±0.03	66.30^{a}±0.06	5.70^{c}±0.01	6.60^{b} ±0.03
Ash (%)	0.54^{c}±0.06	1.30^{b}±0.08	1.35^{a}±0.03	1.58^{c}±0.05	3.15^{a}±0.03	2.60^{b}±0.03
Fat (%)	0.01^{c}±0.00	0.50^{a}±0.11	0.04^{b}±0.03	1.00^{b}±0.00	2.10^{a} ±0.03	2.10^{a} ±0.06
Fiber (%)	0.01^{c}±0.00	7.15^{b}±0.04	9.75^{a}±0.03	0.65^{c}±0.03	2.35^{a}±0.01	1.65^{b}±0.01
Protein (%)	1.65^{c}±0.01	6.64^{a}±0.03	5.69^{b}±0.01	2.63^{c}±0.04	4.38^{b}±0.03	5.26^{a}±0.01
Carbohydrate (%)	7.45^{c}±0.12	49.21^{b}±0.32	61.56^{a}±0.13	28.84^{c}±0.18	84.32^{a}± 0.08	83.79^{b}±0.14
Pro-vitamin A (mg/g)	623.8^{a}±0.14	456.5^{c}±0.14	608.6^{b}±0.28	623.7^{b}±0.28	440.7^{c}±0.28	717.6^{a}±0.14
Vitamin C (mg/g)	17.20^{a}±0.03	15.62^{b}±0.3	15.41^{c} ±0.01	5.13^{b}±0.4	8.63^{a}±0.04	8.63^{a}±0.01
Potassium (mg/g)	4.80^{c}±0.14	6.00^{b}±0.02	15.20^{a}±0.28	4.40^{c}±0.28	7.60^{a}±0.14	5.00^{b}±0.28
Magnesium (mg/g)	0.02^{c}±0.01	0.15^{a}±0.03	0.17^{b} ±0.03	0.03^{a}±0.03	0.02^{b}±0.01	0.03^{a}±0.01
Iron (mg/g)	1.26^{c}±0.03	3.06^{a}±0.03	2.57^{b}±0.03	1.38^{c}±0.01	1.96^{a}±0.01	1.59^{b}±0.01
Thermal Conductivity (W/(m.°C)	0.54^{c}	0.24^{a}	0.25^{b}	0.46^{a}	0. 25^{c}	0.26^{b}
Heat transfer (J)	ND	66.95^{b}	92.06^{a}	ND	68.86^{b}	207.66^{a}
Drying Efficiency (%)	ND	82.1^{b}	86.4^{a}	ND	91.4^{a}	90^{a}
Drying time (g/min)	ND	70^{a}	40^{b}	ND	50^{a}	24^{b}

Values are means ± standard deviation of three determinations. Values on the same row with different superscripts are significantly different (p<0.05). ND = not determined.

Where X represents mass fraction, c = carbohydrate, p = protein, f = fat, a = ash, w = water.

$$Heat\ transfer\ (q) = KA\frac{T1-T2}{z} \quad (2)$$

Where A = Area (m^2); K = Thermal conductivity (W/(m.°C); z = Thickness of the samples (m); T_1 = Initial temperature (°C); T_2 = Final temperature(°C).

Then drying time, (g/min) was determined according to Adeboye (2012);

$$\text{Drying time (g/min)} = \frac{Initialmass(g)-finalmass\ (g)}{Time\ (m)} \quad (3)$$

Drying efficiency was calculated according to Mercer and Eng (2007) and Matuam et al. (2015) as the ratio of energy E_1 required to evaporate all the water in the sample to the energy E_2 used to evaporate water from the sample during drying.

$$E_1 = M_a \times L \quad (4)$$

$$E_2 = M_b \times L \quad (5)$$

$$DryingEfficiency\ (\%) = \frac{E_2}{E_1} \times 100 \quad (6)$$

Where $M_a(L/kg) = Massofwater\ contained\ in\ freshfood\ sample$; $M_b(L/kg) = Mass\ ofwaterevaporated\ from\ fresh\ food\ sample$
$L\left(\frac{J}{kg}\right) = Latent\ heat\ of\ vaporization\ of\ water.$

RESULTS AND DISCUSSION

Chemical composition and thermal characteristics of dried tomato and yam slices

Table 1 showed that the moisture content of tomato and yam decreased significantly (p<0.05) after drying in a charcoal kiln (16.20 and 5.70%) and a microwave (12.25 and 6.60%) ovens. The present observation agreed with that of Nugraheni et al. (2021), who worked on the effect of various drying methods on the physical characteristics of purple yam powder. Lower moisture content is suitable for extended shelf life (Nugraheni et al., 2021). Surendar et al. (2018) reported that moisture content was not significantly affected by the drying method, which was contrary to the results obtained from this study. The ash content of the dried samples was found to be high in microwave dried tomato (1.35%) and charcoal dried yam (3.125%). The low ash (0.54%) value for the fresh tomato strongly suggested that the tomato is not a good source of ash (Haile, 2013; Ramya et al., 2017).

The fat content of charcoal kiln and microwave dried tomato and yam slices ranged from 0.04 to 2.10%. The results obtained for both charcoal kiln and microwave dried yam were similar to the reports of Falade et al. (2007) and Nugraheni et al. (2021). The fibre content of tomato slices was found to be 7.15% for charcoal kiln ovens and 9.75% for microwave ovens. The same result was reported by Surendar et al. (2018). The fibre content of yam slices was found to be 2.35% for charcoal kiln oven and 1.65% for microwave oven, respectively. The higher fat and fiber content in dried tomato and yam slices compared to fresh tomato and yam slices could be attributed to the lower moisture content (Yusufe et al., 2017; Surendar et al., 2018). The protein content of tomato slices was 6.64% for the charcoal kiln oven and 5.69% for the microwave oven, while the yam slice was 4.38% for the charcoal kiln oven and 5.26% for the microwave oven, respectively. The significant (p<0.05) increase in protein content of tomato and yam slices may

be due to the concentration of nutrients because of a significant ($p<0.05$) decrease in moisture content after drying (Surendar et al., 2018).

The carbohydrate content of dried tomato increased after drying with a microwave (61.56%) and a charcoal kiln oven (84.32%). The pro-vitamin A content of microwave dried tomatoes and yams was significantly ($p<0.05$) higher than charcoal-dried tomatoes and yam slices. The vitamin C content of microwave and kiln-dried tomato and yam slices was not significant ($p>0.05$), but it is important to note that drying with microwave and kiln oven affected the vitamin C content of the tomato and yam slices when compared to fresh tomato and yam slices. This could be due to the destruction of ascorbic acid content by heat (Dauda et al., 2019). Charcoal kiln dried tomato slices had significantly ($p<0.05$) higher magnesium and iron content than microwave dried tomatoes, but were low in potassium content. Arslan and Özcan (2011) and Agoreyo et al. (2011) reported similar findings. Charcoal kiln dried yam slices had significantly ($p<0.05$) higher potassium and iron content than microwave dried yam slices but were low in magnesium content. The oven drying method's wave strength may cause damage to these minerals (Arslan and Özcan, 2011). The thermal conductivity of fresh tomatoes and yams was significantly ($p<0.05$) higher than microwave and charcoal kiln dried tomato and yam slices. It was observed that the higher the moisture content, the higher the thermal conductivity and vice versa. A reduction in moisture content caused a substantial reduction in thermal conductivity. This has important implications for unit operations that involved the conduction of heat through food to remove water (Fellows, 2009). The heat transfer in microwave dried tomato and yam was significantly ($p<0.05$) higher compared to kiln dried tomato and yam slices. The microwave oven has significantly ($p<0.05$) higher drying efficiency (86.4 and 90.00%) and less drying time (40 and 24 min) than the charcoal kiln oven for both the tomato and yam slices, respectively.

Conclusion

The two drying techniques showed a significant ($p<0.05$) effect on the chemical composition and thermal characteristics of tomato and yam slices. Charcoal kiln driers were better at drying yams than tomato in terms of chemical composition. The heat transfer in microwave dried tomato and yam slices was significantly ($p<0.05$) higher compared to kiln dried tomato and yam slices. Although, the microwave oven has significantly ($p<0.05$) higher drying efficiency and less drying time than the charcoal kiln oven for both the tomato and yam slices, the charcoal oven kiln dryer could be useful to local farmers in terms of cost and accessibility to dry their produce and reduce postharvest loss, especially in Sub-Saharan African countries where there is no constant electricity to use the microwave oven.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abano EE, Amoah RS (2015). Microwave and blanch-assisted drying of white yam (*Dioscorea rotundata*). Food Science and Nutrition 3(6):586-596.

Adeboye OA (2012). Effect of some drying parameters on the drying rate and proximate composition of green plantain (*Musa paradisiaca*). Master's Degree Thesis (Unpublished) Submitted to Department of Agricultural and Biosystems Engineering, University of Ilorin, Nigeria.

Agoreyo BO, Akpiroroh O, Orukpe OA, Osaweren OR, Owabor CN (2011). The effects of various drying methods on the nutritional composition of *Musa paradisiaca*, *Dioscorea rotundata* and *Colocasia esculenta*. Asian Journal of Biochemistry 6(6):458-464.

AOAC (2010). Official Methods of Analysis. Association of Official Analytical Chemists. 18th ed. AOAC International, Gaithersburg, MD.

Arslan D, Özcan MM (2011) Drying of tomato slices: Changes in drying kinetics, mineral contents, antioxidant activity and color parameters. CyTA - Journal of Food 9(3):229-236.

Bashir N, Bhat MA, Dar BN, Shah MA (2014). Effect of different drying methods on the quality of tomatoes. Advances in Food Sciences 36(2):65-69.

Berk Z (2018). Food Process Engineering and Technology (3rd Edition), Academic Press, London.

Celen S, Kahveci K (2013). Microwave drying behaviour of tomato slices. Czech Journal of Food Sciences 31(2):132-138.

Dauda A, Abiodun O, Salami T, Akintayo O (2019). Chemical and microbiological evaluation of dried tomato slices for Nigerian system. Global Journal of Nutrition and Food Science 1(5):1-4.

Falade KO, Olurin TO, Ike, EA, Aworh OC (2007). Effect of pretreatment and temperature on air-drying of *Dioscorea alata* and *Dioscorea rotundata* slices. Journal of Food Engineering 80(4):1002-1010.

Fellows PJ (2009). Food processing technology: principles and practice. Elsevier.

Figiel A (2009). Drying kinetics and quality of vacuum-microwave dehydrated garlic cloves and slices. Journal of Food Engineering 94(1):98-104.

Haile MA (2013). Microwave-vacuum drying effect on drying kinetics, lycopene and ascorbic acid content of tomato slices. Journal of Stored Products and Postharvest Research 4(1):11-22.

Hattim MMM, Maissa MAA, Dina OMA (2019). Effects of natural and artificial drying methods on the nutritional value and functional properties of vegetables grown in Sudan. Pakistan Journal of Nutrition 18:800-804.

Idi OAM, Ogori AF, Omoniyi SA (2018). Design and fabrication of pneumatic charcoal kiln drying characteristics and residence temperature for cat fish smoking. Journal of Nutritional Health and Food Engineering 8(1):9-12.

Issa WA, Fatile OE, Abdulmumuni B, Ologunye OB, Okpara IN (2020). Design and Fabrication of a Charcoal Fish Smoking KILN. International Journal of Recent Technology and Engineering 9(1):1487-1495.

Jorge A, Sauer Leal E, Sequinel R, Sequinel T, Kubaski ET, Tebcherani SM. (2018). Changes in the composition of tomato powder (*Lycopersicon esculentum* Mill) resulting from different drying methods. Journal of Food Processing and Preservation 42(5):e13595.

Matuam B, Edoun M, Kuitche A, Zeghmati B (2015). Experimental evaluation of the thermal performance of dryer airflow configuration. International Journal of Energy Engineering 5(4):80-86.

Mechlouch RF, Elfalleh W, Ziadi M, Hannachi H, Chwikhi M, Aoun AB, Elakesh E, Cheour F (2012). Effect of different drying methods on the physico-chemical properties of tomato variety 'Rio Grande'. International Journal of Food Engineering 8(2).

Mercer DG, Eng P (2007). An intermediate course in food dehydration and drying. Department of Food Science, University of Guelph,

Ontario, Canada.
Nugraheni NF, Karyadi JNW, Tarwaca SN, Indrasari YP, Albyan R, Setiyadi I, Ayuni D (2021). Effect of various drying methods on the physical characteristics of purple yam powder. IOP Conference Series: Earth and Environmental Science 644(1):012079.
Okeke C, Eje BE, Eze PC (2020). Drying characteristics of yam varieties: A comparative analysis.Poljoprivredna Tehnika 45(1):20-37.
Ramya HN, Ashwini A, Veena B, Fazal.AA, Hanumanthraju KN (2017). Influence of different drying techniques on dehydrated tomato powder. International Journal of Creative Research Thoughts 5(3):474-482.
Surendar J, Shere DM, Shere PD (2018). Effect of drying on quality characteristics of dried tomato powder. Journal of Pharmacognosy and Phytochemistry 7(2):2690-2694.
Yusufe M, Mohammed A, Satheesh N (2017). Effect of drying temperature and duration on nutritional quality of cochoro variety tomato (*Lycopersicon esculentum* L.). Annals of Food Science and Technology 18(2):145-152.

Vol. 16(3) pp. 63-70, March 2022
DOI: 10.5897/AJFS2021.2158
Article Number: 0590B5268743
ISSN: 1996-0794

http://www.academicjournals.org/AJFS

ACADEMIC JOURNALS
expand your knowledge

African Journal of Food Science

Full Length Research Paper

Effect of chitosan coatings on quality and shelf-life of chicken and quail eggs

Esin Derelioğlu[1] and Özlem Turgay[2]*

[1]Bioengineering, Kahramanmaras Sutcu Imam University, Kahramanmaras, Turkey.
[2]Food Engineering, Kahramanmaras Sutcu Imam University, Kahramanmaras, Turkey.

Received 1.December, 2021; Accepted 21 February, 2022

In this study, chitosan-coatings were prepared with acetic, lactic, propionic, gallic and caffeic acids and used for coating chicken and quail eggs to understand their effect on the quality and shelf-life of chicken and quail eggs. Shelf-life study of (weight loss, Haugh unit, yolk index, albumen pH, mineral levels and shell breaking strength) the coating formulations were investigated for 4 weeks. All chitosan coated chicken and quail egg samples showed greater interior (weight loss, Haugh unit, yolk index, albumen pH) and exterior quality (shell breaking strength) than non-coated samples ($p<0.05$).

Key words: Chitosan, phenolic substances, chicken egg, quail egg, shelf-life.

INTRODUCTION

For the past decades, in food packaging, the manufacturing and use of plastic films have grown quickly resulting in serious environmental concerns as resistance to degradation (Muscat et al., 2012). Consumers preferred biodegradable materials in terms of reducing the environmental difficulties related with food packaging. Biopolymer polymers as a raw material for food packaging and preservation have been the subject of research (Persin et al., 2011). Because of its ability to minimize moisture and scent loss, solute movement, water absorption in the food matrix, and oxygen penetration, edible and biodegradable films could be applied as a substitute for synthetic packaging materials (Aider, 2010).

Researches and developments in active food packaging have been focused on bio-based functional packaging materials incorporating natural active compounds and ingredients (Leceta et al., 2013; van den Broek et al., 2015; Madureira et al., 2015). Chitosan is a cationic linear polysaccharide with a variable degree of N-acetylation derived from chitin and is widely used in agriculture, food, biomedicine and environmental industry due to the positive charges on its amino groups and the presence of other multiple functional groups (Ding et al., 2014; Junter et al., 2016). Chitosan is the second most abundant biopolymer in nature. It has been determined to have significant film-forming abilities as well as other advantageous properties such as biodegradability, biocompatibility, low oxygen permeability coefficients, good mechanical properties, muco adhesiveness, and derivability from low-cost biomass (Wu et al., 2013; Szymanska and Winnicka, 2015). In addition, chitosan

*Corresponding author. E-mail: ozlem@ksu.edu.tr. Tel: +903443002083.

has a great potential to be used as film material due to its non-toxicity, low permeability to oxygen, biocompatibility and excellent film forming ability under acidic conditions (Bonilla et al., 2014), also antimicrobial and antifungal properties against various groups of pathogenic and spoilage microorganisms (Derelioğlu and Turgay, 2019; Tan et al., 2015).

The chicken egg has almost complete balance of essential nutrients with protein, vitamins, minerals and fatty acids with great biological value with the lowest cost for the low-income population (Menezes et al., 2012). The loss of moisture and carbon dioxide via the shell pores causes quality changes in albumen and yolk as well as weight loss of eggs during storage (Wardy et al., 2011). Film coatings can be inhibited moisture, gas, and aroma transfer from the shell pores. For example, chitosan coating can be preserved the internal quality of eggs without affecting consumer acceptance (Kim et al., 2009).

In this study we aimed to investigate the synergistic effect of chitosan coating prepared with acetic, lactic, propionic, gallic and caffeic acids, on the shelf life of chicken and quail eggs. The objective was to study the effects of different formulations of coatings on the physical, structural properties of chicken and quail eggs.

MATERIALS AND METHODS

In this study, chicken eggs were obtained from Kahramanmaraş Sütçü Imam University Agricultural Faculty Research and Application Farm, Turkey and quail eggs were obtained from a local producer. All the eggs were obtained daily. The study was conducted in food engineering laboratory of Kahramanmaraş Sütçü Imam University, Turkey.

Shrimp shell chitosan was obtained from the (deacetylation grade was 75%) Sigma (C3646). Chitosan was dissolved by using acetic acid (Sigma, 320099), lactic acid (Sigma, 69775) and propionic acid (Sigma, 402907). Gallic acid (Merck, 1.01347.0500) and caffeic acid (Acros, 114930250) were used in the coating formulations as phenolic materials. Chitosan solutions were prepared by dissolving 3 g of chitosan in 100 ml distilled water that containing equally added as 1% of organic acids (AA: acetic acid, LA: lactic acid, PA: propionic acid) and 1 g/chitosan phenolic compounds gallic acid (AA+GA: acetic acid with gallic acid, LA+GA: lactic acid with gallic acid, PA+GA: propionic acid with gallic acid), caffeic acid (AA+CA: acetic acid with caffeic acid, LA+CA: lactic acid with caffeic acid, PA+CA: propionic acid with caffeic acid). The solution was heated (40°C) and agitated constantly for 45 min. Finally, polyethylene glycol added to the solution for elasticity (0.25 ml/g chitosan) and agitated 15 min (No et al., 2002).

Coating treatment and storage of eggs

Eggs were coated in chitosan solution by dipping and allowed to dry. Coating treatment was made two times. After coating, the eggs were allowed to dry before being placed on cardboard egg racks with the little end down and stored at room temperature (24±2°C) (Kim et al., 2009). For determination of weight loss, Haugh unit, yolk index, albumen pH, shell strength and albumen viscosity ten replicates per each treatment were taken weekly for up to 4 weeks at 24±2°C.

Determination of weight loss, Haugh unit, yolk index, albumen pH, shell strength and albumen viscosity

Weight loss (%) of the eggs was calculated according to Alleoni and Antunes (2004). The height of albumen and yolk was measured with a tripod micrometer (Model S-6428, B.C. Ames Inc., Melrose, MA, USA). The yolk width was measured with a digital calliper (General Tools & Instruments, New York, NY, USA). The Haugh unit was calculated according to described by Alleoni and Antunes (2004). The yolk index was calculated as yolk height/yolk width (Bhale et al., 2003). After measurement of Haugh unit and yolk index, the albumen was separated from the yolk. The thin and thick albumen were mixed thoroughly prior to measuring pH with a pH meter. For each coating group, 20 chicken eggs and 60 quail eggs were broken and the part of the albumen was separated from the yolk and placed in the viscometer tube. Measurements were carried out at 20°C at a speed of 30 rpm using the L62 heading. The first measurement was recorded as 20 s and the second measurement was recorded as millipascal seconds from 10 s rotation of the head. Torque was applied between 10-100%.

Mineral analyses

Mineral analyses of the samples were done according to EPA method (1994).

Shell breaking strength

Shell breaking resistance analysis, the strength of the egg, which proved to be a criterion is resistance against breaking. Measured with a texture analyzer (STM-1, Santam Co., Tehran, Iran), kg/m^2 is expressed as (Ezazi et al., 2021).

Statistical analysis

For internal and external quality of chicken and quail eggs, mean ± standard deviation values were reported based on ten measurements (five eggs/replicate) per treatment. One-way analysis of variance of data was carried out using the IBM SPSS Statistics software (v.24). The difference between pairs of means was resolved by means of confidence intervals using Duncan's tests; the level of significance was set at $P < 0.05$.

RESULTS AND DISCUSSION

Weight loss

The weight loss of the control (non-coated) and coated of chicken eggs with chitosan during 4-week of storage at 24±2°C was shown in Table 1. The weight loss of chicken eggs was significantly ($P<0.05$) increased with storage periods. Non-coated chicken eggs showed more weight loss than all coated ones during of storage. This might be due to the evaporation of water and carbon dioxide from pores (Kumari et al., 2020).

Overall, storage periods progressively increased the weight loss; however, the extent of coated quail eggs was lesser than non-coated quail eggs (Table 1). For all coated quail eggs, weight loss gradually with increase in the storage periods. Significant variations of weight loss existed coated and non-coated quail eggs ($P<0.05$).

Table 1. Weight loss (%) of chicken and quail eggs at room temperature (24±2°C).

Weight loss of chicken eggs at 24±2°C				
Coating groups	**1. Week**	**2. Week**	**3. Week**	**4. Week**
Control	1.346±0.221$^{d.A}$	2.728±0.514$^{e.B}$	3.767±0.503$^{e.C}$	5.141±0.641$^{d.D}$
Ch-AA	0.853±0.150$^{b.A}$	1.573±0.213$^{ab.B}$	2.275±0.291$^{a.C}$	3.218±0.292$^{a.D}$
Ch-LA	0.627±0.121$^{a.A}$	1.585±0.194$^{ab.B}$	2.330±0.343$^{a.C}$	3.089±0.599$^{a.D}$
Ch-PA	0.789±0.114$^{b.A}$	1.601±0.176$^{ab.B}$	2.470±0.221$^{ab.C}$	3.419±0.184$^{ab.D}$
Ch-AA-GA	0.756±0.083$^{ab.A}$	1.490±0.126$^{a.B}$	2.322±0.190$^{a.C}$	3.411±0.195$^{ab.D}$
Ch-LA-GA	0.708±0.152$^{ab.A}$	1.649±0.293$^{ab.B}$	2.499±0.391$^{ab.C}$	3.421±0.543$^{ab.D}$
Ch-PA-GA	1.052±0.176$^{c.A}$	2.068±0.288$^{d.B}$	2.940±0.453$^{cd.C}$	3.963±0.492$^{c.D}$
Ch-AA-CA	1.021±0.124$^{c.A}$	1.972±0.165$^{cd.B}$	2.991±0.385$^{cd.C}$	4.030±0.699$^{c.D}$
Ch-LA-CA	0.992±0.180$^{c.A}$	2.016±0.233$^{cd.B}$	3.063±0.265$^{d.C}$	4.066±0.290$^{c.D}$
Ch-PA-CA	0.830±0.135$^{b.A}$	1.781±0.199$^{bc.B}$	2.710±0.214$^{bc.C}$	3.759±0.299$^{bc.D}$
Weight loss of quail eggs at 24±2°C				
Coating Groups	**1. Week**	**2. Week**	**3. Week**	**4. Week**
Control	4.343±0.292$^{c.A}$	9.459±0.600$^{b.B}$	14.540±0.687$^{b.C}$	17.276±0.695$^{c.D}$
Ch-AA	1.499±0.139$^{ab.A}$	3.253±0.548$^{a.B}$	6.097±0.304$^{a.C}$	8.522±0.696$^{b.D}$
Ch-LA	1.434±0.253$^{ab.A}$	3.619±0.744$^{a.AB}$	6.201±1.887$^{a.BC}$	8.195±2.191$^{b.C}$
Ch-PA	1.118±0.254$^{a.A}$	2.714±0.650$^{a.A}$	4.667±0.984$^{a.B}$	7.281±1.535$^{ab.C}$
Ch-AA-GA	1.155±0.074$^{a.A}$	2.721±0.202$^{a.B}$	4.558±0.763$^{a.C}$	6.659±0.547$^{ab.D}$
Ch-LA-GA	1.197±0.022$^{ab.A}$	2.928±0.179$^{a.B}$	4.805±0.244$^{a.C}$	6.510±0.455$^{ab.D}$
Ch-PA-GA	1.445±0.277$^{ab.A}$	3.629±0.614$^{a.B}$	6.062±1.265$^{a.C}$	8.312±1.427$^{b.D}$
Ch-AA-CA	1.324±0.195$^{ab.A}$	3.168±0.455$^{a.B}$	5.204±1.038$^{a.C}$	7.381±1.285$^{ab.D}$
Ch-LA-CA	1.577±0.136$^{b.A}$	3.528±0.333$^{a.B}$	5.167±0.467$^{a.C}$	5.561±0.494$^{a.C}$
Ch-PA-CA	1.370±0.297$^{ab.A}$	3.125±0.499$^{a.B}$	4.740±0.787$^{a.BC}$	6.231±1.505$^{ab.C}$

Different letters indicate significant difference (P<0.05), small letters: the difference by the treatment during the week, large letters: the difference between the treatment during 4 weeks, ±: standard deviations of 10 measurements.

Without exception, all quail eggs coated with Ch-LA-CA had less weight loss than non-coated quail eggs throughout 4 weeks of storage (P<0.05).

Weight loss of eggs during storage is caused by the evaporation of water and loss of carbon dioxide from the albumen through the shell. According to FAO (2003), a weight loss of 2-3% is common in marketing eggs and is hardly noticeable to consumers. This study demonstrated that chitosan coating may be offered a protective barrier against transfer carbon dioxide and moisture through the eggshell even when stored at 24±2°C, thus minimizing weight loss and extending the shelf life of eggs. Torrico et al. (2011), stated that mineral oil coating significantly reduced the weight loss (0.72 to 1.20%) of coated chicken eggs, compared to (4.17%) non-coated chicken eggs, after 5 weeks of storage at 4°C. Bhale et al. (2003) reported that chicken eggs coated with chitosan storage at 25°C showed a lower weight loss (6.8%) compared with that of non-coated chicken eggs (7.84%). Eggs held at 25°C for 8 weeks lost 14.50% of their weight, according to Ezazi et al. (2021).

Haugh unit

The gelatinous structure of thick albumen ultimately deteriorates during egg storage, ending in thin albumen. The Haugh unit is a measurement of albumen quality that is based on the weight of the egg and the thickness of the thick albumen. The greater Haugh unit value, the better the albumen quality of eggs. Changes in the Haugh unit of non-coated and coated chicken eggs during 4 weeks of storage at 24±2°C were presented in Table 2. Compared with non-coated chicken eggs, coated chicken eggs had significantly greater Haugh units (P<0.05) throughout 4 weeks of storage. Generally, the Haugh unit decreased with increasing storage periods. Non-coated chicken eggs and coated with Ch-AA-GA and Ch-PA-GA chicken eggs had no significant differences at first week (P>0.05). However, at the other weeks there were significant differences between coated and non-coated chicken eggs. During storage Haugh unit of coated chicken eggs were higher than non-coated chicken eggs.

The utmost drop in Haugh unit occurred during the second week of storage for all coated quail eggs. Significant differences were observed (P<0.05) between coated and non-coated quail eggs, except first week. The Haugh unit of Ch-LA after 4 weeks of storage was at the highest level (84.499± 1.266). Haugh unit of coated quail eggs main effects including storage period and initial albumen quality were significant (P<0.05) but in the third

Table 2. Haugh unit of chicken and quail eggs at room temperature (24±2°C).

Haugh unit of chicken eggs at 24±2°C					
Coating groups	**0 Week**	**1 Week**	**2 Week**	**3 Week**	**4 Week**
Control	93.545±6.075^{E}	84.003±4.282$^{a.D}$	73.550±4.112$^{a.C}$	66.808±6.490$^{a.B}$	57.604±7.248$^{a.A}$
Ch-AA	93.545±6.075^{B}	90.660±2.786$^{cd.B}$	91.573±2.443$^{c.B}$	83.654±3.434$^{c.A}$	81.914±4.277$^{b.A}$
Ch-LA	93.545±6.075^{C}	91.275±1.953$^{d.BC}$	83.669±5.067$^{b.A}$	88.792±3.279$^{d.B}$	80.283±4.231$^{b.A}$
Ch-PA	93.545±6.075^{C}	92.073±2.069$^{d.C}$	83.541±4.394$^{b.B}$	83.640±4.441$^{c.B}$	77.516±4.768$^{b.A}$
Ch-AA-GA	93.545±6.075^{D}	86.668±3.857$^{ab.C}$	84.469±3.644$^{b.BC}$	78.281±3.961$^{b.A}$	80.118±6.134$^{b.AB}$
Ch-LA-GA	93.545±6.075^{C}	87.599±2.881$^{bc.B}$	84.676±2.362$^{b.AB}$	84.888±5.029$^{cd.AB}$	81.171±2.543$^{b.A}$
Ch-PA-GA	93.545±6.075^{C}	86.686±4.156$^{ab.B}$	84.050±4.376$^{b.B}$	82.983±3.444$^{c.B}$	78.458±5.143$^{b.A}$
Ch-AA-CA	93.545±6.075^{D}	90.833±3.048$^{d.CD}$	86.773±4.802$^{b.BC}$	82.301±5.637$^{bc.AB}$	78.674±5.769$^{b.A}$
Ch-LA-CA	93.545±6.075^{D}	89.442±3.853$^{bcd.CD}$	85.541±3.148$^{b.BC}$	82.133±3.971$^{bc.AB}$	80.518±5.419$^{b.A}$
Ch-PA-CA	93.545±6.075^{D}	88.895±2.511$^{bcd.C}$	86.969±2.603$^{b.BC}$	84.323±4.397$^{c.AB}$	80.988±5.883$^{b.A}$
Haugh unit of quail eggs at 24±2°C					
Coating groups	**0 Week**	**1 Week**	**2 Week**	**3 Week**	**4 Week**
Control	89.247±2.108^{C}	76.219±1.830$^{a.AB}$	78.194±2.536$^{a.B}$	69.869±2.554$^{a.A}$	73.536±6.837$^{a.AB}$
Ch-AA	89.247±2.108^{C}	85.823±0.753$^{bc.BC}$	80.891±1.497$^{ab.A}$	83.945±3.946$^{b.AB}$	83.985±2.593$^{b.AB}$
Ch-LA	89.247±2.108^{B}	87.103±1.360$^{bc.B}$	84.092±0.441$^{bcd.A}$	83.517±0.571$^{b.A}$	84.499±1.266$^{b.A}$
Ch-PA	89.247±2.108^{AB}	90.861±0.414$^{d.B}$	85.135±3.030$^{cd.A}$	83.856±3.673$^{b.A}$	84.496±3.840$^{b.A}$
Ch-AA-GA	89.247±2.108^{B}	88.465±2.106$^{cd.B}$	84.716±1.670$^{cd.A}$	86.672±0.323$^{b.AB}$	83.506±2.295$^{b.A}$
Ch-LA-GA	89.247±2.108^{C}	86.603±2.995$^{bc.BC}$	84.643±1.880$^{cd.AB}$	84.743±2.208$^{b.AB}$	81.681±1.069$^{b.A}$
Ch-PA-GA	89.247±2.108^{B}	83.622±2.581$^{b.A}$	85.100±1.656$^{cd.A}$	83.388±1.396$^{b.A}$	83.626±2.021$^{b.A}$
Ch-AA-CA	89.247±2.108^{B}	89.253±0.959$^{cd.B}$	85.283±1.214$^{cd.A}$	83.388±2.236$^{b.A}$	84.341±2.016$^{b.A}$
Ch-LA-CA	89.247±2.108^{B}	85.756±2.913$^{bc.AB}$	82.535±2.873$^{bc.A}$	84.276±1.104$^{b.A}$	83.235±1.681$^{b.A}$
Ch-PA-CA	89.247±2.108^{B}	87.151±0.701$^{bc.B}$	86.774±0.993$^{d.B}$	83.404±1.956$^{b.A}$	81.606±1.840$^{b.A}$

Different letters indicate significant difference ($p<0.05$), small letters: the difference by the treatment during the week, large letters: the difference between the treatment during 4 weeks, ±: standard deviations of 10 measurements.

and fourth week there were no significant differences between coated groups of quail eggs ($P>0.05$). Throughout storage of eggs, changes in albumen quality may be occurred primarily due to storage conditions such as time and temperature.

This study shows that all chitosan coating formulations were effective in preserving the albumen quality of chicken and quail eggs. Alleoni and Antunes (2004), reported that chicken eggs coated with whey protein the quality of Haugh unit (A> 55 HU) and non-coated chicken eggs the quality of Haugh unit C (C <30 HU) during storage for 4 weeks.

Several studies have shown that HU decreased as storage duration increases, and that the usage of coatings delayed this decline (Pires et al., 2020). Whey protein isolate, sodium montmorillonite nanoparticles, and sodium metabisulfite were used by Soares et al. (2021). The results demonstrated an 18.33% difference in HU between non-coated and coated eggs after the first week of storage. Between the beginning (7 days) and the end (35 days) of the experimental period, Oliveira et al. (2020) found that HU variation in pectin-coated eggs (86.84) was lower than in uncoated eggs (83.01).

Yolk index

A yolk index value is an indication of freshness of eggs and calculated as yolk height/yolk width. A decrease in a yolk index value during storage indicated a progressive weakening of the vitelline membranes and liquefaction of the yolk caused mainly by diffusion of water from the albumen. Table 3 showed that the changes in yolk index of control and chitosan coated chicken eggs during 4 weeks of storage at 24±2°C. Overall, the yolk index decreased with increasing storage period. Compared with the non-coated chicken eggs, chitosan coated eggs irrespective of formulation of coating, showed significantly higher yolk index during storage. When compared to uncoated eggs, Pires et al. (2019), found that eggs coated with RPC + propolis had the highest yolk indexes (0.37) at the end of 6 weeks of storage (0.33). When Yüceer and Caner (2020), tested that several coatings based on chitosan, lysozyme, and ozone on eggs stored for 6 weeks, they found that coated eggs had higher YI values than untreated eggs. As a result, it is certain that the coatings enhanced in the preservation of the yolk's integrity while storage.

Table 3. Yolk index of chicken and quail eggs at room temperature (24±2°C).

Yolk index of chicken eggs at 24±2°C					
Coating groups	**0 Week**	**1 Week**	**2 Week**	**3 Week**	**4 Week**
Control	43.512±4.173^{D}	30.990±1.377^{a,C}	19.150±1.274^{a,B}	15.330±0.242^{a,A}	14.118±0.554^{a,A}
Ch-AA	43.512±4.173^{D}	38.390±2.297^{c,C}	30.058±1.086^{cd,B}	24.345±1.861^{b,A}	20.992±2.146^{b,A}
Ch-LA	43.512±4.173^{C}	33.624±1.926^{abc,B}	32.007±3.738^{d,B}	22.929±1.971^{b,A}	22.692±1.279^{bc,A}
Ch-PA	43.512±4.173^{C}	36.876±4.459^{bc,B}	27.826±2.310^{bc,A}	23.449±1.408^{b,A}	25.123±2.922^{cd,A}
Ch-AA-GA	43.512±4.173^{C}	34.615±1.564^{abc,B}	26.232±1.925^{b,A}	23.629±0.948^{b,A}	22.685±2.546^{bc,A}
Ch-LA-GA	43.512±4.173^{D}	31.367±1.008^{a,C}	27.758±1.926^{bc,BC}	24.094±0.888^{b,AB}	22.135±0.910^{bc,A}
Ch-PA-GA	43.512±4.173^{C}	33.018±0.616^{ab,B}	29.731±0.878^{cd,B}	24.879±0.788^{b,A}	23.096±0.578^{bc,A}
Ch-AA-CA	43.512±4.173^{D}	36.239±5.005^{abc,C}	29.453±1.373^{bcd,B}	24.530±1.897^{b,AB}	22.587±2.179b^{c,A}
Ch-LA-CA	43.512±4.173^{C}	38.005±4.005^{bc,B}	31.171±0.612^{cd,A}	29.041±0.773^{c,A}	26.750±2.012^{d,A}
Ch-PA-CA	43.512±4.173^{C}	38.409±0.566^{c,B}	30.981±1.063^{cd,A}	29.219±1.479^{c,A}	27.132±1.557^{d,A}
Yolk index of quail eggs at 24±2^{0}C					
Coating groups	**0 Week**	**1 Week**	**2 Week**	**3 Week**	**4 Week**
Control	46.276±3.772^{C}	47.317±3.429^{e,C}	40.066±0.868^{ab,B}	37.903±2.693^{a,B}	33.502±2.297^{a,A}
Ch-AA	46.276±3.772^{B}	46.391±1.477^{de,B}	45.842±1.746^{d,B}	41.772±2.777^{cd,A}	42.431±2.171^{e,A}
Ch-LA	46.276±3.772^{B}	45.988±1.493^{cde,B}	42.997±2.710^{c,A}	42.321±1.916^{d,A}	40.683±1.767^{de,A}
Ch-PA	46.276±3.772^{C}	46.870±1.517^{e,C}	42.044±2.007^{bc,B}	41.422±3.304^{bcd,AB}	39.258±2.085^{cd,A}
Ch-AA-GA	46.276±3.772^{C}	44.003±1.663^{b,BC}	43.175±3.233^{c,B}	40.276±1.864^{bcd,A}	38.986±1.542^{cd,A}
Ch-LA-GA	46.276±3.772^{C}	44.166±2.666^{bc,BC}	42.890±2.692^{c,B}	39.547±1.771^{abc,A}	40.381±2.610^{d,A}
Ch-PA-GA	46.276±3.772^{D}	42.062±1.681^{a,C}	39.505±1.415^{a,B}	39.090±2.560^{ab,B}	36.701±2.453^{b,A}
Ch-AA-CA	46.276±3.772^{C}	44.485±1.735^{bcd,C}	40.190±1.235^{ab,B}	40.286±2.178^{bcd,B}	37.975±1.753^{bc,A}
Ch-LA-CA	46.276±3.772^{C}	42.907±1.834^{ab,B}	41.502±1.991^{abc,AB}	39.519±1.623^{abc,A}	39.734±2.055^{cd,A}
Ch-PA-CA	46.276±3.772^{D}	44.565±1.620^{bcd,CD}	43.071±2.001^{c,BC}	40.912±1.827^{bcd,AB}	39.859±2.810^{cd,A}

Different letters indicate significant difference (P<0.05), small letters: the difference by the treatment during the week, large letters: the difference between the treatment during 4 weeks, ±: standard deviations of 10 measurements.

Albumen pH

The albumen pH can also be used as an indicator of the albumen quality of eggs (Wardy et al., 2011). Freshly laid eggs have an albumen pH value of 7.6 to 8.7 (Waimaleongora-Ek et al., 2009). During storage, carbon dioxide escapes via eggshell pores, resulting in thinning of the thick albumen and an increased albumen pH value up to 9.6-9.7 (Kemps et al., 2007).

In this study, albumen values of chicken eggs coated chitosan groups were significantly (P<0.05) lower than those of non-coated chicken eggs throughout 4 weeks of storage at 24±2°C (Table 4). There were no significant differences (P>0.05) in albumen pH among Ch-PA-GA and Ch-AA-CA coated chicken eggs during 4 weeks of storage.

Table 4 showed that the albumen pH of non -coated quail eggs rapidly increased from initial value of 8.92 to 10.15 after 4 weeks of storage at 24±2°C. However, the albumen pH of quail eggs of coated with chitosan formulations the pH gradually increased from 8.92 to 9.27 (Ch-PA-CA). This implied that chitosan coated groups could be retarded loss of carbon dioxide through eggshell pores by acting as a gas barrier.

In the fifth week of storage at 25°C, Soares et al. (2021) found that albumen pH values above 9 for uncoated eggs. Uncoated eggs had an albumen pH above 9 after 21 days of storage at 25°C, according to Lima et al. (2020).

The release of CO_2 into the environment through the eggshell pores changes the albumen pH over time (Soares et al., 2021). Coatings are effective at delaying this reaction because they operate as a physical barrier, reducing gas exchange between the internal and exterior environments.

Mineral levels

According to Table 5 the coated eggs mineral elements values of mineral elements were higher than the control group. The differences between the values of mineral elements that have been used in the initial experiment thought to be caused by the difference of mineral levels of chicken eggs. Higher values of mineral matter in the coated groups can be explained by the barrier formation properties of the coating material and the reduction of losses.

Table 4. Albumen pH of chicken and quail eggs at room temperature (24±2°C).

Albumen pH of chicken eggs at 24±2°C					
Coating group	**0 Week**	**1 Week**	**2 Week**	**3 Week**	**4 Week**
Control	8.80±0.082^{A}	9.39±0.048$^{c.B}$	9.55±0.049$^{d.C}$	9.59±0.053$^{d.C}$	10.17±0.040$^{d.D}$
Ch-AA	8.80±0.082^{A}	9.08±0.062$^{b.B}$	9.14±0.071$^{c.B}$	9.08±0.109$^{abc.B}$	9.09±0.173$^{bc.B}$
Ch-LA	8.80±0.082^{A}	8.95±0.056$^{a.BC}$	9.05±0.104$^{bc.C}$	8.99±0.252$^{a.BC}$	8.86±0.186$^{a.AB}$
Ch-PA	8.80±0.082^{A}	8.97±0.145$^{ab.B}$	9.04±0.117$^{bc.B}$	9.16±0.084$^{c.C}$	9.02±0.105$^{b.B}$
Ch-AA-GA	8.80±0.082^{A}	8.99±0.128$^{ab.B}$	9.13±0.121$^{c.C}$	9.03±0.138$^{ab.BC}$	9.01±0.161$^{b.B}$
Ch-LA-GA	8.80±0.082^{A}	8.97±0.113$^{ab.BC}$	8.90±0.162$^{a.AB}$	9.05±0.112$^{abc.CD}$	9.11±0.104$^{bc.D}$
Ch-PA-GA	8.80±0.082^{A}	8.95±0.101$^{a.B}$	9.08±0.084$^{bc.C}$	9.14±0.061$^{bc.CD}$	9.20±0.053$^{c.D}$
Ch-AA-CA	8.80±0.082^{A}	8.96±0.099$^{a.B}$	9.08±0.130$^{bc.C}$	9.11±0.070$^{bc.C}$	9.20±0.041$^{c.D}$
Ch-LA-CA	8.80±0.082^{A}	8.98±0.109$^{ab.B}$	9.06±0.060$^{bc.C}$	9.15±0.041$^{c.D}$	9.17±0.101$^{c.D}$
Ch-PA-CA	8.80±0.082^{A}	8.92±0.171$^{a.B}$	8.98±0.105$^{ab.B}$	9.09±0.102$^{abc.C}$	9.18±0.062$^{c.C}$
Albumen pH of quail eggs at 24±2°C					
Coating group	**0 Week**	**1 Week**	**2 Week**	**3 Week**	**4 Week**
Control	8.92±0.308^{A}	9.17±0.030$^{e.AB}$	9.35±0.100$^{d.B}$	9.70±0.170$^{e.C}$	10.15±0.199$^{e.D}$
Ch-AA	8.92±0.308^{BC}	8.36±0.045$^{a.A}$	8.74±0.950$^{ab.B}$	8.91±0.140$^{ab.BC}$	9.09±0.045$^{abcd.BC}$
Ch-LA	8.92±0.308^{B}	8.51±0.083$^{ab.A}$	8.74±0.208$^{ab.AB}$	8.87±0.187$^{ab.B}$	8.90±0.185$^{a.B}$
Ch-PA	8.92±0.308^{B}	8.49±0.126$^{ab.A}$	8.85±0.150$^{abc.B}$	9.24±0.065$^{d.C}$	9.26±0.085$^{cd.C}$
Ch-AA-GA	8.92±0.308^{A}	8.97±0.095$^{de.A}$	9.09±0.062$^{cd.A}$	9.13±0.026$^{cd.A}$	9.14±0.049$^{bcd.A}$
Ch-LA-GA	8.92±0.308^{AB}	8.49±0.231$^{ab.A}$	8.54±0.368$^{a.AB}$	8.94±0.101$^{bc.AB}$	9.04±0.190$^{abc.B}$
Ch-PA-GA	8.92±0.308^{A}	8.91±0.122$^{cd.A}$	9.02±0.090$^{bc.A}$	9.07±0.026$^{bcd.A}$	9.20±0.055$^{bcd.A}$
Ch-AA-CA	8.92±0.308^{AB}	8.68±0.040$^{bc.A}$	8.95±0.141$^{bc.AB}$	9.05±0.111$^{bcd.B}$	9.23±0.041$^{cd.B}$
Ch-LA-CA	8.92±0.308^{A}	8.73±0.096$^{bcd.A}$	8.82±0.070$^{abc.A}$	8.72±0.092$^{a.A}$	8.99±0.062$^{ab.A}$
Ch-PA-CA	8.92±0.308^{AB}	8.56±0.250$^{ab.A}$	8.75±0.268$^{ab.A}$	9.18±0.036$^{d.B}$	9.27±0.096$^{d.B}$

Different letters indicate significant difference (P<0.05), small letters: the difference by the treatment during the week, large letters: the difference between the treatment during 4 weeks, ±: standard deviations of 10 measurements.

Table 5. Mineral levels (%) of chicken and quail eggs at room temperature (24±2°C).

Mineral levels of chicken eggs at 24±2^{0}C						
Coating group	**Ca**	**Cu**	**Fe**	**Mg**	**Mn**	**Zn**
0.Day	1388±8.00^{i}	1.132±0.00^{e}	62.92±0.07^{l}	136.7±0.70^{l}	1.450±0.00^{i}	795.3±2.55^{i}
Control	960.3±0.70^{a}	0.2189±0.00^{a}	44.98±0.01^{a}	92.90±1.00^{a}	0.840±0.00^{a}	412.6±1.10^{a}
Ch-AA	1071±1.00^{d}	1.361±0.02^{g}	47.44±0.38^{b}	98.16±0.16^{c}	1.083±0.00^{d}	557.3±0.70^{d}
Ch-LA	1221±3.00^{g}	1.295±0.00^{f}	64.93±0.35^{i}	100.6±0.10^{d}	1.020±0.00^{b}	682±0.35^{h}
Ch-PA	970.8±2.00^{b}	1.143±0.00^{e}	49.29±0.10^{c}	96.29±0.54^{b}	1.275±0.00^{g}	533.7±1.05^{c}
Ch-AA-GA	1129±3.00^{f}	1.289±0.00^{f}	51.31±0.23^{e}	105.7±0.40^{f}	1.208±0.00^{f}	663.1±3.30^{g}
Ch-LA-GA	1306±9.01^{l}	1.503±0.01^{h}	54.1±0.07^{f}	109.8±0.15^{g}	1.318±0.00^{l}	753.3±2.05^{l}
Ch-PA-GA	1214±6.05^{g}	2.952±0.00^{l}	59.17±0.16^{h}	103±0.75^{e}	1.166±0.00^{e}	627.9±1.15^{f}
Ch-AA-CA	1033±5.00^{c}	0.550±0.02^{b}	50.39±0.14^{d}	100.5±1.50^{d}	1.048±0.00^{c}	531.1±0.55^{c}
Ch-LA-CA	1104±8.00^{e}	0.942±0.02^{c}	67±0.49^{j}	101.6±0.45^{d}	3.928±0.01^{j}	581.7±0.70^{e}
Ch-PA-CA	1298±2.51^{h}	1.051±0.00^{d}	56.95±0.23^{g}	118.7±0.25^{h}	1.285±0.00^{h}	433.4±1.00^{b}
Mineral levels of quail eggs at 24±2°C						
Coating group	**Ca**	**Cu**	**Fe**	**Mg**	**Mn**	**Zn**
0.Day	1340±7.50^{g}	1.669±0.02^{e}	89.25±0.21^{h}	100.5±0.10^{e}	0.934±0.00^{i}	31.35±0.10^{g}
Control	931.5±4.80^{a}	0.990±0.00^{a}	42.42±0.45^{a}	87.53±0.39^{b}	0.621±0.00^{c}	23.69±0.00^{b}
Ch-AA	1282±0.57^{f}	2.064±0.01^{l}	70.76±0.10^{g}	105.5±1.70^{g}	0.926±0.00^{l}	34.61±0.25^{l}
Ch-LA	1195±5.50^{c}	1.395±0.00^{d}	66.44±0.17^{f}	93.46±0.64^{c}	0.694±0.00^{e}	29.42±0.00^{f}
Ch-PA	1237±5.50^{d}	1.697±0.00^{f}	52.63±0.07^{c}	100.9±0.20^{e}	0.851±0.00^{g}	27.99±0.01^{e}

Table 5. Contd.

Ch-AA-GA	1394±9.50^{h}	1.361±0.00^{c}	59.27±0.02^{d}	96.93±0.39^{d}	0.649±0.00^{d}	25.68±0.03^{c}
Ch-LA-GA	978.5±8.95^{b}	1.297±0.00^{b}	47.84±0.22^{b}	87.69±1.16^{b}	0.417±0.00^{b}	27.38±0.15^{d}
Ch-PA-GA	926.9±1.35^{a}	1.902±0.01^{h}	60.42±0.09^{d}	80.93±0.08^{a}	0.385±0.00^{a}	22.92±0.20^{a}
Ch-AA-CA	1536±2.00^{l}	1.276±0.00^{b}	58.74±0.12^{d}	113.5±1.05^{l}	0.713±0.00^{f}	32.15±0.01^{h}
Ch-LA-CA	1268±2.60^{e}	1.743±0.00^{g}	62.24±0.12^{e}	108±1.00^{h}	1.191±0.00^{j}	34.56±0.15^{l}
Ch-PA-CA	1255±2.51^{e}	1.728±0.01^{g}	42.11±0.46^{a}	102.4±0.95^{f}	0.863±0.00^{h}	29.34±0.08^{f}

Different letters indicate significant difference ($p<0.05$), ±: standard deviations of 10 measurements.

Table 6. Shell breaking strength of chicken and quail eggs at room temperature (24±2^{o}C).

Shell breaking strength of chicken eggs at 24±2^{o}C					
Coating groups	**0. Week**	**1. Week**	**2. Week**	**3. Week**	**4. Week**
Control	1.34±0.241^{AB}	1.09±0.288^{a,A}	1.36±0.206^{a,B}	1.34±0.295^{a,AB}	1.30±0.274^{a,AB}
Ch-AA	1.34±0.241^{A}	1.83±0.216^{bc,B}	1.79±0.196^{ab,B}	1.94±0.283^{b,B}	1.92±0.547^{bc,B}
Ch-LA	1.34±0.241^{A}	1.75±0.126^{b,B}	1.95±0.574^{b,B}	1.90±0.266^{b,B}	1.91±0.166^{bc,B}
Ch-PA	1.34±0.241^{A}	1.83±0.116^{bc,B}	1.79±0.237^{ab,B}	2.43±0.928^{c,C}	1.88±0.329^{bc,B}
Ch-AA-GA	1.34±0.241^{A}	1.84±0.171^{bc,B}	1.93±0.400^{b,B}	1.86±0.488^{b,B}	2.26±0.811^{bcd,B}
Ch-LA-GA	1.34±0.241^{A}	1.84±0.447^{bc,B}	2.02±0.782^{b,B}	1.88±0.175^{b,B}	1.79±0.191^{b,B}
Ch-PA-GA	1.34±0.241^{A}	2.06±0.236^{c,B}	2.18±0.385^{b,B}	2.16±0.527^{bc,B}	2.53±0.815^{d,B}
Ch-AA-CA	1.34±0.241^{A}	1.93±0.211^{bc,B}	1.86±0.231^{b,B}	1.98±0.239^{bc,B}	2.27±0.499^{bcd,C}
Ch-LA-CA	1.34±0.241^{A}	1.84±0.206^{bc,B}	2.21±0.779^{b,B}	2.14±0.592^{bc,B}	2.15±0.365^{bcd,B}
Ch-PA-CA	1.34±0.241^{A}	2.04±0.497^{c,B}	2.21±0.582^{b,B}	2.13±0.447^{bc,B}	2.38±0.610^{cd,B}
Shell breaking strength of quail eggs at 24±2^{o}C					
Coating groups	**0. Week**	**1. Week**	**2. Week**	**3. Week**	**4. Week**
Control	7.142±1.670^{A}	6.198±2.655^{a,A}	5.018±1.876^{a,A}	5.338±2.821^{a,A}	5.459±1.021^{a,A}
Ch-AA	7.142±1.670^{A}	12.861±0.660^{c,B}	11.829±0.424^{bc,B}	12.746±0.164^{cde,B}	12.353±1.241^{c,B}
Ch-LA	7.142±1.670^{A}	13.120±0.786^{c,B}	12.856±0.201^{bc,B}	13.144±0.468^{de,B}	12.329±0.753^{c,B}
Ch-PA	7.142±1.670^{A}	10.648±0.945^{b,B}	11.115±1.087^{b,B}	11.865±0.982^{bcde,B}	10.226±0.910^{b,B}
Ch-AA-GA	7.142±1.670^{A}	12.046±0.809^{bc,B}	12.839±0.434^{bc,B}	12.530±0.158^{bcde,B}	12.398±0.666^{c,B}
Ch-LA-GA	7.142±1.670^{A}	13.299±0.602^{c,B}	12.691±1.327^{bc,B}	12.307±0.470^{bcde,B}	12.296±0.640^{c,B}
Ch-PA-GA	7.142±1.670^{A}	10.260±1.435^{b,B}	12.004±1.196$^{bc.B}$	10.685±0.524^{b,B}	11.380±0.228^{bc,B}
Ch-AA-CA	7.142±1.670^{A}	11.676±1.173^{bc,BC}	12.664±0.611^{bc,C}	10.961±0.593^{bc,BC}	10.452±0.350^{b,B}
Ch-LA-CA	7.142±1.670^{A}	13.754±0.793^{c,B}	14.012±0.633^{c,B}	13.536±0.200^{e,B}	12.654±0.524^{c,B}
Ch-PA-CA	7.142±1.670^{A}	13.384±0.504^{c,C}	11.749±0.953^{bc,BC}	11.456±0.101^{bcd,B}	11.907±0.667^{c,BC}

Different letters indicate significant difference ($P<0.05$), small letters: the difference by the treatment during the week, large letters: the difference between the treatment during 4 weeks, ±: standard deviations of 10 measurements.

Shell breaking strength

Analysis of the fracture of the shell that repeated every week for the duration of 4 weeks storage the control group had the lowest value ($p<0.05$). Addition of phenolic compounds caused higher fracture resistance (Table 6). According to Table 6, Ch-AA, Ch-LA, Ch-PA, CH-AA-GA, Ch-LA-GA, Ch-PA-GA and CH-LA-CA shell coating caused the fracture resistance ($p<0.05$).

In the poultry industry, shell breaking has generally been associated with significant financial loss. The resistance of eggshells coated with RPC plus propolis was not improved, according to Pires et al. (2019) (5 or 1%).

Pires et al. (2020), summarized that the studies published between 1957 until 2020 that evaluated the use of egg coating and found that coated eggs have reduced quality loss when compared to uncoated eggs.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

This work was supported by KSU-BAP (2014/2-48D).

REFERENCES

Aider M (2010). Chitosan application for active bio-based films production and potential in the food industry: Review. LWT-Food Science and Technology 43(6):837-842.

Alleoni AC, Antunes AJ (2004). Internal Quality of Eggs Coated with Whey Protein Concentrate. Science Agriculture 61(3):276-280.

Bhale S, No HK, Prinyawiwatkul W, Farr AJ, Meyers SP (2003). Chitosan coating improves shelf life of eggs. Journal of Food Science 68:2378-2383

Bonilla J, Fortunati E, Atares L, Chiralt A, Kenny JM (2014). Physical, structural and antimicrobial properties of poly vinyl alcohol-chitosan biodegradable films. Food Hydrocolloids 35:463-470.

Derelioğlu E, Turgay Ö (2019). Effect of chitosan combined coating on chicken and quail eggs for controlling *Escherichia coli* and *Salmonella enteritidis*. Journal of Food and Health Technology Innovations 2(6):160-168.

Ding F, Deng H, Du Y, Shi X, Wang Q (2014). Emerging chitin and chitosan nanofibrus materials for biomedical applications. Nanoscale 6:9477-9493.

EPA (1994). Method 200.7. Determination of Metals and Trace Elements in Water and Wastes by Inductively Coupled Plasma-Atomic Emission Spectrometry. https://www.epa.gov/esam/method-2007-determination-metals-and-trace-elements-water-and-wastes-inductively-coupled-plasma

Ezazi A, Javadi A, Jafarizadeh-Malmiri H, Mirzaei H (2021). Development of a chitosan-propolis extract edible coating formulation based on physico-chemical attributes of hens' eggs Optimization and characteristics edible coating of egg using chitosan and propolis. Food Bioscience 40:100894.

FAO (2003). Egg marketing. A guide for the production and sale of eggs. In FAO Agricultural Services Bulletin (Vol. 150).

Junter GA, Thebault P, Lebrun L (2016). Polysaccharide-based antibiofilm surfaces. Acta Biomaterialia 30:13-25.

Kemps BJ, De Ketelaere B, Bamelis FR, Mertens K, Decuypere EM, De Baerdemaeker JG, Schwägele F (2007). Albumen freshness assessment by combining visible near-infrared transmission and low-resolution proton nuclear magnetic resonance spectroscopy. Poultry Science 86:752-759.

Kim SH, Youn DK, No HK, Choi SW, Prinyawiwatkul W (2009). Effect of chitosan coating and storage position on quality and shelf life of eggs. International Journal of Food Science and Technology 44:1350-1359.

Kumari K, Tripathi UK, Maurya V, Kumar M (2020). Internal quality changes in eggs during storage. International Journal of Science, Environment and Technology 9(4):615-624.

Leceta I, Guerrero P, dela Caba K (2013). Functional properties of chitosan-based films. Carbohydrate Polymers 93:339-346.

Lima VVC, de Oliveira Gomes, B, Pereira M, do Carmo Barros EK, Pereira ALF, Silva DS, Freitas ER, Abreu VKG (2020). Cassava and yam starch coverings in egg conservation. (in Portuguese). Research, Society and Development 9:e23984949.

Madureira AR, Pereira A, Pintado M (2015). Current state on the development of nanoparticles for use against bacterial gastrointestinal pathogens. Focus on chitosan nanoparticles loaded with phenolic compounds. Carbohydrate Polymers 130:429-439.

Menezes PC, Evilda RL, Juliana PM, Wanessa NKO, Joaquim EN (2012). Egg quality of laying hens in different conditions of storage, ages and housing densities. Revista Brasileira de Zootecnia 41(9):2064-2069.

Muscat D, Adhikari B, Adhikari R, Chaudhary DS (2012). Comparative study of film forming behaviour of low and high amylose starches using glycerol and xylitol as plasticizers. Journal of Food Engineering 109(2):189-201.

No HK, Park NY, Lee SH, Samuel PM (2002). Antibacterial activity of chitosan and chitosan oligomers with different molecular weights. International Journal Food Microbiology 74:65-72.

Oliveira GO, Santos VM, Rodrigues JC, Santana AP (2020). Conservation of the internal quality of eggs using a biodegradable coating. Poultry Science 99:7207-7213.

Persin Z, Stana-Kleinschek K, Foster TJ, van Dam JEG, Boerio CG, Navard P (2011). Challenges and opportunities in polysaccharides research and technology: The EPNOE views for the next decade in the areas of materials, food and health care. Carbohydrate Polymers 84(1):22-32.

Pires PGS, Pires PDS, Cardinal KM, Bavaresco C (2020). The use of coating in eggs - a systematic review. Trends Food Science and Technology 106:312-321.

Pires PGS, Pires PDS, Cardinal KM, Leuven AFR, Kindlein L, Andretta I (2019). Effects of rice protein coatings combined or not with propolis on shelf life of eggs. Poultry Science 98(9):4196-4203.

Soares RA, Borges SV, Dias MD, Piccoli RH, Fassani EJ, Silva EMC (2021). Impact of whey protein isolate/sodium montmorillonite/sodium metabisulfite coating on the shelf life of fresh eggs during storage. LWT-Food Science and Technology 139:110611.

Szymanska E, Winnicka K (2015). Stability of chitosan a challenge for pharmaceutical and biomedical applications. Marine Drugs 13:1819-1846.

Tan YM, Lim SH, Tay BY, Lee MW, Thian ES (2015). Functional chitosan-based grapefruit seed extract composite film for applications in food packaging technology. Materials Research Bulletin 69:142-146.

Torrico DD, No HK, Prinyawiwatkul W, Janes M, Herrera A, Osorio F (2011). Mineral Oil-Chitosan Emulsion Coatings Affect Quality and Shelf-Life of Coated Eggs during Refrigerated and Room Temperature Storage. Journal of Food Science 76(4):262-268.

van den Broek LAM, Knoop RJI, Kappen FHJ, Boeriu CG (2015). Chitosan films and blends for packaging material. Carbohydrate Polymers, 116:237-242.

Waimaleongora-Ek P, Garcia K, No HK, Priyawiwatkul W, Ingram D (2009). Selected quality and shelf-life of eggs coated with mineral oil with different viscosities. Journal of Food Science 74:423-429.

Wardy W, Torrico DD, Jirangrat W, No HK, Saalia FK, Prinyawiwatkul W (2011). Chitosan-soybean oil emulsion coating affects physico-functional and sensory quality of eggs during storage. LWT-Food Science and Technology 44:2659-2668.

Wu J, Zhong F, Li Y, Shoemaker CF, Xia WS (2013). Preparation and characterization of pullulan-chitosan and pullulan-carboxymethyl chitosan blended films. Food Hydrocolloids 30(1):82-91.

Yüceer M, Caner C (2020). The effects of ozone, ultrasound and coating with shellac and lysozyme-chitosan on fresh egg during storage at ambient temperature – Part 1: interior quality changes. International Journal of Food Science and Technology 55(1):259-266.

Vol. 16(3) pp. 71-80, March 2022
DOI: 10.5897/AJFS2021.2108
Article Number: 1A988EE68808
ISSN: 1996-0794

http://www.academicjournals.org/AJFS

ACADEMIC JOURNALS
expand your knowledge

African Journal of Food Science

Full Length Research Paper

Physicochemical and consumer acceptability of different particle-sized cassava strips

Chioma Illoh[1], Helen Obioma Agu[1*], Chioke Amaefuna Okolo[1] and Victoria Adaora Jideani[2]

[1]Department of Food Science and Technology, Nnamdi Azikiwe University, P. M. B. 5025, Awka, Anambra State, Nigeria.
[2]Department of Food Science and Technology, Cape Peninsula University of Technology, Bellville, South Africa.

Received 11 March, 2021; Accepted 15 November, 2021

This study was carried out to study the physicochemical and sensory characteristics of *Abacha* with different particle sizes. Dried cassava strips (*Abacha*) were produced in variable length, 2, 2.5 and 5 mm with the average length of 5 cm market size used as control. The proximate, physicochemical, functional and sensory properties were analyzed for various *Abacha* strips. The proximate composition of the *Abacha* chips ranged from 9.1 - 13.3% for moisture content, ash 2.5 - 2.8%, protein 1.9%, fibre 1.0 - 1.2%, fat 0.5 - 0.6%, and carbohydrate 80.7 - 84.4%. The physicochemical composition of the *Abacha* samples showed a pH range of 4.2 - 4.5, total titratable acidity 0.0 - 0.1%, hydrogen cyanide 2.5 - 2.6 mg.100 g- 1, phytate 0.5 mg.100 g-1 and no tannin detected. In general, all the *Abacha* strips were accepted, although the degree of likeness decreased as the particle size decreased. Consumers preferred market *Abacha* to the other samples based on familiarity followed by the 5 mm strips. Principal Component Analysis (PCA) indicated that 5 cm and 5 mm length *Abacha* sizes accounted for 80.5% of the variation and were high in proximate and physicochemical properties while 2 and 2.5 mm *Abacha* sizes accounted for 16.3% of the variation with 2 mm higher in functional properties and 2.5 mm length lower than all samples in functional, proximate and physicochemical properties. The reduced particle-sized strips could be used as breakfast cereals.

Key words: Cassava, *abacha*, particle size, sentiment, functional, consumer acceptability.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz), a dicotyledonous plant traditionally an African staple food grown by small-starchy root crop that develops underground. The edible, tuberous root grows between 15 and 100 cm and 0.5 and 2.0 kg in mass. It is a primary food security crop in Africa because of its resistance to drought and disease, flexible planting and harvest cycle, and tolerance of low-quality soils. After maturity, cassava can remain in the ground for scale farmers belong to the family Euphorbiaceae (Meridian Institute, 2013; Alves, 2002). Cassava is a up to 18 months depending on the variety and adapts well in regions that suffer both environmental and political

*Corresponding author. E-mail: ho.agu@unizik.edu.ng.

hardships (Meridian Institute, 2013).

Approximately 90% of cassava produced in West Africa is for human consumption and less than 10% is semi-processed for on-farm animal feed (Sanni et al., 2009). Among the starchy staples, cassava has about 40% higher than rice and 25% more than maize in carbohydrates. Consequently, cassava is the cheapest source of calories for both human nutrition and animal feeding (Tonukari, 2004). Cassava is a main staple food crop in Nigeria as its products are found in the daily meals of Nigerians and cut across cultures and social divides within Nigerian households. Mostly, the bulk of the tuber is consumed locally as traditional food and it is the most important food crop by production, and second by consumption (FAO, 2014). Traditionally, the most common food products obtained from the processing of cassava in Nigeria are garri, *Abacha*, fufu, starch, lafun, chips and flour.

Abacha is prepared from shredded boiled cassava, soaked for 8 to 24 h in cold water, washed thoroughly and then dried (Ekwu et al., 2014). It is consumed as a snack or main dish in the eastern states of Nigeria and considered a delicacy in some communities, where the dried slices are rehydrated and then mixed with palm oil sauce (Ncha) and smoked fish or meat with other seasonings referred to as *Abacha Ncha*. It is also a ceremonial dish served during indigenous festivals, such as agricultural festivals, funerals and child naming (Sanni et al., 2009).

In most parts of the country where *Abacha* (dried cassava strips) is produced, the strips are long, ranging from 3 to 5 cm. Shorter strips of *Abacha* are not common and a lack of standardized particle sizes has also contributed to the limited use of *Abacha* in the preparation of meals other than taking it as a snack or as a salad (African salad). *Abacha* is a food product, though locally produced is hardly found on shelves in departmental stores across the country. Furthermore, not much is known about the physicochemical and sensory properties of *Abacha* chips. Consequently, it is necessary to study the physicochemical and sensory characteristics of *Abacha* with different particle sizes to find alternative food use for the chips.

The objectives of this study were to (1) develop standardized *Abacha* of varied particle sizes (length-wise) from the commercial *Abacha* strips; (2) evaluate the functional properties of *Abacha* with different particle sizes; (3) determine the consumer acceptability of the varied particle sizes when prepared as a meal of "*Abacha* Ncha" and (4) compare the physicochemical properties of the consumer acceptable *Abacha* strips to the commercial.

MATERIALS AND METHODS

Source of materials

Commercially processed unstandardized/varied length sizes of *Abacha* strips were bought from a local market in Awka, Anambra State, Nigeria and were used as the intermediate product as well as the control for this study.

Measurement of commercial cassava strips length and cleaning

The commercial dried *Abacha* strips were dry cleaned to remove all physical and biological contaminants (sand, stones, leaf particles, insects, etc.) by manual sorting. The length of the strips was measured 8 times using a vernier calliper and expressed as the average length in mm.

Production of cassava strips with different particle sizes

The cleaned *Abacha* was then coarsely crushed by passing them through a hammer mill twice after which it was passed through a screen of different mesh sizes (2, 2.5 and 5 mm) to obtain standardized *Abacha* particle sizes (Plate 1). The produced samples were oven-dried to reduce the microbial load that may be present in the samples using a hot air oven at 70°C for 45 min. The samples were allowed to cool, weighed and then packed into clean marked plastic containers in their respective sizes (Figure 1). A one-factor completely randomized design with three different treatment levels was employed for the proximate, functional, anti-nutritional and sensory analysis of the *Abacha* strips.

Determination of functional properties of *Abacha*

Bulk density determination of Abacha strips

The method described by Nwanekezi et al. (2001) was used to determine the bulk density of the *Abacha* strips. Each sample was slowly filled into a 250 mL cylinder mark. The base of the cylinder was gently tapped with the fingers until no further decrease of the sample. The sample weight was noted. The bulk density was calculated as mass per unit volume of the sample using Equation 1. The mean of the triplicate measurement was taken as the estimate of the bulk density of each *Abacha* strip.

$$\text{Bulk density (g/mL)} = \frac{\text{Mass of sample}}{\text{Volume occupied by sample}} \quad (1)$$

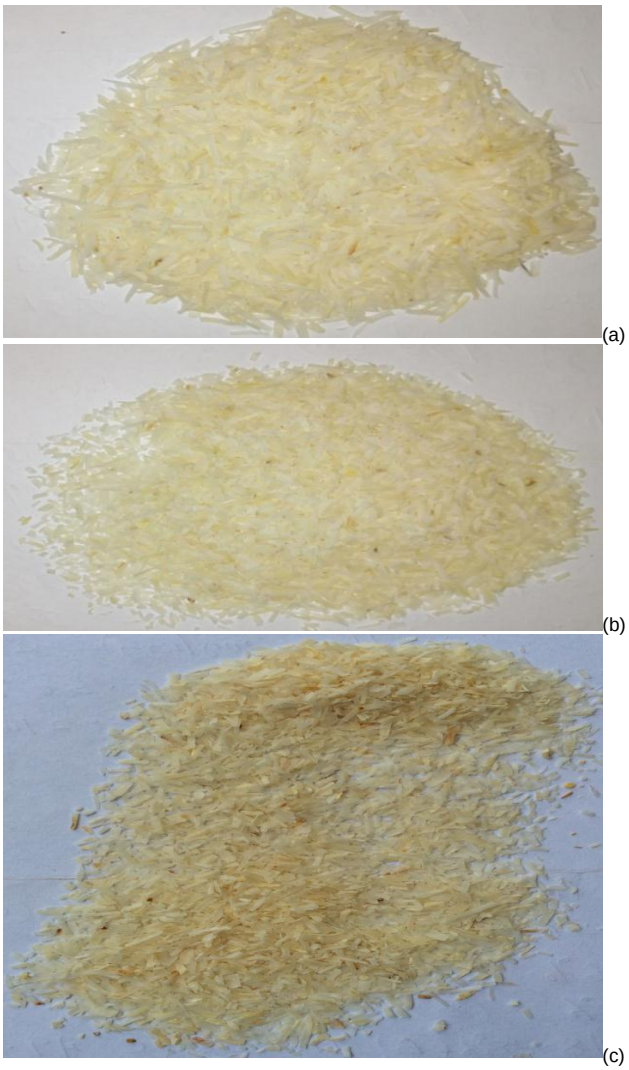
Water absorption capacity determination of Abacha strips

The water absorption capacity (WAC) of the *Abacha* strips was estimated using the method of Omah (2012). *Abacha* strips (1 g) meted out into a weighed centrifuge tube with 10 mL of distilled water added to it and combined thoroughly. This mixture was allowed to stand for 1 h after which it was centrifuged at 3500 rpm for 30 min. The excess water was decanted and the tube inverted over a Whatman No. 1 filter paper to drain and dry. The volume of the water absorbed was estimated by the difference of the initial and final volumes of water in the sample and the water absorption capacity (%) calculated using Equation 2.

$$\text{WAC (\%)} = \frac{\text{Volume of water used} - \text{Volume of free water}}{\text{Weight of sample used}} \times 100 \quad (2)$$

Oil absorption capacity determination of Abacha strips

The oil absorption capacity (OAC) of the *Abacha* strips was



(a)

(b)

(c)

Plate 1. Cassava grits: (a) Sample LPS: 5 mm particle size; (b) Sample MPS: 2.5 mm particle size; (c) Sample SPS: 2 mm particle size.

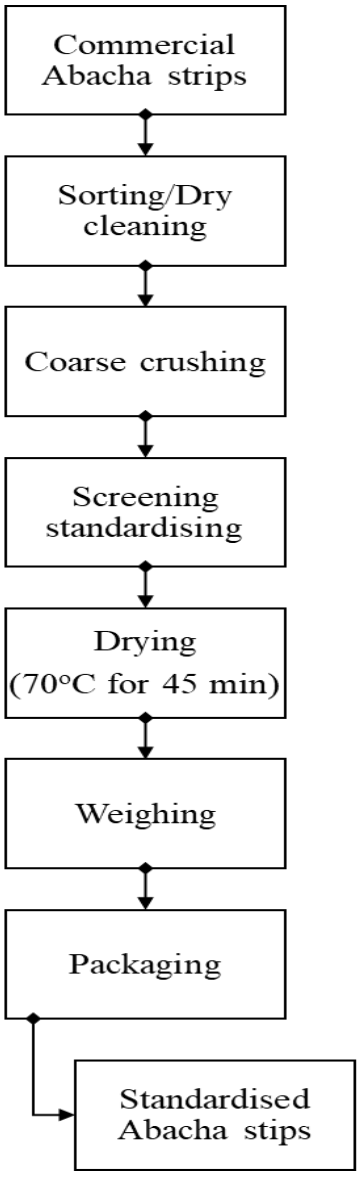


Figure 1. Standardized *Abacha* particle size production process.

estimated using the method reported by Adebowale et al. (2005). An aliquot of oil (10 mL) of known specific gravity was added to 1 g of the sample in a 250 mL measuring cylinder. The content was mixed for 3 min using a magnetic stirrer and thereafter centrifuged at 3500 rpm for 30 min. The supernatant was measured into a 10 mL graduated cylinder and the oil absorbed (%) by the samples was calculated using Equation 3.

$$\text{OAC (\%)} = \frac{\text{volume of oil absorbed} \times D}{\text{Weight of sample}} \times 100 \quad (3)$$

Where, D = oil density.

Swelling capacity determination of Abacha strips

The swelling capacity of the *Abacha* strips was estimated as described by Bankole et al. (2013) with slight modifications. *Abacha* strips (1 g) were weighed into a test tube containing 10 mL of distilled water, mixed and heated with shaking in a water bath at 60°C for 30 min. The test tube was centrifuged at 3500 rpm for 15 min and the supernatant decanted. The weight of the sample was taken and the swelling capacity was estimated from Equation 4.

$$\text{Swelling Capacity} = \frac{\text{Weight of wet strips}}{\text{Weight of dry strips}} \quad (4)$$

Production of Abacha Ncha with different particle sizes

The *Abacha* strips were rehydrated by soaking each in hot water for 30 min. The rehydrated strips were passed through a colander to drain the water for 5 min. *Ncha* was prepared (an oil emulsion prepared by mixing palm oil with potash, dry pepper). The rehydrated *Abacha* strips were each mixed with the *ncha* to produce the *Abacha Ncha*.

Sensory evaluation of Abacha Ncha with different particle Sizes

Sensory evaluation of the three *Abacha Ncha* from the standardized particle sizes and the market *Abacha Ncha* as control was carried out using 50 untrained consumer panellists. The samples were identified with a 3-digit code. The panellists were instructed to appraise the samples for appearance, texture, chewiness, aroma and overall acceptability *on a* 9-point hedonic scale, 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely (Busie et al., 2017). The panellists rinsed their mouths with water in between tasting the samples. The most acceptable *Abacha* strip and the commercial strips were further analysed for physicochemical and anti-nutritional properties.

Sentiment analysis of Abacha Ncha

The individual comments for each sample and the general comments from the sensory evaluation were separately loaded into the Konstanz Information Miner (KNIME) software. The comments were tagged to positive and negative sentiments using the Multi-perspective question answering (MPQA) sentiment corpus followed by pre-processing by filtering and stemming. The terms were converted to strings and colour coded according to the sentiment category. The categories were filtered and a word cloud of each was produced.

Physicochemical and anti-nutrient of most acceptable *Abacha*

Proximate composition of most acceptable Abacha

The moisture, ash, protein, crude fibre and fat contents of the *Abacha* strips and that of the commercial (control) were determined using the AOAC (2010) method. The moisture, ash, protein, crude fibre, and fat contents were determined according to AOAC (2010) method. The available carbohydrate was determined by difference.

pH determination of most acceptable Abacha

The pH of the *Abacha* sample was determined in a 10% (w/v) mixture of the sample in distilled water. The sample was mixed thoroughly and the pH was measured using a standard pH meter by dipping the pH electrode into the mixture of the sample particulates. After 10 min of equilibration, the pH reading of the sample was taken.

Total titratable acidity determination of most acceptable Abacha

The total titratable acidity was measured using the colour indicator method reported by Obilie et al. (2004) where 10 mL of the concentration of the *Abacha* suspension was used for the titration after filtration using a Whatman No. 1 filter paper. A funnel was used to pour 0.1 M NaOH into a 25 mL burette until it reached the zero mark. The total titratable acidity was estimated from Equation 5.

$$\text{TTA} = \frac{\text{Titre x Acid factor}}{\text{Volume of sample}} \times 100 \quad (5)$$

Where acid factor = 0.009

Determination of anti-nutritional factors of Abacha strips

Phytate content determination of Abacha strips

The spectrophotometric method reported by Pearson (1976) with modifications was used to estimate the phytate content of the cassava strips. A 1 g of sample was weighed into a 500 mL flat bottom flask. The flask was placed in a shaker and the sample was extracted with 2.4% HCl for 1 h. The aliquot was filtered with 5 mL of the filtrate pipetted and diluted with distilled water to 25 mL, 15 mL of NaCl was added to 10 mL of the diluted sample and this was passed through an ample resin (200 - 400 mesh) to elude inorganic phosphorus. About 15 mL of 0.7 M NaCl was added to the solution and mixed for 5 s on a vortex mixer, centrifuged at 3500 rpm for 10 min. The supernatant absorbance was read at 520 nm wavelength using UV spectrophotometer. The phytate concentration was read off from a standard curve prepared with standard inositol phytate and the value expressed in mg/l00 g from Equation 6.

$$\text{Phytate (mg)} = \frac{\text{Conc. of phytate (mg/100g) from standard curve x Dilution factor}}{\text{Weight of sample}} \quad (6)$$

Hydrogen cyanide determination of Abacha strips

The hydrogen cyanide content was estimated using the alkaline picrate colorimetric method reported by Bradbury et al. (1999). A 1 g of the sample was weighed into a conical flask and 200 mL of distilled water was added to it and thoroughly mixed. With the aid of a rubber stopper, a strip of alkaline picrate paper was suspended over the mixture such that the paper did not touch the surface of the mixture and was incubated for 18 h at room temperature. The picrate paper was carefully removed and placed in 60 mL of distilled water. Meanwhile, a standard cyanide solution was prepared and treated as described earlier. The absorbance from the standard and the sample was measured in a spectrophotometer at 540 nm. The cyanide content (HCN) in mg/kg was calculated from Equation 7.

$$\text{HCN (mg/kg)} = \frac{100}{W} \times \text{Au (As)} \quad (7)$$

Where W = weight of sample analyzed (g); Au = Absorbance of the sample (nm) and As = Absorbance of the standard HCN solution (nm).

Tannin content determination

Tannin content was estimated using the Folis-Denis colorimetric method reported by Kirk and Sawyer (1998). A known amount of the sample (5 g) was meted in 50 mL of distilled water and shaken. The mixture was allowed to stand for 30 min at 28^{o}C before being filtered using a Whatman grade1 filter paper. Into a 50 mL volumetric flask was dispersed 2 mL of the extract. After which, 2 mL of standard tannin solution (tannic acid) and 2 mL of distilled water was put into separate volumetric flasks to serve as standard and reagent was added to each of the flasks. Then 2.5 mL of saturated Na_2CO_3 solution was added into each flask. The content of each flask was made up to 50 mL with distilled water and allowed to incubate at 28°C for 90 min. The absorbance was measured using a spectrophotometer at 260 nm. The blank reagent was used to calibrate the instrument at zero.

Statistical analysis of data

The results were expressed as mean ± standard deviation of triplicate values. Multivariate analysis of variance (MANOVA) was

Table 1. Functional properties of A*bacha* with different particle sizes*.

Abacha strips	Bulk density (g.mL^{-1})	WAC (%)	OAC (%)	Swelling capacity (%)
NMA	39.8 ± 1.0^{a}	53.2 ± 0.3^{a}	14.2 ± 0.2^{a}	44.2 ± 0.1^{a}
LPS	47.6 ± 0.2^{b}	56.3 ± 0.3^{b}	15.9 ± 0.1^{b}	48.3 ± 0.1^{b}
MPS	55. 6 ± 0.2^{c}	50.2 ± 0.1^{c}	18.1 ± 0.1^{c}	41.6 ± 0.0^{c}
SPS	57. 1 ± 0.1^{d}	60.1 ± 0.1^{d}	24.0 ± 0.1^{d}	49.4 ± 0.1^{d}

*Values are mean ± SD of triplicate determination. Samples with different superscripts within the same column were significantly ($p< 0.05$) different. WAC = water absorption capacity; OAC = oil absorption capacity; NMA (control) = 5 cm, LPS = 5 mm, MPS = 2.5 mm and SPS = 2 mm.

used to ascertain differences between treatments and Duncan multiple range test was used to distinguish means where significant differences existed among samples at a 5% confidence level. Principal Component Analysis was also carried out to extract the components that explained the variation in the characteristics of the crushed cassava strips (IBM SPSS version 25).

RESULTS AND DISCUSSION

Functional properties of *Abacha* with different particle sizes

The functional properties of *Abacha* with different particle sizes were compared with the control sample (NMA) shown in Table 1. There were significant ($p < 0.05$) differences in all the functional properties. The bulk densities of the *Abacha* processed into different particle sizes were significantly different from each other and the control (NMA). The mean values ranged from 39.8 g/mL for the control to 57.1 g/mL for the smallest particle size (SPS). Different values for bulk density have been reported for cassava products. Abu et al. (2006) reported a range of 40.1 to 50.2 g.cm^{-3} for garri. Ekwu et al. (2011) reported that the bulk density of cassava flour processed from dried *Abacha* slices ranged from 50.5 to 57.1 g.cm^{-3}. The results in this work fall within these ranges. Bulk density governs the fill weight of food materials; *Abacha,* when size is reduced, will give a characteristic quality of good filling weight even when it is reduced to tiny particles such as seen in flour (Ekwu et al., 2011).

The water absorption capacity of the *Abacha* with the different particle sizes was significantly ($p < 0.05$) different. The control sample (NMA) had the lowest value (53.2 g.mL^{-1}) and there was an observed increase in value as the particle sizes decreased with SPS being the highest (60.1 g.mL^{-1}). Oluwole et al. (2004) reported that size reduction of cassava, gelatinization of starch and swelling of crude fibre which may occur during heating increases the water absorption capacity of cassava products. From this study, strips with increased water absorption capacity rehydrated slower than those with lower values, thus showing a significant reduction in the meal preparation time in samples with a lower water absorption capacity.

The oil absorption capacity shows a significant ($p < 0.05$) difference in all the samples. The control (NMA) had the lowest value (14.2 g.mL^{-1}) and there was an observed increase in value as the particle sizes decreased with SPS having the highest absorption (24.0 g.mL^{-1}). Oluwole et al. (2004) also reported that the size reduction of cassava in processing can significantly increase the oil absorption capacity of cassava products.

The swelling capacity of the samples was significantly ($p < 0.05$) different. A gradual increase was observed in the swelling capacities of the samples ranging from the control to the smallest particle size (SPS). Swelling capacity is an important functional property in a food system and it has been reported that good quality *Abacha* should have a swelling capacity of 30 to 50 volume increase (Maxiya-Dixon et al., 2007; Sanni et al., 2008). The swelling capacities of all the *Abacha* samples were in agreement with the earlier-stated report.

All the samples were compared favourably with each other as all samples had good functional properties though they were significantly ($p < 0.05$) different from the other. Chisenga et al. (2019) reported that sources of variations in cassava physicochemical properties were due to differences in amylose, protein, lipid contents and starch granule size and distribution. Thus, depending on end use the sample which caters to that objective of production can be selected.

Sensory characteristics of *Abacha* with different particle sizes and consumer sentiment

The sensory characteristics of *Abacha* with different particle sizes were compared with the commercial sample (*Abacha* strips purchased from the local market) shown in Table 2. Significant differences existed in all the sensory attributes. The appearance, aroma, texture, chewiness and overall acceptability follow the same trends of a significant ($p < 0.05$) decrease in acceptability as the particle sizes decreased from the control NMA (average length of 5 cm) to SPS (2 mm).

In appearance, they were all significantly ($p < 0.05$) different from each other. NMA had the highest scoring value which showed that the consumer panellists liked the sample very much, followed by LPS (5 mm), liked moderately with SPS (2 mm) having the lowest score and disliked slightly.

In terms of aroma, NMA, LPS and SPS were not

Table 2. Sensory characteristics of samples of Abacha with different particle sizes*.

Abacha	Appearance	Aroma	Texture	Chewiness	Overall acceptability
NMA	7.7 ± 1.0^{a}	6.8 ± 1.4^{a}	7.4 ± 1.2^{a}	7.3 ± 1.7^{a}	7.6 ± 1.0^{a}
LPS	6.8 ± 1.2^{b}	6.6 ± 1.3^{a}	6.8 ± 1.4^{b}	6.7 ± 1.7^{a}	6.8 ± 1.1^{b}
MPS	5.0 ± 1.8^{c}	6.1 ± 1.5^{b}	5.7 ± 1.5^{ce}	5.9 ± 1.8^{bd}	5.8 ± 1.4^{ce}
SPS	4.2 ± 2.2^{d}	6.4 ± 1.6^{cb}	5.5 ± 1.9^{de}	5.8 ± 2.1^{cd}	5.5 ± 2.1^{de}

*Values are mean scores of 50 panelists ± SD. Samples with different superscripts within the same column were significantly ($p < 0.05$) different. NMA (control) = 5cm; LPS = 5 mm; MPS = 2.5 mm and SPS = 2 mm. Sensory scale 1 = dislike extremely to 9 = like extremely.

significantly different from each other, while MPS and SPS also showed no significant difference among each other. MPS had the lowest mean score but was not significantly different from SPS in the aroma.

The texture of the samples NMA and LPS differed significantly ($p < 0.05$) from all other samples, while MPS and SPS showed no significant difference in texture between each other. The difference observed in NMA and LPS could be attributed to the change in the length of the *Abacha* strips, reducing the ratings of the samples, while samples MPS and SPS were not significantly different from each other and this can be attributed to their particle sizes being close to each other in terms of length size 2.5 to 2 mm, respectively.

For the chewiness attribute, the control sample (NMA) had the highest ratings compared to all other samples evaluated, and a decrease in trend was observed as the particle sizes were reduced in length for all the samples. NMA and LPS were not significantly different from each other but both showed a significant ($p < 0.05$) difference from MPS and SPS. MPS and SPS were also not significantly different from each other. This could be attributed to the fact that LPS is closer in particle size to NMA and MPS and SPS are closer in particle sizes which invariably imparted the judgments of the panellists.

In overall acceptability, NMA was significantly ($p < 0.05$) different from the other samples, however, there was no significant difference between samples MPS and SPS. The degree of likeness decreased as the particle size decreased. The mean scores indicated that all samples were generally accepted, though sample SPS appeared to be the least preferred with a mean score of 5.5. NMA was the most preferred with a mean score of 7.6 which translates to like very much. The low and high mean scores of both SPS and NMA, respectively could be attributed to the smaller particle size of SPS compared to other samples and that of NMA could be a result of the familiarity in the form in which panellists were generally used to *Abacha*. Samples MPS and SPS were not significantly different from each other and this can be attributed to the similarity in particle sizes. Based on the overall acceptability, LPS was closest in preference to the control (NMA) and hence considered the best of the three sizes. LPS was then compared to the control sample (NMA) in terms of the proximate and physicochemical characteristics.

The high consumer acceptability of the commercial *Abacha* may be as a result of the familiarity of the panel members to the form of *Abacha* in which *Abacha* is served as a meal thus, influencing the overall acceptability of the samples of *Abacha* presented as the strip lengths decreased, and it could be assumed that the smaller particle sizes were less accepted.

The sentiments for the *Abacha* samples were represented using a word cloud. This is the pictorial representation of the word frequencies of comments made for the samples in the sensory evaluation, thus the larger the appearance of the word, the higher its frequency of occurrence. Positive and negative sentiments were recorded for all the samples. For SPS the words of the positive sentiment such as “prefer” and “better” had a higher frequency of occurrence. The words “best” and “taste” were next in terms of usage frequency followed by the word “improved” and seen to be the least used word, thus having the least amount of occurrence in the comments made by panellists. The positive comments made by the panellists on sample SPS in the sensory evaluation ranged from the sample having the best taste amongst the other samples, preference of particle size, best in ingredient absorption, better in texture than other samples and further improvement needed on the sample.

The negative sentiments for SPS recorded the words “least” being larger in occurrence than the words “unacceptable” and “bad”. The word “bad” was the least word used by the panellists. The negative comments on sample SPS ranged from the appearance of the sample being unacceptable, bad and should be improved upon. The particle size should be increased as the sample had a sandy mouth feel and it had the least overall acceptability.

The sentiments for NMA were both positive and negative. The positive sentiment words included “best” which showed the highest frequency of usage amongst the samples. Other words such as “prefer”, “taste”, “good”, “like”, “pleasing” and “love” were also used with the word “love” having the least frequency of occurrence. The positive statements made by the panellists for sample NMA ranged from it being the most preferred amongst the other samples, overall best, better in

Table 3. Proximate compositions on NMA and LPS *Abacha* samples.

Sample	Moisture (%)	Ash (%)	Protein (%)	Fibre (%)	Fat (%)	CHO (%)
NMA	13.4 ±0.2[a]	2.5 ± 0.0[a]	1.9 ± 0.0[a]	1.0 ± 0.0[a]	0.5 ± 0.0[a]	80.7 ± 0.2[a]
LPS	9.1 ± 0.0[b]	2.8 ± 0.0[b]	1.9 ± 0.0[b]	1.2 ± 0.0[a]	0.6 ± 0.0[b]	84.4 ± 0.1[b]

Values are mean ± SD of triplicate determinations. Samples with different superscripts within the same column were significantly ($p < 0.05$) different. NMA (control) = 5 cm and LPS = 5 mm.

appearance than other samples, best in taste, best in length size(though this occurred less frequently) and particularly pleasing to chew. The negative sentiments associated with sample NMA were the words “long” and “least”. The sizes of these words show that their frequencies of occurrence were low. The negative comments which were associated with NMA ranged from NMA in terms of length size and MPS being the overall best in the opinion of some panel members. The negative sentiment highlighted was the word “bad” for sample MPS. From the negative comments made by panellists for MPS, it was generally not accepted by some panel members.

The general sentiments of the panellists included words such as “moderate”, followed by words like “above”, “better”, “good” all appeared to have the same frequencies of occurrence, with the words “like”, “best” “okay” and “good” all appeared to be of the same size hence signifying the same level of occurrence in the comments section. The comments of panellists ranged from the general appreciation of the work conducted, which was shown by the high usage of the word “painstaking” (painstaking effort), the samples generally liked and preparation preferences. The negative sentiments from the word cloud display the word “least”. This word represents how the panellists perceived the samples generally and from comments made; samples MPS and SPS received more negative comments, mostly in terms of their appearance.

Proximate composition of *Abacha* commercial and 5 mm abacha strips

The proximate composition of the best sample LPS (5 mm) was compared to the control sample NMA (5 cm) shown in Table 3. There were significant ($p < 0.05$) differences between the samples in proximate composition. The moisture content ranged from 9.1 to 13.4% for LPS and NMA, respectively.

The control sample (NMA) having the higher moisture content compared to LPS indicates that the additional heat treatment (oven drying) that was given to LPS as it was heated at 70°C for 45 min in a hot air oven after crushing and standardizing resulted in low moisture content. The control sample (NMA) was not given a heat treatment as it was analyzed in the form in which consumers who purchase *Abacha* normally process the sample having the least aroma, least taste, least chewiness, too long strip size and an indication for improvement on the characteristic attributes mentioned.

The positive sentiments highlighted include the word “better” which had the highest frequency of occurrence and “best” having the lower frequency of occurrence. The comments ranged from sample MPs being better than before consumption as consumers usually do not pass the product through a heating process before rehydration. The low moisture content of LPS is in agreement with that reported by Ekwu et al. (2009). The final moisture content of LPS (9.11%) after the heat treatment was slightly lower than that reported by Ekwu et al. (2009) which was 9.53% for laboratory prepared *Abacha.* The difference could be a result of differences in the processing methods employed in the work.

The ash content for both samples was significantly ($p < 0.05$) different from each other. The ash content for LPS was higher than that of NMA and this can be as a result of the decrease in moisture content of LPS due to the heat treatment. This significant increase in ash content is in agreement with Onyeike et al. (2010) in which the authors reported that a decrease in moisture content of most root and tuber crops can significantly lead to an increase in their ash content.

In terms of protein content, there was no significant difference between the samples. This can be deduced that the additional heat treatment given to LPS did not affect the protein content significantly ($p > 0.05$). Ngiki et al. (2014) reported that cassava tubers have very low protein content (0.7 to 2.5%) in fresh weight. Thus, a cassava meal must be supplemented with a protein food source (Nagib and Sousa, 2007).

The crude fibre content in both samples showed a significant ($p < 0.05$) difference between them. LPS had a higher value than the control sample (NMA). This increase in the fibre content with a decrease in the moisture content follows the literature work reported by Morgan (2016) that a decrease in the moisture content of cassava leads to a significant increase in crude fibre, hemicellulose and cellulose levels.

The fat content of both samples was significantly ($p < 0.05$) different with LPS having a higher fat content value. *Abacha*, which is a cassava product, is low in fat as cassava has been reported to have very low-fat content (Gomes et al., 2005). Gomes et al. (2005) reported that cassava contains less than 1% fat content when compared to other root crops. The low level of fat in the

Table 4. Physicochemical properties of NMA and LPS *Abacha* samples.

Sample code	pH	TTA (%)	HCN (mg.100 g^{-1})	Phytate (mg.100 g^{-1})	Tannin (mg.100 g^{-1})
NMA	4.5 ± 0.0[a]	0.0 ± 0.0[a]	2.6 ± 0.0[a]	0.5 ± 0.0[a]	0.0 ± 0.0[a]
LPS	4.2 ± 0.0[a]	0.1 ± 0.0[b]	2.5 ± 0.0[b]	0.5 ± 0.0[a]	0.0 ± 0.0[b]

Values are mean ± SD of triplicate determination. Samples with different superscripts within the same column were significantly ($p < 0.05$) different. NMA (control) = 5 cm and LPS = 5 mm.

both samples of *Abacha* means that it is a poor source of fat-soluble vitamins (Promthong et al., 2005). Therefore, the fat content of the samples of *Abacha* is in agreement with the work reported by Gomes et al. (2005).

The carbohydrate content of both samples were significantly ($p < 0.05$) different, with the control sample (NMA) having a lower carbohydrate content than LPS. There was a significant increase in the mean value of the carbohydrate content of LPS. This observed increase in the carbohydrate content in LPS could be an indication that the further processing (heating) of the sample influenced the nutrient availability as also reported by Adepoju et al. (2010).

It can be deduced that the moisture contents of NMA and LPS played an influential role in the nutrient availability in the samples. Thus, a reduction in the moisture content led to an increase in all proximate parameters checked, except in the case of the protein content which showed no significant difference, though the protein content of LPS was slightly higher than that of the control (NMA).

Physicochemical properties of *Abacha*

The physicochemical properties of the best sample were compared to the control sample NMA (control) and LPS (5 mm particle size) *Abacha* shown in Table 4. There exists a significant ($p < 0.05$) difference in the HCN content in both samples as their mean scores varied from 2.6 to 2.5 mg.100 g^{-1} for NMA and LPS, respectively. The low HCN in the samples is as a result of the soaking and drying processes. The lower HCN observed in LPS could be attributed to the further heat treatment it received. This difference observed is supported by the report of Lambri et al. (2013) that the drying process lowered the HCN level by more than 90%. Thus, it is observed that the hydrogen cyanide content in food products decreases by drying and processing operations like soaking and cooking (Cardoso et al., 2005). The HCN content of both samples was lower than the safe level of 10 $mg.kg^{-1}$ recommended by FAO/WHO (Adindu et al., 2003).

The pH for both samples LPS and NMA ranged from 4.2 to 4.5 and showed no significant difference among the samples. Oluwole et al. (2004) reported that the pH of fresh cassava is 6.7. This indicated that the processing carried out on these samples reduced the pH of the *Abacha*. This reduction could be a result of slight fermentation that occurred during processing. Statistically, the additional heat treatment given to sample LPS did not significantly ($p > 0.05$) affect the pH of the sample. Oluwole et al. (2004) also reported that the production of lactic acid as a result of the slight fermentation during the drying of the wet *Abacha* slices could have increased lactic acid, thereby leading to a reduction of the pH of the *Abacha* product.

The titratable acidity (TTA) of the *Abacha* samples ranged from 0.0 to 0.1% for sample NMA (control) and LPS, respectively. Both samples differed significantly ($p < 0.05$) from each other. It can be said that further heat treatment (drying) of sample LPS increased the TTA to 0.1% and this report is in agreement with that reported by Ekwu et al. (2011), where it was reported that drying increased the TTA of wet *Abacha* slices from 0.207 to 0.230%.

The phytate content for NMA and LPS was 0.5% respectively. Statistically, both samples were not significantly different from each other. The phytate values obtained in the result showed that it was much lower than the lethal dose of phytate (250-500 mg.100 g^{-1}) reported by Oyetayo and Oyetayo (2013). The values obtained agreed reasonably well with the phytate levels reported by Okpala and Okoli (2011) which was between 0.45 and 0.70 mg.100 g^{-1} for a root crop product. The result showed a reduction in the phytate level of the sample compared to that of fresh unprocessed cassava with a reported phytate content of 226 mg.100 g^{-1} by Oyetayo and Oyetayo (2013), which indicates that processing caused a large reduction in the phytate levels of the *Abacha* samples. Oyetayo (2006) also reported that phytate concentrations in cassava were reduced by fermentation, soaking and heating methods. Fermentation makes use of microbes, some of which secrete phytases that hydrolyze a significant portion of phytate, reducing its affinity for various actions (Oyetayo, 2006; Oboh et al., 2003).

The value obtained for tannins in both samples showed that the presence of tannins in the samples were extremely low, tending to not being present. From the result, we can say that processing significantly reduced the tannin levels in *Abacha* to levels that may be considered insignificant. This low value of tannins present in these samples would make them suitable for human consumption as the consumption of high concentrations of tannins in a food product can be deleterious to health. Tannin being a secondary phenolic plant metabolite with

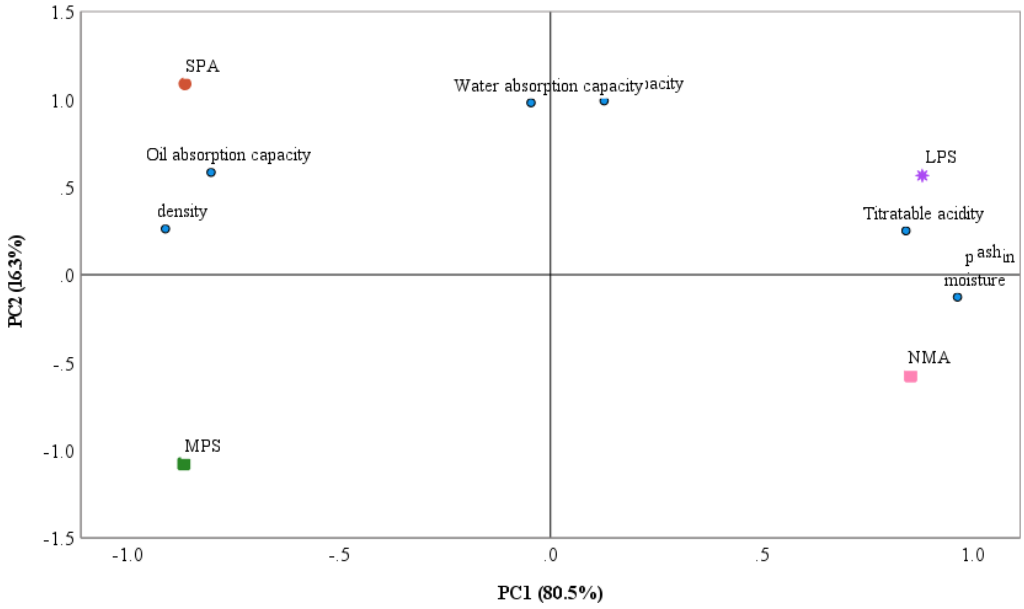


Figure 2. Principal Components for the Variation in *Abacha* Characteristics. NMA (control) = 5 cm, LPS = 5 mm, MPS = 2.5 mm and SPS = 2 mm.

one or more hydroxyl substrates bonded to an aromatic ring, tannin produces anthocyanoside, a toxic product on acid degradation (Getachew et al., 2000; Han et al., 2007).

Principal components describing the variation in *Abacha* characteristics

Principal component analysis (PCA) helps to visualize the most important information held in a data set. PCA finds the groupings of variables that explain the main trends in the data set from the principal component chart shown in Figure 2. There are two components - principal component 1 (PC 1) and principal component 2 (PC 2). The largest possible variance which accounts for as much of the variability in data is seen in PC 1. The samples can be categorized into three groups. NMA (5 cm) and LPS (5 mm) are in one group, SPS (2 mm) in the second group and MPS (2.5 mm) in the third group. Samples NMA and LPS are in group 1 and related to PC 1 accounting for 80.5% variation. These samples are high in proximate and physicochemical properties compared to the others. PC 2 accounting for 16.3% variation correlates to SPS which is higher in functional properties (bulk density, water absorption capacity and swelling capacity) than the other samples. MPS which is the third group is lower than all the other samples in functional, proximate and physicochemical properties.

Conclusions

By crushing the commercial *Abacha* strips in a hammer mill and passing the crushed product through different sieves with varying mesh sizes it was possible to produce three standardized particle sizes 2, 2.5 and 5 mm. The commercial *Abacha* (5 cm) and the 5 mm strips were high in proximate and physicochemical properties compared to the others. The 2 mm strips were higher in functional properties (bulk density, water absorption capacity and swelling capacity) than the other samples. The 2.5 mm strips were lower than all the other samples in functional, proximate and physicochemical properties. Though the commercial *Abacha strips* were preferred to the other samples when eaten as a meal of *Abacha Ncha*, the other samples could be highly accepted if used in other meal forms such as porridge or breakfast cereal. Consumer acceptability of the samples prepared from the commercial *Abacha* indicated the possibility of using different particle sized strips thereby expanding the use of *Abacha.*

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abu JO, Badifu GTO, Akpapunam MA (2006). Effect of crude palm oil inclusion on some physicochemical properties of gari –A fermented cassava Food product. Nigerian Food Journal 24(1):73-75.

Adebowale YA, Adeyei IA, Oshodi AA (2005). Functional and physicochemical properties of flour from six Mucuna Species. African Journal of Biotechnology 4(12):1461-1468.

Adepoju OT, Adekola Y, Mstapha SO, Ogunola SI (2010). Effect of processing on nutrient retention and contribution of cassava

(*Manihot* spp) to nutrient intake of consumers. African Journal of Food Agriculture Nutrition and Development 10(2):2099-2111.
Adindu MN, Olayemi FF, Nze-Dike OU (2003). The cyanogenic potential of some cassava products in Port Harcourt markets in Nigeria. Journal of Food Composition and Analysis 16:21-24.
Alves AAC (2002). Cassava Biology, Production and Utilization. CABI Publishing, Wallingford, UK pp. 67-89.
Association of Official Analytical Chemists (AOAC) (2010). Official Methods of Analysis. 18th ed. Association of Official Analytical Chemists, Washington, D.C., U.S.A.
Bankole Y, Tanimola A, Odunukan R Samuel D (2013). Functional and nutritional characteristics of cassava flour (lafun) fortified with soybeans. Journal of Educational and Social Research 3(8):163-172.
Bradbury MG, Egan S, Bradbury JH (1999). Picrate paperkits for determination of total cyanogens in cassava roots and all forms of cyanogens in cassava products. Journal of the Science of Food and Agriculture 79(4):598-601.
Busie MD, Alamu EO, Popoola IO, Yomeni M (2017). Nutritional and Sensory Properties: Snack food made from high-quality cassava flour and legume blend. Food Science and Nutrition Journal 5(3):805-811.
Cardoso AP, Mirione E, Ernesto M, Massaza F, Cliff J, Haque RM, Bradbury JH (2005). Processing of cassava roots to remove cyanogens. Journal of Food Composition and Analysis 18(5):451-460.
Chisenga SM, Workneh TS, Bultosa G, Laing M (2019). Characterization of physicochemical properties of starches from improved cassava varieties grown in Zambia. AIMS Agriculture and Food 4(4):939-966.
Ekwu FC, Ngoddy PO, Aniekwe CO (2009). *Abacha* making qualities of selected cassava varieties. Nigerian Food Journal 27(1):49-58.
Ekwu FC, Ngoddy PO, Uvere PO (2011). Functional and rheological properties of cassava flour processed by adaptation of traditional "*abacha*" processing technology. Journal of Raw Materials Research 9(1):17-30.
Ekwu FC, Ngoddy PO, Uvere PO (2014). Effect of processing on the quality of flour, slices and its flour derived from cassava (*Manihot esculenta* Crantz) TMS97/4779. African Journal of Food Science 8(9):476-483.
Food and Agriculture Organization (FAO) (2014). Why Cassava? http://www.fao.org/ag/agp/agpc/gcds/index_en.html. Accessed on 21/01/2018.
Getachew G, Makkar HPS, Becker K (2000). Effect of polyethylene glycol on *in-vitro* degradability of nitrogen and microbial protein synthesis from tannin-rich browse and herbaceous legumes. British Journal of Nutrition 84(1):73-83.
Gomes E., Souza SR, Grandi RP, Silva RD (2005). Production of thermostable glucoamylase by newly isolated *Aspergillus flavus* A1. 1 and *Thermomyces lanuginosus*A13 37. Brazil Journal of Microbiology 36:75-82.
Han X, Shen T, Lou H. (2007). Dietary polyphenols and their biological significance. International Journal of Molecular Sciences 8(9):950-988.
Kirk RS, Sawyer R (1998). Pearson's Composition and Analysis of Foods. 9th edition. Churchill Livingstone Edinburgh pp. 17-20.
Lambri M, Fumi MD, Roda A, De Faveri DM (2013). Improved processing methods to reduce the total cyanide content of cassava roots from Burundi. African Journal of Biotechnology 12(19):2685-2691.
Maxiya-Dixon B, Dixon AGO, Adebowale AA (2007). Targeting Different End Uses of Cassava, Genotypic Variation for Cyanogenic Potentials and Pasting Properties International Journal of Food Science and Technology 42(8):969-976.
Meridian Institute (2013). Cassava Value Chain Overview. Innovations for Agricultural Value Chains in Africa: Applying Science and Technology to Enhance Cassava, Dairy, and Maize value chains. http://www.merid.org/en/value-chain-innovations/Examples.aspx Accessed on 18/01/2018.
Morgan NK (2016). Cassava: Nutrient Composition and nutritive value in poultry diets. Journal of Animal Nutrition 2(4):253-261.
Nagib MA, Sousa MV (2007). Amino acid profile in cassava and its interspecific hybrid. Genetic and Molecular Research Journal 6(2):292-297.
Ngiki YU, Igwebuike JU, Moruppa SM (2014). Utilization of Cassava Products for Poultry feeding: A review. International Journal of Science and Technology 2(6):48-59.
Nwanekezi EC, Ohagi NC, Afam-Anene OC (2001). Nutritional and organoleptic quality of infant formulation from natural and solid statefermented tubers (cassava, sprouted and unsprouted yam) – soybean flours blend. Nigerian Food Journal 19:55-62.
Obilie EM, Tano-Debrah K, Amoa-Awua WK (2004). Souring and breakdown of cyanogenic glucosides during the processing of cassava into akyeke. International Journal of Food Microbiology 93(1):115-121.
Oboh G, Akindahunsi AA, Oshodi AA (2003). Dynamics of phytate-zinc balance of fungi fermented cassava product (gari and flour). Plant Food for Human Nutrition Journal 58(3):1-7.
Okpala LC, Okoli EC (2011). Nutritional evaluation of cookies produced from pigeon pea, cocoyam and sorghum flour blends. African Journal of Biotechnology 10(3):433-438.
Oluwole OB, Olantunji O, Odunfa SA (2004). Process technology for conversion of dried cassava chips into gari. Nigerian Food Journal 22(1):66-77.
Omah EC (2012). Production and evaluation of baked and extruded snacks from blends of millet, pigeon pea and cassava cortex flour. M. Sc. Thesis, Department of Food Science and Technology, University of Nigeria, Nsukka.
Onyeike EN, Akaninwor JO, Ifemeje JC (2010). Effect of Heat Processing on the Proximate Composition and Energy Values of. Selected Nigerian Staple Foods from Oil Producing Areas of the Niger Delta. Journal of Nigerian Society for Experimental Biology 20(1):1-9.
Oyetayo FL, Oyetayo VO (2013). Phytate-zinc dynamics of retted cassava product "pupuru" processed with water from different sources. Journal of Biological and Scientific Opinions 1(3):142-144.
Oyetayo VO (2006). Nutrient and Anti-Nutrient Content of Cassava Steeped in Different Types of Water for "Pupuru" Production. Research Journal of Microbiology 1(5):423-427.
Pearson D (1976). The Chemical Analysis of Foods 7th Edition. London: Churchill Livingstone.
Promthong S, Kanto U, Tivawattanawanich C, Tongyai S, Isariyodom, S, Markvichtr K (2005). Comparison of Nutrient Compositions and Carbohydrate Fractions of Corn, Cassava Chip and Cassava Pellet Ingredients. Proceedings of 43rd Kasetsart University Annual Conference, Thailand pp. 211-220.
Sanni LO, Adebowale AA, Awoyale W, Fetuga GO (2008). Quality of gari (roasted cassava mash) in Lagos State, Nigeria. Nigerian Food Journal 26(2):125-134.
Sanni LO, Onadipe OO, Ilona P, Mussagy MD, Abass A, Dixon AGO (2009). Success and challenge of cassava enterprises in West Africa: A case study of Nigeria, Benin and Sierra Leone. International Institute of Agriculture (IITA). www.iita.org
Tonukari NJ (2004). Cassava and the Future of Starch. Electronic Journal of Biotechnology 7(1):2004.

Vol. 16(3) pp. 81-91, March 2022
DOI: 10.5897/AJFS2021.2121
Article Number: 67AFF9C68846
ISSN: 1996-0794

http://www.academicjournals.org/AJFS

ACADEMIC JOURNALS
expand your knowledge

African Journal of Food Science

Full Length Research Paper

Nutritional and sensory quality of a sorghum snack supplemented with sesame and baobab fruit powder

David Edgar Kimani[1*], Catherine Nkirote Kunyanga[1] and Eliud Kahiu Ngugi[2]

[1]Department of Food Science, Nutrition and Technology, University of Nairobi, Kenya.
[2]Department of Plant Science and Crop Protection, University of Nairobi, Kenya.

Received 26 May, 2021; Accepted 9 February, 2022

Sorghum, sesame seeds and baobab fruit are commercially viable, underutilized crops in sub-Saharan Africa with potential for use in development of high-quality value-added products for food and nutritional security. This study evaluated effects of processing methods on the nutritional and sensory attributes of a ready to eat snack bar developed from sorghum supplemented with sesame and baobab fruit pulp powder. The moisture content ranged between 6.38 and 10.28%, total fiber content ranged between 5.59 and 10.455 g/100 g while protein and fat content ranged between 11.28 and 16.74 g/100 g and 9.65 g/100 g and 18.58 g/100 g, respectively. The carbohydrates content in the snack bars ranged between 46.37 and 60.31 g/100 g, while energy content averaged 426.33 kcal/100 g for raw materials and 414.38 kcal/100 g for formulated snack bars. Concentrations of iron, calcium and zinc ranged between 5.46 and 14.611 mg/100 g, 82 and 246 mg/100 g, and 1.377 and 4.98 mg/100 g, respectively. Sensory evaluation of the bars formulations was based on a 5-point hedonic scale and revealed significant differences ($p<0.05$) in color, taste and overall acceptability. The aroma and crunchiness of the snacks were not significant. The study found underutilized crops have the versatility to improve the range of products and spur innovation in new product development.

Key words: Sorghum, sesame, baobab, malting, roasting, fermentation, supplementation.

INTRODUCTION

Sorghum is an important underutilized cereal in Africa due to its drought resistance (Chikuta et al., 2014). Ranked the fifth most important cereal, sorghum provides protein and energy through gruels to many people in sub-Saharan Africa (Pelembe et al., 2002). The biochemical composition in sorghum structure generally compares with other cereals with some minor compositions (Taylor and Kruger, 2019). Sorghum is high in fiber content, protein though deficient in lysine content, starch and good distribution of micronutrients albeit in low levels (Serna-saldivar et al., 2019). In addition, sorghum has limiting levels of sulphur containing amino acids such as cysteine and methionine (Pelembe et al., 2002). Hence, there is the need to complement the biochemical composition of sorghum with an oil seed such as sesame for protein and polyunsaturated fatty acids (Hegde, 2012)

*Corresponding author. E-mail: davidkedgar@gmail.com.

and baobab fruit which is noted for its ascorbic acid and mineral content (Aluko et al., 2016).

Sesame (*Sesamum indicum* L.) is an important oil seed that is widely grown in some parts of Africa and Asia (Asghar et al., 2014). Sesame seed is noted for its high protein content at ranges of 17 to 32% and abundant quantities of oil at 40 to 50% and laden with tocopherols (Gharby et al., 2015). In addition, sesame is rich in calcium, phosphorous and iron (Onsaard, 2012). Thus, sesame seeds have found a multitude of uses across the food industry such as processing of margarines, oil, sauces (Hiremath et al., 2010) but not limited to production of soaps and lubricants in the non-food niche (Nyongesa et al., 2013). However, despite the nutritional and industrial importance of sesame, its cultivation and yield remains low in Kenya averaging 400 kg ha^{-1} (Nyongesa et al., 2013), with its range of applications limited to roasted seeds and sesame oil (Koitilio et al., 2018).

Further, it has been shown that Baobab (*Adansonia digitata* L., Malvaceae) is localized in lower Eastern and coastal parts of Kenya where it remains as a wild undomesticated tree (Muthai et al., 2017). The importance of baobab is underpinned as the tree is composed of edible leaves, seeds and fruit pulp (Muthai et al., 2017). The baobab fruit pulp is particularly noted for its high ascorbic acid content reported at 337 mg/100 g pulp (Momanyi et al., 2020). The pulp has significant levels of micronutrients particularly calcium, zinc and potassium (Aluko et al., 2016), however, it has low levels of protein and fat content (Momanyi et al., 2020).

These orphan crops have been underutilized in production of value-added products for commercialization. In sub-Saharan Africa, a significant portion of sorghum is utilized in form of thin and thick gruels (Kilambya, 2013), for sesame, it has been used widely as roasted snack balls and as toppings in baked goods (Amoo et al., 2017) while baobab fruit remains largely unexploited. Therefore, there is need for diversifying these crops for end products that are nutritious, convenient aligned to increased consumer awareness. Popkin (1999) noted increased nutrition shift towards consumption of superior grains of rice, wheat and maize while indigenous cereals such as sorghum have been neglected and christened a poor man's crop (Hadebe et al., 2017; Orr, 2017). Snacks are ready-to-eat products which have been characterized by high calorie, low nutritional density and has contributed to increased incidences of lifestyle diseases such as diabetes and cardiovascular diseases (Popkin, 2015; Bhurosy and Jeewon, 2016). Development of sorghum-based snacks has yet to be fully exploited, and which has the potential to improve its utilization.

In particular is sorghum, which is laden with anti-nutrients that can chelate available micronutrients (Singh et al., 2016). As a result, sorghum is reported to have a poor starch and protein digestibility (Taylor and Taylor, 2017). Traditional processing methods of malting and fermentation have a profound effect on the digestibility of sorghum. Prior studies have revealed that fermentation and malting processes lead to a surge in the endogenous activity of sorghum via *de novo* activation of inherent phytases (Onyango et al., 2013). Roasting has the effect of imparting desirable sensory qualities whilst also denaturing anti-nutrient factors such as trypsin inhibitors (Adedeji et al., 2015; Msheliza et al., 2018).

The potential of incorporating these components in developing a nutritious ready-to-eat snack bar will improve their utilization, whilst alleviating consumer health concerns regarding snacks. This study was aimed at formulating and analyzing the effect of sorghum treatment methods and incorporation of sesame and baobab on the nutritional and biochemical composition of the developed snack bar.

MATERIALS AND METHODS

Sample preparation

Sorghum (*Sorghum bicolor* L. Moench) and sesame (*S. indicum* L.) seeds were sourced from Kangemi market, Nairobi while dried baobab fruits were sourced from Makueni County, Kenya. Preliminary steps of cleaning, grading, removal of broken kernels and foreign matter were done at the Department of Food Science, Nutrition and Technology, College of Agriculture and Veterinary Sciences, University of Nairobi.

Sorghum grains were prepared in three batches through malting, fermentation and roasting processes. The sorghum grains were steeped in water (2:1, w/v) for 18 h, the malted batch was placed in damp muslin cloths and allowed to germinate for 72 h. For the roasted batch, the steep grains were air-oven dried at 105°C for 3 h, and thereafter roasted at 180°C for 15 min in an open pan. For the fermented batch, the steeped cereals were oven dried at 105°C for 3 h and milled into 1 mm particle size. The flour was added to potable water followed by spontaneous fermentation by lactic acid fermentation under anaerobic conditions for 48 h. The fermented flour was oven dried at 105°C for 3 h and milled back into 1 mm flour.

Sesame seeds were cleaned, and steeped in water for 18 h. Sesame seeds were dehulled by method described by Inyang and Ekanem (1996) with some modifications. The steeped seeds were soaked in 10% NaCl solution for 12 h. The seeds were thereafter consecutively washed thoroughly with water and rubbed by hands so as to decorticate them. The water was drained off and the seeds air oven-dried at 65°C for 3 h. The dried seeds were separated from the hulls by winnowing thereafter pan roasted at 110°C for 15 min in a pan to impart desirable sensory qualities.

The baobab fruits were cleaned and the dried pulp scrapped out with a knife on clean containers. The seeds were separated from the scraped-out pulp. The pulp was crushed in a blender (Krups, Model Type KB703, Mayenne - France) which reduced the pulp to fine particles of 1 mm.

Formulation(s) of ready-to-eat snack bars

The formulations consisted of fermented, malted and roasted sorghum, roasted sesame and baobab fruit modeled in a 3 × 4 full factorial experiment by Nutrisurvey 2007 version (Erhardt, 2007) and Momanyi et al. (2020). Baobab fruit pulp powder substitution

Table 1. Experimental design of the various formulations

Formulation	Factors		
	Roasted	Malted	Fermented
Formulation 1	RSF1	MSF1	FSF1
Formulation 2	RSF2	MSF2	FSF2
Formulation 3	RSF3	MSF3	FSF3
Formulation 4	RSF4	MSF4	FSF4

RS = Roasted sorghum, MS = Malted sorghum, FS = Fermented sorghum.

Table 2. Basic formulation of a sorghum lunch bar.

Ingredients	Samples			
	F1	F2	F3	F4
Sorghum (%)	60	70	80	100
Sesame (%)	25	20	15	0
Baobab fruit pulp powder (%)	15	10	5	0
Sugar (g)	70	70	70	70
Margarine (g)	70	70	70	70
Xanthan gum (%)	1	1	1	1
Egg (ml)	10	10	10	10

levels were determined by Momanyi et al. (2020) owing to their astringency nature in levels above 20%. Table 1 shows the factors and formulations developed.

The sorghum flour variations were added at different proportions with dry ingredients of sugar, hydrogenated margarine, egg white and xanthan gum, and were stirred vigorously. The ingredients were standardized for all factors of roasting, malting and fermentation. Xanthan gum was added as a binding agent at 1% level of total flour weight (Shittu et al., 2009; Preichardt et al., 2011). The liquid egg white functioned as an emulsifying agent, while the margarine was added to improve the texture of the dough, due to the rough texture of sorghum attributed to the coarse grits formed during milling which causes a sandy mouthfeel (Onyango et al., 2011) while also replacing the use of water. To this mixture, sesame paste was incorporated and it was stirred well. The sesame paste was prepared by taking the previously dehulled roasted sesame seeds and grinding them into a fine paste in a blender (Krups, Model Type KB703, Mayenne - France). The dough was placed in pre-molds and baked at 130°C for 30 min. Baobab fruit pulp was sprinkled on the formulations, then remolded and packaged. Table 2 indicates the ingredient formulation for the snack.

Nutritional analysis

The nutritional content of the snack bars was determined as per AOAC (2005) methods in terms of moisture content (method 930.15), crude protein (N 6.25) by the Kjeldahl method (method 978.04), crude fibre (method 978.10) and crude fat (method 930.09). Carbohydrate content of the snack was by difference method as described in AOAC (2000). Total energy of the snacks was determined as per the formula described by Momanyi et al. (2020):

Total energy (kcal/100 g) = [(%Carbohydrates × 4) + (%Protein × 4) + (Fat × 9)]

Mineral analysis

Iron, calcium, and zinc were determined by wet digestion method as described by Palma et al. (2015). 0.5 g of sample(s) was digested by HNO_3:$HClO_4$ (2:1) at 260°C for 3 h. Thereafter, the samples were topped up with 50 ml distilled water. The specific minerals of Fe, Zn and Ca were determined by AAS spectrophotometry (Model 210 VGP). Standards solutions of Fe, Zn, and Ca were prepared and used to prepare a calibration curve. Fe was measured at 248 nm, Zn at 213.9 nm and Ca at 422.7 nm. Concentration was calculated as:

((Absorbance - Blank) / 10 × Sample weight) × V = mg/100 g

Where V = is the volume of distilled water topped up to the mark.

Sensory analysis

The sorghum snack bar was assessed by a semi-trained panel consisting of undergraduate, postgraduate students and staff from the Department of Food Science and Technology at the University of Nairobi. A 5-point hedonic scale (1= dislike extremely to 5= like extremely) was used to assess color, taste, crunchiness, aroma and overall acceptability. Clean water was provided to the panelists for rinsing their mouths after evaluating each sample so as to minimize errors during the process.

Statistical analysis

The analysis was done in duplicates. Collected data was statistically analyzed by GenStat software version 15.0 at $P<0.05$ significance level. Data was subjected to a one-way ANOVA to determine the least significant difference at $p \leq 0.05$ and post hoc mean separation and comparisons performed by Tukey's multiple range test.

Table 3. Nutritional composition of the roasted, malted and fermented blends in dry matter basis

Factor	Sample	Parameter					
		Moisture (%)	Protein (%)	Fiber (%)	Fat (%)	Carbohydrates (%)	Energy (kcal/100 g)
Raw unprocessed samples	Sorghum	4.83±0.13^{b}	10.37±0.12^{b}	6.46±0.39^{a}	3.38±0.11^{b}	74.96±0.76^{g}	371.7±1.53^{a}
	Sesame	6.60±0.10^{c}	19.98±0.09^{h}	5.61±0.03^{a}	37.65±1.41^{h}	30.16±1.39^{a}	539.4±6.77^{e}
	Baobab	3.09±0.09^{a}	4.89±0.10^{a}	5.60±0.24^{a}	0.53±0.16^{a}	85.90±0.20^{h}	367.9±0.20^{a}
Roasted sorghum formulations	RSF1	8.31±0.38^{cd}	16.74±0.34^{h}	8.18±0.08^{b}	18.58±0.39^{fg}	48.20±0.25^{b}	426.9±3.14^{d}
	RSF2	6.84±0.17^{ab}	15.20±0.63^{fgh}	6.26±0.04^{a}	15.69±0.27^{cd}	55.82±0.83^{de}	425.3±1.59^{d}
	RSF3	6.39^{a}±0.34^{a}	13.65±0.29^{def}	5.59±0.20^{a}	14.52±0.19^{c}	57.75±0.65^{f}	424.7±3.11^{d}
	RSF4	8.78±0.22^{d}	13.27±0.70^{de}	7.65±0.39^{a}	12.55±0.21^{b}	59.85±0.06^{ef}	397±1.71^{c}
Malted sorghum formulations	MSF1	9.21±0.14^{e}	14.90±0.61^{efg}	7.90±0.03^{b}	19.45±0.53^{g}	48.54±0.03^{b}	428.8±2.21^{d}
	MSF2	9.67±0.31^{e}	13.67±0.39^{def}	6.51±0.05^{a}	17.42±0.39^{ef}	52.73±0.36^{c}	422.4±3.38^{d}
	MSF3	10.29±0.43^{f}	12.12±0.36^{bcd}	6.44±0.06^{a}	17.53±0.07^{ef}	53.63±0.06^{cd}	420.7±1.82^{d}
	MSF4	9.94±0.30^{e}	11.28±0.57^{abc}	7.62±0.33^{b}	11.46±0.46^{b}	59.71±1.66^{ef}	387.1±0.22^{bc}
Fermented sorghum formulations	FSF1	9.90±0.002^{e}	15.51±0.29^{gh}	8.49±0.20^{b}	19.73±0.15^{g}	46.37±0.64^{b}	425.1±0.08^{d}
	FSF2	7.72±0.35^{bcd}	14.45±0.22^{efg}	8.10±0.07^{b}	16.65±0.04^{de}	53.08±0.01^{cd}	420±1.30^{d}
	FSF3	6.79±0.26^{ab}	13.37±0.33^{de}	8.46±0.58^{b}	15.67±0.52^{cd}	55.71±0.65^{de}	417.3±5.95^{d}
	FSF4	7.28±0.07^{abc}	12.31±0.37^{cd}	9.46±0.46^{c}	9.65±0.31^{a}	60.31±0.33^{f}	377.3±0.02^{ab}

Mean values of duplicate with different superscript in a column are significant at $p<0.05$. Means separated and compared with Tukey's test.

RESULTS

Moisture content

The moisture content of the formulations is shown in Table 3. There were significant differences in all formulations ($p<0.05$) with values ranging from 6.39 to 10.29% DM. The raw unprocessed samples were 4.83, 6.60, and 3.09% for sorghum, sesame and baobab, respectively. The roasted sorghum formulations had moisture content values ranging from 6.39 to 8.78% DM. Malted sorghum formulation moisture levels ranged between 10.29 and 9.21% DM while fermented sorghum formulations ranged between 6.79 and 9.90% DM. The moisture values in malted sorghum had slightly elevated moisture levels as compared to roasted and fermented sorghum formulations.

Protein

There were significant differences ($p<0.05$) in the protein content in the formulations. Roasted sorghum formulations had protein content levels ranging between 13.27 and 16.74%, malted sorghum formulations ranged between 11.28 and 14.90%, whereas fermented sorghum formulations ranged between 12.31 and 15.51%/100 g DM (Table 3). The unprocessed sesame had high overall protein content (19.98%) compared to sorghum (10.37%) and baobab fruit pulp (4.89%). The trend in all formulations showed a decrease in protein content with low sesame supplementation. Thus, the trend indicated higher sesame substitution levels at 25% have a positive net improvement in overall protein content. Formulations RSF4, MSF4, and FSF4 had least protein levels as they had no sesame in them. In addition, roasted and fermented sorghum formulations had improved protein content as compared to malted sorghum formulations which were slightly lower compared to the two.

Fiber

The fiber content of the samples is presented in Table 3. The formulations had improved fibre content as compared to the raw unprocessed samples. The fiber levels were not significant ($p>0.05$) for the raw unprocessed samples at 6.46, 5.61 and 5.60% for sorghum, sesame and baobab fruit pulp respectively. Significant differences ($p<0.05$) among the roasted formulation of RSF1, malted formulation of MSF1 and MSF4 and fermented formulation FSF4, respectively. Crude fibre content ranged between 5.59 and 8.18% for roasted sorghum formulations, 6.44 and 7.90% for malted sorghum formulations and 8.10 and 9.46% for fermented sorghum formulations, respectively. The trend expresses the fermented sorghum formulations to have improved fiber content as compared to roasted and malted sorghum formulations. In addition, sesame seeds substitution had no marked impact on overall fiber levels.

Fat

The fat content in the snack bar formulations is as presented in Table 3 was significant at $p<0.05$. The raw unprocessed sesame seeds had the highest fat content (37.65%) compared to raw sorghum (3.38%) and baobab fruit pulp (0.53%) which had the least content. Roasted sorghum formulations fat content levels ranged between 12.55 and 18.58%, malted sorghum formulations ranged between 11.46 and 19.45%, while fermented sorghum formulations fat levels were between 9.65 and 19.73% (Table 3).

Carbohydrates and energy content

The carbohydrate content of the formulations is shown in Table 3. There was significant differences ($p<0.05$) in the carbohydrate content across the various formulations with roasted sorghum formulations had carbohydrate content ranging between 48.20 and 59.85%/100 g DM, malted sorghum formulations ranged between 48.54 and 59.71%/100 g DM and fermented sorghum formulations at 46.37 and 60.31%/100 g DM.

Table 3 presents the energy content expressed in kcal/100 g of the formulations. The roasted sorghum formulations energy content was between 397 and 426.9 kcal/100 g, malted sorghum formulations were between 387.1 and 428 kcal/100 g and fermented sorghum formulations were between 377.3 and 425.1 kcal/100 g.

Mineral content

Iron content was high in raw sesame (157.76 mg/100 g) as compared to sorghum and baobab fruit pulp powder. Iron content in all formulations were significantly different at $p<0.05$ with RSF1 recording highest content at 14.61 mg/100 g. The roasted sorghum formulations iron content ranged between 6.39 to 14.61 mg/100 g, malted sorghum formulations at 5.46 to 11.44 mg/100 g, and fermented sorghum formulations were at 6.48 to 11.45 mg/100 g.

The calcium content varied significantly ($p<0.05$) among the snacks. The trend shows improved calcium levels in the formulations. Roasted sorghum formulations had calcium content between 82 to 227.2 mg/100 g, malted sorghum formulations were between 131.5 and 246.7 mg/100 g, whilst fermented sorghum ranged between 122.1 and 171.5 mg/100 g. The formulation(s) MSF1 recorded the highest concentration (246.7 mg/100 g) while RSF4 recorded the least amount at 82 mg/100 g. High calcium content was realized at 15% baobab supplementation level in RSF1, MSF1 and FSF1.

The zinc content varied significantly ($p<0.05$) among the formulations with roasted formulations ranging between 1.38 and 4.82 mg/100 g, malted sorghum formulations ranged between 2.30 and 4.98 mg/100 g and fermented sorghum zinc content ranged between 1.73 and 2.95 mg/100 g (Table 4). The processing effect on zinc content was not significant ($p>0.05$) across the formulations, but higher zinc contents were observed with increase in sesame seeds and baobab fruit pulp concentrations.

Sensory analysis results

Table 5 presents the sensory scores of the sorghum-based snack bars. The results show that the sensory perception of color, aroma, taste crunchiness and the overall acceptability of the snack bars were not significantly different ($p>0.05$) across the treatments of roasted-, malted-, and fermented sorghum-based snack bars.

DISCUSSION

Moisture content

Cereal snack products are normally associated with low moisture levels primarily attributed to processing techniques involving heat treatment. Moisture content ranges as outlined in Table 3 are in agreement with Momanyi et al. (2020) who reported moisture levels between 9.43 and 9.5%. The slight increase in water content could be attributed to sesame which in its composition has elevated moisture levels. The malted sorghum formulations had slightly elevated moisture levels which could be attributed to release of metabolic water during malting and resultant drying regimes (Asuk et al., 2020). Low moisture content in cereal baked goods is essential in maintaining the microbiological integrity thus extending their shelf life (Kince et al., 2017). Yeast and molds are common spoilage microorganisms in low moisture cereal products and thus water activity below 0.65 is preferable in retarding their growth.

Protein content

High supplementation of sesame seeds at 25% in the formulations resulted in protein quality enhancement in the snack bars (Table 3). The trend in crude protein content in the roasted, malted and fermented sorghum snack bars decreased with decreased supplementation of roasted sesame (Figure 1). Sesame seeds have been profiled to contain up to 18 to 25% protein (Tenyang et al., 2017) and rich in essential amino acids tryptophan and methionine (Lawal et al., 2019). In addition, dehulling roasting sesame seeds had no effect on protein quantity which agrees with studies by Lawal et al. (2019). Thus, by supplementing sesame seeds, there is overall improvement in overall protein quality which is essential

Table 4. Mineral composition of the roasted, malted and fermented blends in dry matter basis.

Formulation	Sample	Parameter		
		Iron (mg/100 g DM)	Calcium (mg/100 g DM)	Zinc (mg/100 g DM)
Raw unprocessed samples	Sorghum	72.52±1.38^{d}	179.5±0.95^{cd}	25.35±1.91^{b}
	Sesame	157.76±3.16^{f}	124.49±28.16^{f}	119.60±2.97^{d}
	Baobab	138.55±4.47^{e}	155.96±28.90^{g}	52.47±2.08^{c}
Roasted sorghum formulations	RSF1	14.61±0.17^{c}	227.2±2.45^{de}	4.82±0.54^{a}
	RSF2	8.47±0.01^{ab}	161.1±3.02^{c}	4.24±0.99^{a}
	RSF3	8.38±0.23^{ab}	101.8±2.07^{ab}	2.56±0.88^{a}
	RSF4	6.39±0.30^{ab}	82±3.18^{a}	1.38±0.08^{a}
Malted sorghum formulations	MSF1	11.44±0.03^{bc}	246.7±23.96^{e}	4.98±0.20^{a}
	MSF2	6.49±0.51^{ab}	153.6±15.16^{bc}	2.95±1.32^{a}
	MSF3	6.79±0.03^{ab}	149.1±15.37^{bc}	2.93±0.55^{a}
	MSF4	5.46±0.63^{a}	131.5±11.25^{abc}	2.30±1.02^{a}
Fermented sorghum formulations	FSF1	11.45±0.32^{bc}	171.5±11.32^{cd}	2.95±0.24^{a}
	FSF2	11.45±0.01^{bc}	166.8±5.10^{c}	2.17±1.14^{a}
	FSF3	8.18±0.12^{ab}	145.4±6.21^{bc}	1.83±0.11^{a}
	FSF4	6.48±0.55^{ab}	122.1±13.12^{abc}	1.73±0.88^{a}

Mean values of duplicate with different superscript in a column are significant at p<0.05. Means separated and compared with Tukey's test.

Table 5. Sensory evaluation of the prepared lunch bar snacks.

Sample	Parameter				
	Color	Aroma	Taste	Crunchiness	Overall acceptability
RSF1	3.62±0.99^{ab}	3.21±1.12^{a}	3.24±1.10^{ab}	3.12±1.34^{a}	3.35±1.07^{abc}
RSF2	3.41±0.82^{ab}	2.94±1.13^{a}	3.47±1.16^{ab}	3.15±1.33^{a}	3.27±0.09^{abc}
RSF3	3.59±1.10^{ab}	2.85±1.16^{a}	3.24±1.10^{ab}	3.29±1.14^{a}	3.12±0.91^{abc}
RSF4	3.59±1.13^{ab}	3.32±1.09^{a}	3.65±0.98^{b}	3.29±1.32^{a}	3.85±0.99^{c}
MSF1	3.50±0.96^{ab}	2.77±1.23^{a}	2.56±1.13^{a}	2.77±1.10^{a}	2.77±1.05^{a}
MSF2	2.91±1.22^{a}	2.82±1.09^{a}	3.00±1.28^{ab}	3.56±1.21^{a}	2.97±1.17^{ab}
MSF3	3.41±1.21^{ab}	2.91±1.26^{a}	2.62±1.18^{a}	2.88±1.09^{a}	3.09±1.08^{abc}
MSF4	3.47±1.11^{ab}	3.21±1.07^{a}	3.71±0.80^{b}	3.59±1.16^{a}	3.53±0.99^{abc}
FSF1	3.82±0.72^{b}	2.88±1.15^{a}	3.03±1.47^{ab}	3.21±1.25^{a}	3.38±1.21^{abc}
FSF2	3.91±0.79^{b}	3.09±1.08^{a}	2.97±1.17^{ab}	3.24±1.16^{a}	3.15±0.99^{abc}
FSF3	3.18±1.03^{ab}	3.00±1.10^{a}	2.94±1.35^{ab}	3.41±1.16^{a}	3.24±1.33^{abc}
FSF4	3.47±1.19^{ab}	3.27±1.05^{a}	3.35±1.35^{ab}	2.94±1.21^{a}	3.68±1.34^{bc}

Mean values of duplicate (n = 17) with different superscript in a column are significant at p<0.05. Post hoc mean separation and comparison by Tukey's test.

in combating protein energy malnutrition.

There was observed effects of processing on crude protein among the formulations. The protein content has been reported to range between 11.5 and 12.3% (Serna-saldivar et al., 2019), thus processing techniques are essential in improving the overall protein content. Roasted sorghum formulations snacks had higher crude protein content when compared with fermented formulations (12.31 15.51% g/100 g) and malted formulations (11.28 to 14.90% g/100 g) as per Table 3. These observations agree with Tamilselvan and Kushwaha (2020) who recorded increase in crude protein during fermentation and net reduction during malting of sorghum. Malted sorghum formulations had lower crude protein content which could be due to degradation of proteases present which are synthesized during the

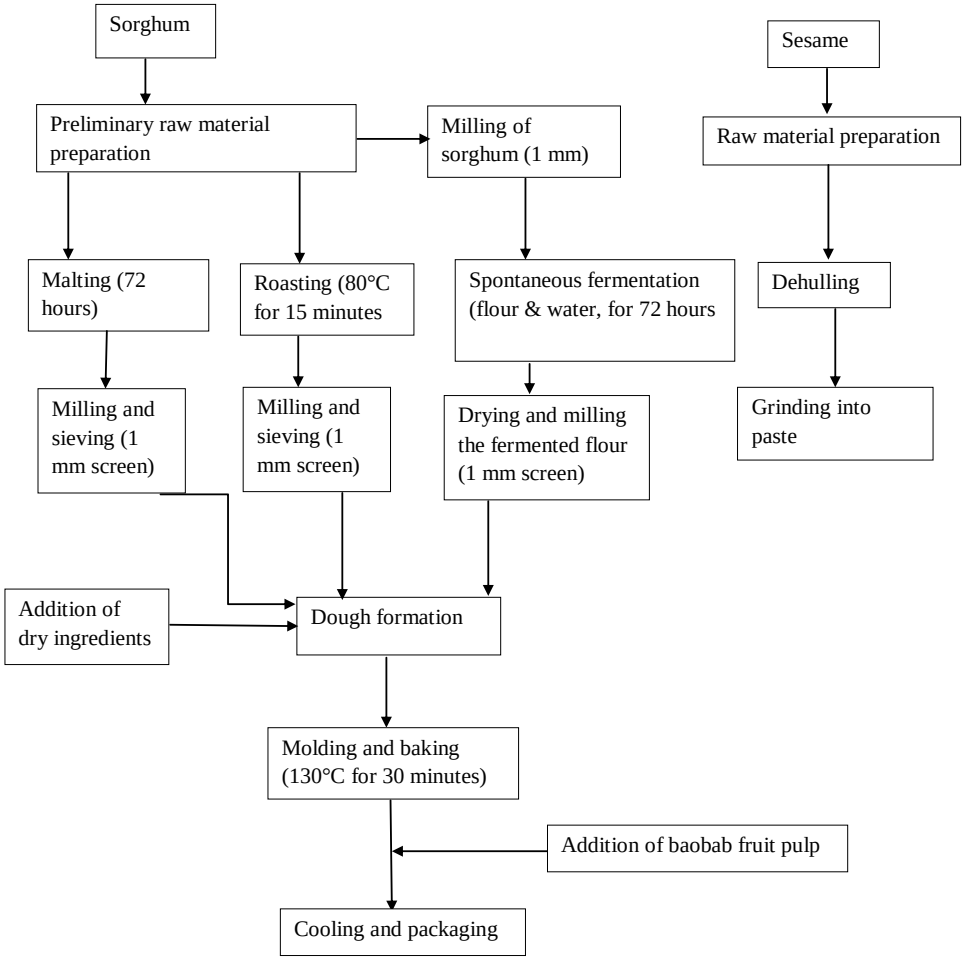


Figure 1. Flow diagram for the product formulation.

germination period (Nkhata et al., 2018). Roasting of sorghum disrupts the encapsulated protein in the endosperm complex thus releasing the stored protein (Ratnavathi, 2016). These could be attributed to the high crude protein content in roasted sorghum formulations as compared to the malted and fermented snack bars. Sorghum proteins are localized in the endosperm, germ and pericarp and fermentation has been attributed to breakdown these complexes by action of microorganisms (Tamilselvan and Kushwaha, 2020). Improved crude protein during fermentation may be attributed to breakdown of complex sorghum kafirins thus releasing peptides and amino acids particularly lysine and improving their digestibility (Nkhata et al., 2018).

Thus, the combined effects of sesame supplementation and processing methods had a net effect in overall crude protein content in the snack bars.

Fiber content

Sorghum is a rich source of dietary fiber that is associated with its pericarp and endosperm walls, usually ranging from 6 to 9.3% (Stefoska-needham et al., 2015; Serna-saldivar et al., 2019). The fiber in sorghum is largely the insoluble type which has been associated with decrease in gastrointestinal problems, glycemic control and slow release of glucose into the bloodstream (Stefoska-Needham et al., 2015).

The effect of substitution across the processing methods of roasting, malting and fermentation with sesame and baobab fruit pulp did not yield an increase in crude fiber. Sesame seeds have fiber in the range of 6 to 8% concentrated in their hull layers (Hegde, 2012), while baobab fruit has been reported in the 6 to 8 g/100 g (Muthai et al., 2017). Dehulling is done on sesame seeds to remove the hull which contains significant oxalic acid that have a bitter taste and as a consequence, most crude fiber is lost in the process. That could be a possible reason for sesame seeds not improving the overall crude fiber content in the snack bars. Nevertheless, the crude fiber content in fermented snack bars was comparatively higher when compared with roasted and malted snack bar formulations. The findings agree with Mohapatra et

al. (2019) who observed increase in fiber content from 2.76 to 3.41% in fermenting sorghum grain. However, the findings from malted sorghum snack bars indicate lower crude fiber content relative to fermented snack bars. These are contrary to findings by Ogbonna et al. (2012) who reported increase in crude fiber by 72.5% by malting sorghum grist. Sprouting of sorghum could have reduced the crude fiber due to degradation of cell walls during sprouting (Taylor and Kruger, 2019). In addition, by subjecting sorghum to roasting temperatures ruptures the endosperm complex, thus degrading the starch and fiber content (Taylor and Kruger, 2019).

Thus, the result findings suggest fermentation has positive effect on the crude fiber content as compared to roasting and malting. In addition, dehulling of sesame has net negative on crude fiber; however, the process is necessary for reduction in the bitter oxalates.

Fat content

Sesame seeds have significant levels of oil content in the upward ranges of 48 to 55% (Hegde, 2012). Baobab fruit pulp is usually low in fat content, with some studies reporting contents in the average of 0.5 to 2% (Zahrau et al., 2014; Aluko et al., 2016). High fat content in the formulations was attributed to the roasted sesame seeds. The trend indicated increased fat content with improved sesame supplementation among formulations RSF1, MSF1 and FSF1 with 25% sesame supplementation recording high fat content. Thus, as the level of sesame seeds were increased in the formulations, there was a net positive improvement in the fat content. Snacks have a reputation for saturated fats content which renders dietary fears among potential consumers due to associated health risks such as heart diseases, hypertension and diabetes. However, sesame oil is rich in unsaturated fats of oleic and linoleic fatty acids that have beneficial health benefits of lowering of blood cholesterol levels and reducing the risk of heart related ailments (Anilakumar et al., 2010).

Carbohydrates and energy content

Previous studies have reported the contribution of available carbohydrates by sorghum to contribute to 72% of its total weight (Stefoska-Needham et al., 2015), raw sesame seeds have 20 to 25% (Onsaard, 2012) and baobab fruit pulp at 74% (Oyeleke et al., 2012). Processing of sorghum by fermentation reduced available carbohydrate attributed to decrease in dry matter by *Lactobacillus plantarum* (Mugula and Lyimo, 2000). The corresponding benefit contributes to carbohydrates bioavailability encapsulated in the sorghum's endosperm (Taylor and Kruger, 2019). The malted snack bar samples had reduced total carbohydrates which could be attributed to metabolism during steeping and sprouting periods (Ogbonna et al., 2012). Similar observations by Folasade and Makanjuola (2012) observed a significant decrease in carbohydrate for a sorghum based kunun-zaki supplemented with sesame seeds from 80.67 to 63.59%. Thus, while the snack bars had reduced carbohydrates, the corresponding benefit is improved fat and protein content which have important roles in cell metabolism.

Snack bars are preferred due to their nutritional density, convenience and source of energy. There is improved energy intake with increase sesame and baobab fruit supplementation. This could be attributed to high oil content in sesame which once metabolized by body cells, releases energy.

Energy requirements are dependent on factors such as the person's age, sex, height, weight and level of physical activity. Fermented snack bars exhibited slightly higher energy content which could be attributed to the role of microorganisms in improving the starch and protein digestibility. For malted snack bars, there is the possibility of respiration during the germination period that depletes some of the stored starches, which ultimately has an effect on the overall energy content.

Two servings of the formulated snack bars will meet the total RDI for men and women >19 years old who have a moderate active lifestyle and who need minimum of 1600 kJ in women and 2000 kJ in men (USDA and HHS, 2015). The snack bar FSF4, with least energy content (Table 3) which recorded 1578.62 kJ will meet 98% of total RDI for children < 8 years old (USDA and HHS, 2015). For teenagers with moderate active and active lifestyles, the snack bars will adequately their total energy RDA (USDA and HHS, 2015). It should be noted that while estimates are provided, the differences in basal metabolic rates among men and women will ultimately determine needed energy content.

Mineral content

Iron is an important micro-nutrient in diets which is important in formation of hemoglobin in the body. The processing steps thus had the effect on mineral content in final formulations.

Fermentation has the positive impact of breaking down tannins and phytates in the sorghum and this is indicated by positive iron concentration in FSF1, FSF2, and FSF3. This suggests that while sesame was dehulled, fermentation of sorghum is efficient in releasing complexed iron content. In contrast, the malted sorghum bars recorded lower iron content which is contrary to past observations that sprouting has a positive effect on mineral content. It is postulated by sprouting, the process reduces antinutrients present thus improving their bioaccessibility (Taylor and Kruger, 2019). It can be deduced that leaching of iron during steeping and dehulling of sesame reduced iron contribution, however,

contrary observations by Folasade and Makanjuola (2012) found improved mineral content for sorghum based kunun-zaki supplemented drink supplemented with sesame prepared by washing, steeping, wet milling and sieving.

Calcium is essential for bone development, cardiac and muscular contractions, transmission of nerve impulses and coagulation of the blood (WHO, 2001). The formulation(s) MSF1 recording the highest concentration (246.7 mg/100 g) and RSF4 recording the least amount at 82 mg/100 g. High calcium content was realized at 15% baobab supplementation level in RSF1, MSF1 and FSF1. Sesame seeds hulls have predominant calcium fractions, which once dehulled, lowers its content (Hegde, 2012). Thus, predominant calcium in the formulations was provided by baobab fruit pulp. Various authors have evaluated the baobab fruit pulp and found high calcium levels at 430 mg/100 g (Muthai et al., 2017) and 128 mg/100 g (Amarteifio and Mosase, 2009). The trend shows improved calcium levels in the formulations. However, snack bars RSF4, MSF4, and FSF4 had no supplementation. The malted bar, MSF4 compared better to FSF4 and RSF4 which can be attributed to processing parameters during malting such as type of water used, steeping and deculming steps. In particular, the breakdown of anti-nutrients present especially phytates contents, makes calcium more bioavailable in sorghum (Taylor and Kruger, 2019). The least calcium concentration in formulation RSF4 (82 mg/100 g) could be attributed to roasting temperatures not able to breakdown the anti-nutrient elements so as to release complexed calcium content.

The processing effect on zinc content was not significant ($p>0.05$) across the formulations, but a difference with increase in sesame seeds and baobab fruit pulp. Zinc is essential for gene expression, metabolic breakdown of proteins, carbohydrates and fats and forms part of the enzyme structure and proteins (WHO, 2001).

Sensory analysis

There were no significant differences in the aroma and crunchiness of the snack bars ($p>0.05$) with average sensory scores of 3 indicative of the perception of neither liking nor dislike. These results are in agreement with Momanyi et al. (2020), the effect of beany flavor in cowpeas lowered the scores. Sesame seeds have significant oil content which is utilized in frying operations (Hwang, 2005), and roasting their seeds enhances the aroma. Furthermore, malting of sorghum involves activation of endogenous enzymes, release of starch content, which, during baking, improves the overall flavor of the snacks. For the fermented snacks, the prevalence of residue lactic acid that could have added an acidic taste was minimal. Snack bars are appealing to consumers due to their crunchy nature. Furthermore, the fiber content in sorghum maintains its rough texture if milling or sifting is inadequate. The prepared snacks were not significant with sensory scores <3.5. Sorghum has characteristic rough nature which processing operations of malting and fermentation have a great impact in reducing its fiber content to soluble form.

The trio of roasted, malted and fermented sorghum treatments had a dark color (sensory score >3). The prevalence of dark color was attributed to higher sesame seed supplementation which caramelizes during roasting process, and lower baobab levels. These observations agree with Momanyi et al. (2020), where the color of lunch bars were comparatively darker with increase in cowpea and low baobab supplementation. In addition, roasting sorghum improved the appearance due to maillard reactions of its stored starch levels (Taylor and Kruger, 2019). The palatability of the snack bars was significant ($p<0.05$) among the panelists. Samples MSF4 and RSF4 with 0% sesame and baobab were most preferred with MSF1 and MSF3 least preferred. Baobab has characteristic astringency taste due to high vitamin C content. Momanyi et al. (2020) points that supplementation of baobab above 25% levels will consequently have a characteristic bitter taste in the final product which is not acceptable amongst most consumers. Sesame which is sweet can be overwhelmed by the astringency in the baobab fruit, and generally, snacks with lower baobab were preferred.

In general, the snack bars had an acceptability score of between 2.76 and 3.67, $p<0.05$. The mark of good quality is a rating score of ≥4 on a 5-point hedonic scale. The skepticism among consumers regarding new product could be a factor for the low overall acceptability scores.

Conclusion

A nutritional viable ready-to-eat snack bar at supplementation level of sorghum, sesame and baobab fruit was due to high protein, fat and mineral content as compared to subsequent supplementation levels. This level of supplementation will address issues of protein energy malnutrition and low nutrient density associated with highly processed snacks. The sensory attributes of the snack bars were not affected by processing modes of roasting, malting and fermentation and influence of sesame seeds and baobab fruit. Nevertheless, this study demonstrates the potential of underutilized crops in food product innovation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Association Official Analytical Chemist (AOAC) (2000). Methods of analysis of AOAC International. AOAC International, Maryland, USA (2003).

Association Official Analytical Chemist [AOAC], 2005. Official methods of analysis.
Adedeji O, Jegede D, Abdulsalam K, Umeohia U, Ajayi O, Iboyi J (2015). Effect of processing treatments on the proximate, functional and sensory properties of soy-sorghum-roselle complementary food. British Journal of Applied Science and Technology 6:635-643.
Aluko, AE, Kinyuru J, Chove LM, Kahenya P, Owino W (2016). Nutritional quality and functional properties of baobab (*Adansonia digitata*) pulp from Tanzania. Journal of Food Research 5:23.
Amarteifio J, Mosase M (2009). The chemical composition of selected indigenous fruits of Botswana. Journal of Applied Sciences and Environmental Management 10(2).
Anilakumar KR, Pal A, Khanum F, Bawa AS (2010). Nutritional, medicinal and industrial uses of sesame (*Sesamum indicum* L.) seeds - An overview. Agriculturae Conspectus Scientificus 75(4):159-168.
Asghar A, Majeed MN, Akhtar MN (2014). A review on the utilization of sesame as functional food. American Journal of Food and Nutrition 4(1):21-34.
Asuk AA, Ugwu MN, Idole B (2020). The Effect of Different Malting Periods on the Nutritional Composition of Malted Sorghum-Soy Composite Flour. Journal of Food Science Nutrition and Research 3(3):217-230.
Chikuta S, Odong T, Kabi F, Mwala M, Rubaihayo P (2014). Farmers perceptions on dual-purpose sorghum and it's potential in Zambia. International Journal of Agricultural Research, Innovation and Technology 4:76-81.
Erhardt J (2007). Nutrisurvey (Version 2007). Available from http://www.nutrisurvey.de
FAO/WHO (2001). Human Vitamin and Mineral Requirements. Rome.
Folasade M, Makanjuola O (2012). Effect of sesame seed addition on the chemical and sensory qualities of sorghum based kunun- zaki drink. African Journal of Food Science and Technology 3:204-212.
Gharby S, Harhar H, Charrouf Z (2015). Chemical characterization and oxidative stability of seeds and oil of sesame grown in Morocco. Journal of the Saudi Society of Agricultural Sciences 16(2):105-111.
Hadebe ST, Modi AT, Mabhaudhi T (2017). Drought Tolerance and Water Use of Cereal Crops: A Focus on Sorghum as a Food Security Crop in Sub-Saharan Africa. Journal of Agronomy and Crop Science 203(3):177-191.
Hegde DM (2012). Sesame, in: Handbook of Herbs and Spices: Second Edition. Woodhead Publishing Limited pp. 449-486.
Hiremath S, Patil C, Patil K, Nagasampige M (2010). Genetic diversity of seed lipid content and fatty acid composition in some species of *Sesamum L.* (Pedaliaceae). African Journal of Biotechnology 6(5):539-543.
Hwang LS, (2005). Sesame Oil, Bailey's Industrial Oil and Fat Products. John Wiley & Sons Inc. pp. 537-575.
Inyang UE, Ekanem JO (1996). Effect of dehulling methods and desolventizing temperatures on proximate composition and some functional properties of sesame (*Sesamum indicum* L.) seed flour. Journal of the American Oil Chemists' Society 73(9):1133-1136.
Jeewon TB, Rajesh J (2016). Changes in eating habits and food traditions of Indo-Mauritians. Indian Journal of Traditional Knowledge 15(3):355-362.
Kince T, Galoburda R, Klava D, Tomsone L, Senhofa S, Straumite E, Kerch G, Kronberga A, Sturite I, Kunkulberga D, Blija A (2017). Breakfast cereals with germinated cereal flakes: changes in selected physical, microbiological, and sensory characteristics during storage. European Food Research and Technology 243(9):1497-1506.
Koitilio B, Kinyua M, Kiplagat O, Pkania K, Chepkoech E, Kimno S (2018). Morphological Characterization of Selected Sesame (Sesamum Indicum L.) Genotypes in Western Kenya. African Journal of Education, Science and Technol0gy 4(4):120-134.
Lawal SO, Idowu AO, Malomo SA, Badejo AA, Fagbemi TN (2019). Effect of toasting on the chemical composition, functional and antioxidative properties of full fat and defatted sesame (*Sesamum indicum* L.) seed flours. Journal of Culinary Science and Technology 19(1):18-34.
Mohapatra D, Patel AS, Kar A, Deshpande SS, Tripathi MK (2019). Effect of different processing conditions on proximate composition, anti-oxidants, anti-nutrients and amino acid profile of grain sorghum. Food Chemistry 271:129-135.
Momanyi D, Owino W, Makokha A (2020). Formulation, nutritional and sensory evaluation of baobab based ready-to-eat sorghum and cowpea blend snack bars. Scientific African 7:e00215
Msheliza EA, Ilesanmi JOY, Hussein JB, Nkama I (2018). Effect of pretreatments on the microbial and sensory quality of weaning food produced from blends of sorghum and soybean. African Journal of Food Science 12(12):353-359.
Mugula JK, Lyimo M (2000). Evaluation of the nutritional quality and acceptability of sorghum-based tempe as potential weaning foods in Tanzania. International Journal of Food Science and Nutrition 51(4):269-277.
Muthai KU, Karori MS, Muchugi A, Indieka AS, Dembele C, Mng'omba S, Jamnadass R (2017). Nutritional variation in baobab (*Adansonia digitata* L.) fruit pulp and seeds based on Africa geographical regions. Food Science and Nutrition 5(6):1116-1129.
Nkhata SG, Ayua E, Kamau EH, Shingiro JB (2018). Fermentation and germination improve nutritional value of cereals and legumes through activation of endogenous enzymes. Food Science and Nutrition 6(8):2446-2458.
Nyongesa BO, Were BA, Gudu S, Dangasuk OG, Onkware AO (2013). Genetic diversity in cultivated sesame (*Sesamum indicum* L.) and related wild species in East Africa. Journal of Crop Science and Biotechnology 16(1):9-15.
Ogbonna AC, Abuajah CI, Ide EO, Udofia US (2012). Effect of malting conditions on the nutritional and anti-nutritional factors of sorghum grist. The Annals of the University Dunarea de Jos of Galati, Fascicle VI Food Technology 36(2):64-72.
Onsaard E (2012). Sesame proteins. International Food Research Journal 19(4):1287-1295.
Onyango C, Mutungi C, Unbehend G, Lindhauer MG (2011). Modification of gluten-free sorghum batter and bread using maize, potato, cassava or rice starch. LWT - Food Science and Technology 44(3):681-686.
Onyango CA, Ochanda SO, Mwasaru MA, Ochieng JK, Mathooko FM, Kinyuru JN (2013). Effects of malting and fermentation on anti-nutrient reduction and protein digestibility of red sorghum, white sorghum and pearl millet. Journal of Food Research 2(1):41-49.
Orr A (2017). Smallholder Value Chains as Complex Adaptive Systems : A Conceptual framework. Series Paper Number 36.
Oyeleke GO, Salam MA, Adetoro RO (2012). Some Aspects of Nutrient Analysis of Seed, Pulp and Oil of Baobab (*Adansonia digitata* L.). IOSR Journal of Environmental Science, Toxicology and Food Technology 1(4):32-35.
Palma MNN, Rocha GC, Valadares FSC, Detmann E (2015). Evaluation of acid digestion procedures to estimate mineral contents in materials from animal trials. Asian-Australasian Journal of Animal Sciences 28(11):1624-1628.
Pelembe LAM, Erasmus C, Taylor JRN (2002). Development of a protein-rich composite sorghum - Cowpea instant porridge by extrusion cooking process. LWT - Food Science and Technology 5(2):120-127.
Popkin BM (1999). Urbanization, lifestyle changes and the nutrition transition. World Development 27(11):1905-1916.
Popkin BM (2015). Nutrition Transition and the Global Diabetes Epidemic. Current Diabetes Report 15(9):1-8.
Preichardt LD, Vendruscolo CT, Gularte MA, Moreira ADS (2011). The role of xanthan gum in the quality of gluten free cakes: Improved bakery products for coeliac patients. International Journal of Food Science and Technology 46(12):2591-2597.
Ratnavathi CV (2016). Sorghum Processing and Utilization, in: Sorghum Biochemistry: An Industrial Perspective. Elsevier Inc. pp. 311-327.
Serna-saldivar SO, Espinosa-ramırez J, Leo N (2019). Grain structure and Grain Chemical Composition, in: Sorghum and Millets. AACC International Press pp. 85-129.
Shittu TA, Aminu RA, Abulude EO (2009). Functional effects of xanthan gum on composite cassava-wheat dough and bread. Food Hydrocolloids 23(8):2254-2260.
Stefoska-needham A, Beck EJ, Johnson SK (2015). Sorghum : An Underutilized Cereal Whole Grain with the Potential Sorghum : An Underutilized Cereal Whole Grain with the Potential to Assist in the

Prevention of Chronic Disease. Food Reviews International 31(4):401-437.
Tamilselvan T, Kushwaha A (2020). Effect of Traditional Processing Methods on the Nutritional Composition of Sorghum (Sorghum bicolour L. Moench) Flour. European Journal of Nutrition and Food Safety pp. 69-77.
Taylor JRN, Taylor J (2017). Proteins from sorghum and millets. In Sustainable Protein Sources. Elsevier Inc, pp. 79-104.
Taylor JRN, Kruger J (2019). Sorghum and Millets: Food and Beverage Nutritional Attributes. In Sorghum and Millets. AACCI International Press pp. 171-224.
Tenyang N, Ponka R, Tiencheu B, Djikeng FT, Azmeera T, Karuna MSL, Prasad RBN, Womeni HM (2017). Effects of boiling and roasting on proximate composition, lipid oxidation, fatty acid profile and mineral content of two sesame varieties commercialized and consumed in Far-North Region of Cameroon. Food Chemistry 221:1308-1316.
USDA and HHS (2015). Dietary Guidelines for Americans, 8th ed. U.S. Government Printing Office.
Zahrau B, Mohammed AS, Ghazali HM, Karim R (2014). Baobab tree (*Adansonia digitata* L) parts: Nutrition, applications in food and uses in ethno-medicine - a review. Annals of Nutritional Disorders and Therapy 1(3):1011.

Related Journals: