Nutritional and Structural Characteristics of Insect-Based and Mixed-Grain Puffed Cakes

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Abstract

The consumption of healthy snacks is on the increase leading to exploration of various ingredients in the production. Edible insect can be explored and included into puffed snack ingredient as alternative source of protein for sustainable food system. In this study, single grain (100% rice and 100% corn) and mixed-grain (corn, bambara groundnut, cassava grits) with higher proportion of corn (50-60%) were used as ingredients in the production of puffed grain cakes using rice cake popping machine at 220 ^{0}C, 5 seconds. Insect powder (cricket powder) at 10% level was included in the mixed-grain formulation with 50% corn. Parameters such as nutritional composition, pasting properties, textural attributes and microstructure were used to assess the quality of the puffed grain cakes. Results shows that addition of 25% bambara groundnut to the puffed cakes increased the protein content to 8.50% while inclusion of 10% insect powder yielded highest protein content of 12.44%. The deformation and expansion of corn starch during puffing process dominates the products' pasting and structural attributes. The 100% rice grain had highest peak viscosity of 212 cP while 100% corn, mixed-grain and insect-based puffed cakes had low peak viscosity ranging from 25.08 to 89.83 cP. Low hardness (0.61 N to 29.05 N) was obtained in all puffed grain cakes with low peak viscosity except 100% rice. It was discovered that the lower the peak viscosity, the lower the hardness and this improved crispiness. The microstructure reveals presence of large air bubbles in all puffed cakes except 100% rice. This study has created an opportunity for the use of insect and non-rice grain in the production of nutritious puffed grain cake that will serve the nutritional requirements of developing countries and special diet consumers.

Keywords: *Crispy; Expansion; Ingredients; Insect-Based; Mixed-Grain; Puffing*

1 Introduction

The development of insect-based snacks could contribute to the sustainability of the food system for an improved food and nutrition security. United Nations has advocated for diversified food system if its number 2 (Zero hunger) sustainable development goals (SDGs) would be achieved by 2030.

Although about 800 species of edible insect are available for consumption with protein content ranging from 35%–60% dry weight or 10%–25% fresh weight (Collavo *et al*., 2005; Kim *et al.*, 2019) yet limited high protein ready to eat food products (snacks) are manufactured from it. Many factors such as appropriate choice and nature of ingredients, formulation, processing procedures and consumer's acceptability may be responsible for the low availability of insect-based snacks. However, many research articles reported that insect-based foods are more acceptable by consumers if the insect are ground into powder in an invisible appetising appearance and texture of product improved (Ros-Baro *et al*., 2022).

The gelatinisation and expansion of starch during cooking has resulted to development of many snacks especially puffed snacks. Puffed snacks are snacks with aerated porous structure. It is also described as a solid foam-like (spongy texture) product characterized by a solid internal framework formed by air-filled cells (Nath *et al*., 2007; Sanchez-Jimenez *et al*., 2022). Many processing methods such as hot surface popping, extrusion cooking, microwave, hot air toasting, hot air or hot oil popping, gun puffing and deep fat frying are adopted for the manufacturing of puffed snacks (Mishra *et al*., 2014; Mykolenko *et al*., 2022). All these methods are guided by common mechanism of starch gelatinisation and expansion as starch has a nature of expansion when subjected to heat and pressure (deformation). Some unique principles could be applicable to each puffed snack.

Puffing with rice cake popping machine is among the most sustainable technology for the expansion of starch during production of puffed snack. The heating and compression processes deform and fuse the starchy grains so that at sudden release of superheated water vapour through the micropores of the starchy grain, the fused grain instantaneously expand. The expansion results to the porous and spongy texture of puffed snacks. These properties of rice such as expansion, hardness, degree of gelatinisation, glass transition temperature, crystallinity, color, nutrient content, porosity, and microstructure are altered during the processing of puffed rice (Lee and Yang, 2020; Saha and Roy 2020; Mishra *et al*., 2014; Navarro-cortez *et al*., 2014; Xu *et al*., 2023). Through modification of processing protocols, such as temperature, puffing time, speed, feed volume size and grain size, grain moisture content, production of expanded snacks from nutritious composite and expanded food ingredients could be possible (Orts *et al*., 2000; Lee *et al*., 2008; Hossain and Shin, 2013; Shaviklo *et al*, 2015; Xu *et al*., 2023).

In addition to the nutritional value of puffed snacks, the texture of the final products is highly important as it determines consumer acceptability. The demand for ready to eat nutritious puffed snacks is on the increase because of their nutritional quality (improved digestibility and nutrient bioavailability), low calorie, sensory attributes (crispy texture) and light weight (Subramani *et al*., 2023; Lisiecka *et al*.,2023; Culetu *et al*.,2023). To achieve these characteristics, the ingredient formulation is considered important during production of ready to eat puffed foods (Photinam and Moongngarm, 2023).

Researchers have developed puffed snacks with rice or non-rice ingredients using the popular rice cake popping machine (Orst *et al*., 2000; Nath *et al*., 2007; lee *et al*., 2008; Lee and Yang, 2020; Sanchez-Jimenez *et al*., 2022) but enrichment of puffed cakes with insect-based material are limited. Probably, the inability of ground insect which majorly consist of protein, fat and fibre to expand during heating may have impacted its application in puffed snacks. Appropriate selection of ingredients and modification of machine operating conditions could result to puffed cake products with acceptable qualities. Considering the high cost of rice and high production cost (irrigation and unique cultivation system), non-rice ingredients such as corn, cassava, bambara groundnut could be blended with edible insect at right proportion and used for puffed grain cake production. The processing of these non-rice ingredients into puffed grain cake using rice popping machine would be able to provide solution and increase in food security to teeming world population especially in Africa.

This study will investigate the possibility of developing an expanded puffed mixed-grain cakes with non-rice composite ingredients and insect. Other specific aims includes determination of the nutritional value, evaluation of the textural properties, the extent of starch deformation on pasting properties and the effect of structural composition on the stability of the snacks.

2.0 Materials and methods

2.1 Materials

All the materials used in the manufacturing of puffed snacks were locally sourced in Nigeria. Both the corn and bambara groundnut were purchased from local market in Awka, Anambra State. The cassava was obtained from a local farm in Ndiokpalaeze, Orumba North Local Government Area of Anambra State while the cricket *(Acheta domesticus*) was in-house reared at Federal Polytechnic Oko, Anambra State.

2.1 Methodology

2.1.1 Preparation of puffing ingredients

The corn and bambara groundnut after cleaning were milled separately into grit particle size of 3-5 mm while the cassava was processed with the method of production of unfermented high-quality cassava flour (UHQCF) as described by Okpala *et al* (2022) with some modification. The cassava roots were manually cleaned to remove adhering soil and other extraneous materials before processing. It was immediately peeled, washed and allowed to drain, after which the roots were grated using grating machine. The mash was dewatered using hydraulic press machine, and pulverized. The fibrous materials in the cassava cake were removed before oven drying at 60 ^{0}C to obtain unfermented high-quality cassava grits (UHQCG) measuring between 3-5 mm. These ingredients were air-tight packaged until ready to use.

2.1.2 Preparation of insect (cricket) powder

The cricket after freezing for 5 hours was blanched at 100 ^{0}C, 5 min and then oven dried at 60 ^{0}C. Dried cricket was milled into powder and packaged till use.

2.1.3 Production of puffed grain cakes

The ingredient formulation for the production of the puffed grain cakes is shown in Table 1. Each formulation which serves as puffing blend (feed) was manually fed through the hopper into the rice cake popping machine (SPY 9002, Shinyoung Machanics South Korea). It then flows automatically into the feeding plate according to selected feeding rate. The grain inside the feeding plate was automatically enclosed by the heated moulds at 220 ^{0}C. Following the heating and deformation (compression) of the grain inside the moulds for 5 seconds, a puffed grain cake was obtained.

Table 1: Puffing blend ingredient formulation

Sample	Rice (%)	Corn (%)	Bambara Groundnut (%)	Cassava (%)	Cricket (%)
R100	100	-	-	-	-
C100	-	100	-	-	-
LCBC	-	50	25	25	-
HCBC	-	60	20	20	
ICBC	-	50	20	20	10

2.2 Analytical methods

2.2.1 Determination of nutritional values (proximate composition)

The moisture, protein, fat, crude fibre and ash were determined by AOAC 18th edn (2010) analytical method. The carbohydrate was determined by difference while calorific value (food energy) was determined by Atwater factors by calculating the sum of calories of fat, protein and carbohydrate (4.27 x kcal /g for protein, 8.79 kcal/g for fat and 3.87 kcal/g for carbohydrate).

2.2.2 Determination of pasting properties

The pasting properties were determined using the RVA (Rapid Visco Analyser) super 4 model by Newport Scientific Australia according to the method of Okpala *et al* (2022). The puffed grain cake powder weighing 3 g solids content (dry basis) based on this formula (3g x 100/100-moisture content of the flour) were measured in the canisters and deionized water was added to the sample and mixture made up to 28 g. The mixture (suspension) was inserted into the RVA tower and then lowered into the system while rotating the canister at a speed of 160 rpm with continuous stirring of the content with a plastic paddle. A 13 min analysis protocol was used and it consists of heating the suspension from starting temperature of 50 °C for 1 min and then heated up to 95 °C with holding time of 2 min. It was then cooled back to 50 °C with 2 min holding time. Each of the samples was prepared and analyzed in triplicate and the results of pasting viscosities (peak, breakdown, setback and final), peak temperature and time were reported as mean value.

2.2.4 Texture analysis

The instrumental texture analysis of the puffed grain cake was done using a TA-XTplus (Stable Microsystems) texture analyser equipped with a 50kg load cell and an Ottawa cell with a 5-blade grid. The grain cake samples were placed in the Ottawa cell and force of extrusion which indicates the texture parameters especially the hardness was determined by compression through the 5-blade grade. Pre-test speed and test speed of 2 mm/s and 1 mm/s respectively were used. Also, a trigger force of 20 g and target of 20 mm was used for the measurement of hardness of the puffed snacks.

2.2.5 Scanning Electron Microscopy

The scanning electron microscopy (SEM) was performed to examine the microstructural changes of grain cakes using SEM model Phenom ProX, by PhenomWorld Eindhoven, Netherlands. Sample was placed on double adhesive which was mounted on a sample stub and sputter coated with gold (5nm target thickness) using Quorum Technologies model Q150R sputter coater. Thereafter it was taken to the chamber of SEM machine where it was viewed via NaVCaM for focusing and little adjustment before transferred to SEM mode. In the SEM mode, the morphologies were focused and brightness and contrasting were automatically adjusted. Afterward the morphologies of different magnification were saved as final picture.

2.3 Statistical Analysis

All data reported are mean value and standard deviation of triplicate analysis. Data were analysed using one-way ANOVA and mean separated with *Tukey's* HSD test to determine statistical significance ($P<0.05$) of data. The statistical analyses were carried out using IBM SPSS statistics 2022.

3.0 Result and Discussion

3.1 Nutritional composition

The nutritional composition shown in Table 2 relates to the proximate composition of the puffed grain cakes. The result shows that puffed grain cakes protein ranging from 5.52% to 12.44% were significantly different ($P<0.05$). The insect-based cake (ICBC) with 10% cricket powder had the highest protein content of 12.44% while the single grain puffed cakes (100% rice and corn) had the lowest. The high protein content of the insect-based puffed cake satisfies the need for the inclusion of cricket powder as alternative protein compared to single cereal grain puffed cake with low protein content. The increase in protein content agreed with report of Biro *et al*. (2020) where inclusion of cricket powder to wheat-based snack increased the protein content from 9.48 g/100 g to 11.22 g/100 g in 5 g/100 g cricket enrichment and 12.97% in 10 g/100 g enrichment. The increase in bambara groundnut significantly ($P<0.05$) increased the protein content from 7.01% in HCBC with 20% bambara groundnut to 8.50% in LCBC with 25% bambara groundnut. In addition to inclusion of 10% cricket, bambara groundnut should be included in puffed snack as a special ingredient for increasing protein consumption.

Based on literature, puffing process increases protein digestibility since the heating and shear process has the tendency of denaturing protein (Azollini *et al.*, 2018). The benefit of consumption of high protein snacks includes control of appetite, building up of muscles and promotion of healthy metabolism. The consumption of high insect-protein snacks is recommended for children's growth as majority of their available snacks are low in protein and this deprive the children access to high proteinous foods. Cricket has many of the essential amino acids and high protein digestibility score of 0.65 (Pauter *et al*., 2018) and therefore, its use as alternative protein source in fast moving snack products would help to remedy protein malnutrition in developing countries.

Majority of the developed puffed grain cakes in this study have low moisture content (8.26-9.29%) that were comparable to research article (Lee and Yang, 2020). Moisture content is used in the evaluation of shelf stability of snack as pathogenic microorganism thrive less in low moisture snacks due to reduced moisture activity level. The control of moisture content of snacks is important during production as many consumers preferred low moisture content (5-15%) savoury snacks for its easy to eat on the go than bulky (high density) snacks with associative inconvenience.

The addition of 10% cricket powder into the ingredient, increased the fat content of the puffed grain cakes to 9.44% compared to snacks without cricket powder. Cricket originally contains 17 to 28 % fat. The high fat content of the insect-based has no health challenges because is majorly of polyunsaturated (omega 3 and omega 6) and unsaturated fatty acid (Oonincx *et al*., 2020). The replacement of major ingredient used in bakery with less than 20% cricket was reported to cause an increase in fat content (Pauter *et al*., 2018).

Table 2: Nutritional values of puffed grain cakes

Samples	MC (%)	Protein (%)	Fat (%)	Crude Fibre (%)	Ash (%)	CHO (%)	Calorific value (Energy value) (kcal)
R100	9.29[a] ±0.09	5.52 ± 0.01	1.43 ± 0.13	1.39 ± 0.09	1.88 ± 0.33	80.51 ± 0.05	356.99[d] ± 0.12
C100	9.61 ± 0.11	5.45 ± 0.21	7.45 ± 0.05	1.50 ± 0.11	1.85 ± 0.02	74.14 ± 0.02	385.41[a] ± 0.03
LCBC	8.28 ± 0.22	8.50 ± 0.16	5.29 ± 0.27	2.30 ± 0.04	2.42 ± 0.05	74.65 ± 0.07	380.21[b] ± 0.01
HCBC	8.59 ± 0.37	7.01 ± 0.08	4.39 ± 0.18	2.14 ± 0.19	2.38 ± 0.17	75.49 ± 0.16	369.51[c] ± 0.07
ICBC	8.34 ± 0.05	12.44 ± 0.38	9.44 ± 0.34	4.38 ± 0.31	2.89 ± 0.14	62.51 ± 0.12	384.76[a] ± 0.23

Values are mean values of three measurements and standard deviations. Values with different letters within the same column are significantly different.

R100:100% puffed rice, C100: 100% puffed corn, LCBC: Low (50%) corn-based puffed snack, HCBC: High (60%) corn-based puffed snack, ICBC: Insect-based puffed snack

There was significant difference (P< 0.05) in the crude fibre content of the puffed grain cakes that ranged from 1.40 to 4.32%. The highest fibre content (4.32%) was recorded in the insect based and least (1.40%) in 100% puffed rice cake. This result supports the report that increase in addition of cricket powder increases the fibre content of puffed snacks (Combrzynski *et al*., 2023). The influence of high fibre content of all mixed grain and insect-based puffed cakes would aid digestion and reduce low fibre intake-related diseases such as obesity, colon cancer and degenerative diseases. The enrichment with cricket powder lowered the carbohydrate values. Puffed grain cake are categorized as low-calorie snack. Among the puffed cakes, 100% rice (R100) had the highest carbohydrate (80%) but lowest calorific value 356.99 kcal. Due to the high fat content of cricket powder, the calorific value increased to 384.76 kcal. Due to the low calorie of these puffed grain cakes irrespective of blends, it would be an appropriate snack for weight control.

3.2 Pasting properties

The pasting properties of the puffed grain cakes are represented in Table 3. The pasting properties indicate the degree of cook (starch conversion) of the snacks during the puffing process. The inclusion of 10% cricket to the insect-base (ICBC) reduced the peak viscosity from 89 cP in 100% corn puffed cake to 25.08 cP in the insect based. Peak viscosity indicates the ability of raw materials composition to water absorption and starch swelling and is influenced mostly by starch content in blends (Combrzynski *et al*., 2023). The addition of insect powder reduced the starch level in the ingredient which invariably reduced the peak viscosity. Similar report by Combrzynski *et al* (2023) has shown that increasing the amount of cricket flour up to 30%, reduced peak viscosity due to the lower amount of starch coming from starchy materials (wheat and corn flour). They confirmed that replacing the starchy component of the ingredient with high-protein cricket flour reduces the water absorption and swelling capacity which reduces the peak viscosity. Low peak viscosity values were observed in extruded legumes with low starch content after extrusion cooking which is similar to the present study puffing technology (Mitrus *et al*., 2020; Okpala *et al*., 2023a).

In addition to low starch content, the presence of high amount of gelatinised starch also contributed to low peak viscosity (25.08-89.93 cP) of corn and mixed grain puffed cakes during pasting when compared to100% rice puffed grain cake that had 212 cP. The low peak viscosities signify high degree of cook of corn starch when compared to rice starch. The pasting of puffed grain cake is a second heating (gelatinisation) process which is not necessary to occur as the starch would have been fully gelatinised and the product ready to eat. This supported the finding of Agama-Acevedo *et al*. (2018) that hydrothermal treatment is not commonly performed on gelatinised starches as their granule structure is usually disrupted.

Although there is non-corn starch from bambara groundnut and cassava in all the mixed-grain puffed cakes, but due to the high level of corn (50-60%) in the puffing ingredient formulation, corn starch conversion dominates the pasting characteristic of the puffed grain cake. The low peak viscosity is expected as majority of the corn granule integrity would have been disrupted by heat and shear forces in the puffing process (Sánchez-Jiménez *et al*., 2022). Therefore, the presence of pre-gelatinised starch which would neither absorb water nor swell at the high pasting temperature (95 ^{0}C) where the peak viscosity was determined contributed to the low peak viscosity of all puffed grain cakes except 100% rice. Due to this low peak viscosity (cold-water peak viscosity) of the insect-based and mixed grain, an indication of higher degree of cook, these puffed cakes when ground into grit or powder could serve as a breakfast meal of soft gel texture.

Table 3: Pasting properties of insect-based and grain-based puffed cakes

Sample	Peak (cP)	Trough (cP)	Breakdown (cP)	Final Visc (cP)	Setback (cP)	Peak Time (min)	Pasting Temp (^{0}C)
R100	212.17	73.75	138.42	158.50	84.75	5.60	95.00
C100	89.83	42.17	47.67	65.42	23.25	1.60	50.15
LCBC	36.00	33.42	2.58	51.92	18.50	7.00	94.70
HCBC	45.83	45.00	0.83	62.67	17.67	6.67	50.20
ICBC	25.08	23.00	2.08	36.50	13.50	7.00	50.20

Values are mean values of three measurements
R100:100% puffed rice, C100: 100% puffed corn, LCBC: Low (50%) corn-based puffed snack, HCBC: High (60%) corn-based puffed snack, ICBC: Insect-based puffed snack

The high peak viscosity of 100% rice (R100) puffed grain cake is an evidence that the heating and puffing time were too short for majority of the rice starch to gelatinised and expand. Probably the rice is not from the variety of easy to cook rice and therefore, the starch would require longer cooking at this second cooking stage (pasting) before the rupture of the crystalline structure and swelling. For such rice, it would be appropriate if the hydration conditioning time and heating time were increased to allow more access for water penetration into the rice kernel (Lee and Yang 2020) and full gelatinisation to occur. Thus, only partial gelatinisation occurred in 100% rice puffed grain cake. Based on literature report, the starch crystalline structure of rice is more rigid compared to corn. Similar features of higher peak viscosity in the pasting properties of rice have been recorded in research articles where the starch granule had partial gelatinisation during puffing process (Lee and yang, 2020).

A high breakdown (138.42 cP), setback (84.75 cP) and final viscosities (158.5 cP) were obtained only in the 100% rice puffed grain cake. The high value of the breakdown viscosity of 100 % rice does not portray the fragility of the paste during pasting but rather relates to initial high peak viscosity (212 cP) from partial gelatinised starch (Okpala *et al*., 2023b). Breakdown viscosity measure the ability of gelatinsed and swollen granule to disintegrate under shear and heat. Contrary to the result obtained in this study, Arise *et al*. (2018) reported that addition of 30% bambara groundnut in a maize-based snacks increased the breakdown viscosity which reduced the gelling stability of the paste. The set-back viscosity is a measure of viscosity recovered during cooling of heated starch suspension with higher setback values indicating greater retrogradation. Due to starch degradation by mechanical shear forces and heat during the puffing, low setback viscosities where obtained in all corn-based and insect-based cakes (Mitrus *et al*., 2020; Lee and Yang, 2020). Though this research shows a low setback viscosity (212 cP) of puffed rice but higher values (391-1662 cP) were obtained by Lee and Yang (2020) in 100% rice produced with pre-gelatinised rice.

3.3 Textural attributes of puffed grain cakes

Texture is one of the major criteria that consumers use to judge the quality and freshness of foods. The hardness result obtained as shown in Table 4 indicates how the puffed grain cake would behave when chewed. The 100% rice (R100) exhibited the highest hardness (68.24 N) while 100% corn puffed snack had the lowest hardness 0.61N. The low hardness of the puffed cake produced with 100% corn (C100) indicate the higher ability of corn starch to easily puff and becomes crispy. When compared with 100% rice puffed cake, the all the corn-based puffed grain cakes (insect-based and mixed grain puffed cakes) showed reduction in hardness ranging from 1.47 to 29.05 N. Corn is characterized with high puffing quality which resulted in low hardness in puffed snacks and give rise to its' use in the manufacturing of many expanded and crispy snacks (Boonyasirikool and Charunuch, 2000; Xu *et al*., 2023).

Table 4 Textural properties of puffed snacks

Sample	Hardness (N)	Resilience (%)	Springiness (%)
R100	$68.24^{a} \pm 0.23$	$7.4675^{d} \pm 0.13$	$67.914^{a} \pm 0.44$
C100	$0.61^{e} \pm 0.07$	$9.68^{b} \pm 0.25$	$14.105^{e} \pm 0.05$
LCBC	$5.97^{c} \pm 0.14$	$13.305^{a} \pm 0.19$	$29.6255^{b} \pm 0.01$
HCBC	$1.47^{d} \pm 0.09$	$7.725^{c} \pm 0.08$	$15.015^{d} \pm 0.06$
ICBC	$29.05^{b} \pm 0.54$	$7.165^{e} \pm 0.02$	$16.8^{c} \pm 0.21$

Values are mean values of three measurements and standard deviations.
Values with different letters within the same column are significantly different.
R100:100% puffed rice, C100: 100% puffed corn, LCBC: Low (50%) corn mixed-grain puffed snack, HCBC: High (60%) corn mixed-grain puffed snack, ICBC: Insect-based mixed grain puffed snack

The increased hardness (68.24 N) of 100% rice grain cake (R100) indicated formation of puffed cake with harder texture. As earlier observed rice cake possessed high peak viscosity probably due to it is long to cook variety which requires longer cooking time before starch gelatinisation and swelling. Possibly the puffing condition used in this study limits gelatinisation and expansion of rice granules as majority of the starch granule were partially gelatinised. It has been demonstrated that expansion during puffing is being promoted by starch gelatinisation (Mahatta and Bhattarya, 2010). From literature, the hardness value reported for partially gelatinised and non- gelatinised puffed rice cake ranged from 19N to 44.30 N with puffed rice produced from partially gelatinised rice lower than those of the non-partially gelatinised samples (Lee and Yang, 2020). These hardness values were lower than the studied rice cake but in between the corn-based puffed cakes.

The spongy (porous) texture of puffed grain cake (snacks) which result to crispiness of the snack emanated from the interaction between starch and moisture components of the food material under the influence of heat and shear force during puffing. The adhesion of deformed and compressed grains to each other after heating in the popping machine mould resulted in the expansion and formation of stable porous structure (crispy texture) of the snacks on exit from the mould. An incomplete adhesion and expansion of the grains may occur if inadequate gelatinisation and deformation of grain takes place in the heating and shearing process. Similar to puffing with rice cake cracker popping machine, it has been demonstrated during extrusion cooking that the expansion resulting from the formation of air bubbles (air cells) in starch-based materials depends on starch conversion (Okpala *et al* 2023a).

The reduction in hardness in the mixed-grain puffed cakes suggests an improvement in air bubble structure and relates to crispiness of the puffed cake. Puffed grain cake with low number of air cells would impact much hardness and difficulties in mastication. The formation and structure of air cells are the major factors contributing to the crispy texture of puffed snacks and consumer acceptability even though it was produced without frying (Nath *et al*., 2007; Gulati *et al* 2018; Lee and Yang, 2020; Swarnakar *et al*., 2022; Sánchez-Jiménez, *et al*., 2022).

This low hardness of the insect-based puffed grain cake is in agreement with Suga *et al* (2023) who observed a lightening effect on the texture of baked rice crackers after replacement with 10-30% cricket powder even though the panelist disliked the appearance of the product due to the darker colour. As stated by Combrzynski *et al*. (2023), the inclusion of 10% cricket caused the loosening of the internal structure of extruded snacks due to the increase in non-starchy components impact disruption of the internal molten starch matrix. This loosened structure is also confirmed by the low peak viscosity of the puffed extruded snack.

Similarly, Lisiecka *et al.* (2023) noticed the reduction in hardness of extruded and expanded potato crispy snacks after inclusion of 10-30% Cricket. Hardness reduced from 63.5 N in zero carrot pulp to 60 N in 30% fresh carrot pulp. The lower the hardness, the crispier the snack. Probably the major components of crickets such as protein and fat may have some texturising (emulsifying) and softening effect. Wójtowicz *et al.* (2023) recommended the incorporation of 20% cricket flour to achieve high durability product in wheat-corn snacks. The presence of fibre was observed to reduce the porosity and increase hardness of snack (Altan *et al*., 2008, Lisiecka *et al*., 2023).

The springiness of the puffed snacks ranged from 14% to 67% with highest in 100% puffed rice grain and least in 100% corn puffed snack. Springiness is related to the elasticity of snack sample. It describes how the snack recovers during the end of first bite and start of second bite. Similar to hardness, if the springiness is high, it would require more energy for mastication.

3.4 Microstructure of puffed snacks

The magnification images of the puffed grain cake are displayed in Fig 1. The images show that a solid structure was formed in all the puffed grain cakes though with some changes in the structural appearances due to the puffing blend ingredient formulations. Image of 100% rice (R100) shows white patches of tiny broken particles which probably were non-gelatinised and fragmented granules. In the C100 image (100% corn) there appeared a smooth homogenous exterior surface of the snack with continuous swollen granule network that formed the air cells and absence of white patches or particles. The high expansion of corn starch granule is well depicted in the image as larger air cells. This is an evidence of the high expansion of corn starch (Navarro-cortez *et al*., 2014). The visible large intact air bubbles relating to high porous structure is a confirmation of the low hardness of the 100% puffed corn cake (Maisont and Narkrugsa, 2010). Although the 100% corn is a cereal similar to rice but the microstructure of the corn shows well expanded continuous network that flow without disruption compared with rice.

High clusters of small native or partially gelatinised starch granule were more pronounced at the core edges of LCBC produced with 50% corn and 25% each of bambara groundnut and cassava. It is possible that these small sized partially gelatinised and non-fragmented granules originated from bambara groundnut and or small grain that were protected from the heat-deformation operations in the puffing mould due to improper mixing. As a legume, bambara groundnut starch structure is highly rigid and difficult (hard-to-cook phenomenon) to gelatinize except where it was subjected to some preconditioning hydrothermal treatment (Mubaiwa *et al*., 2018). With the improved pasting and textural properties of this mixed grain puffed cake, it seems that the highly gelatinised corn component dominate the central surface structure than the core.

In Fig 1, image HCBC of mixed-grain puffed cake with highest proportion of corn (60% corn, 20% bambara groundnut and 20% cassava), fewer white patches were observed on the surfaces of the puffed snack. About 50% of the surface was covered with large air bubble that contributed to the formation of the homogenous network and less hardness of the snack. A similar formation of large bubbles by corn through puffing process has been reported (Xu *et al*., 2023).

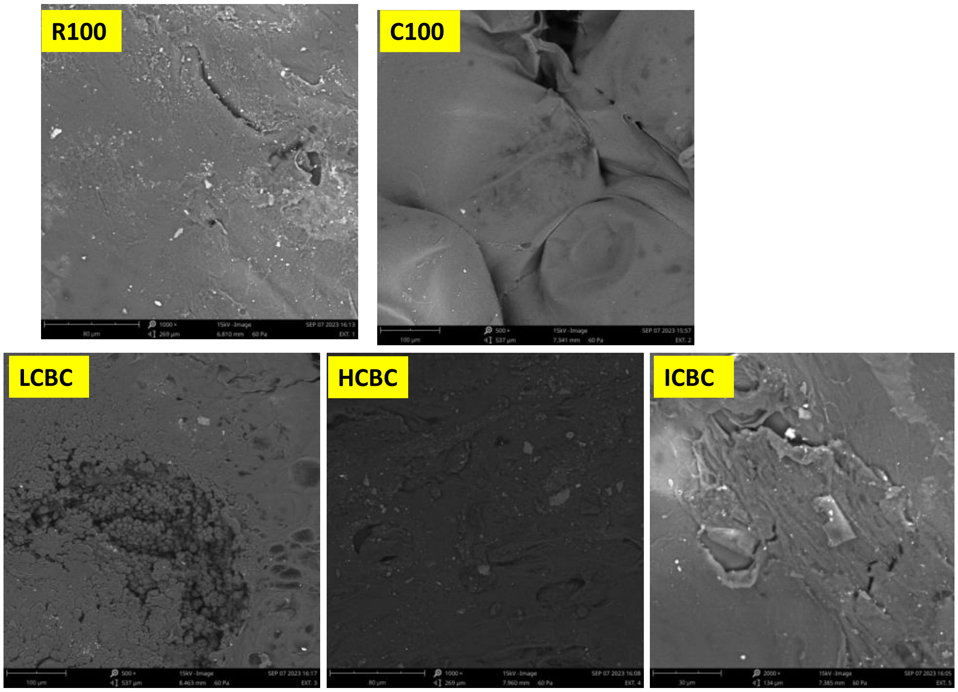

Fig 1: SEM microstructure image of puffed grain cakes

Apparently, the inclusion of 10% cricket into the ingredient formulation (ICBC) resulted to much difference in the microstructure. Collapsed and continuous large bubbles in the middle of the snack intersecting with continuous smooth network were noticed while the non-collapsed continuous air bubbles were surrounded with thick cell walls. The inclusion of cricket which earlier reduced the textural hardness may have contributed to the high structural stability of this puffed grain cake. The homogenous structural network formed in the insect-based puffed cake (ICBC) may be attributed to the non-starch components (protein and oil) of the cricket power. In addition to the protein enrichment, the insect powder may have acted as an additive for the enhancement of structure and texture of the puffed snacks.

It is possible that before the formation of puffed grain cake complex structure, the hydrated grains first undergoes a structural re-arrangement of the native structure inside the enclosed heated mould of the popping machine. The extent of the re-arrangement depends on the deformation and compression (pressurization) of the grain. The absorption of the thermo-mechanical shock helps in building up a new product structure from the native structure. Since there is no added binder to the puffing ingredients, the compressed (pressurized) heated mould fuses the individual grains together for formation of expanded product with large bubbles (the unique porous and crispy texture of puffed grain cake).

The small air bubbles formed in R100 may be attributed to inadequate starch conversion during puffing and this contributed to high hardness of the snack. As earlier stated, it seems that the processing conditions of the popping machine did not facilitate the formation of much bubbles in the 100% puffed rice cake. The selection of this research puffing temperature of 220 ^{0}C and time

5 sec was based on literature (Orts *et al*., 2000; Hossain and Shin, 2013; Lee and Yang 2020; Xu *et al*., 2023) where puffed rice cake was manufactured at temperature ranging from 210 ^{0}C to 245 ^{0}C and heating time 5-10 sec. It is possible that the rice variety used in this study is hard to cook type that requires higher temperature and higher cooking time before gelatinisation could occur. Tie *et al*. (2012) noticed that the pore size in a puffed rice snack produced with waxy rice was very small and uniform. It was reported that the degree of expansion of air bubbles during puffing is associated with the textural properties of the final product (Nakamura *et al*., 2012). For the desired high quality puffed rice cake product to be form, appropriate processing conditions should be adopted due to differences in food crop varieties.

The production of puffed grain cake with mixed grain of different shapes and sizes has some limitations that affects the microstructure of the final products. This limitation includes the improper mixing of mixed grains. This affects the volume of grains inside the feeding plate as small grains may be entrapped under big grains, thereby causing the stickiness of the grain after compressing, less expansion and formation of compact product. It can also reduce the compression and deformation of grain by the heated upper and lower moulds which will result to product that did not pop very well. It is possible that some non-starch components of the mixed grain cake cannot deform well when compressed and hence affects the formation of a spongy solid structure.

It can be confirmed that expanded grain that popped well forms the basic matrix structure (continuous network) of puffed grain cake while the partially puffed grains embed as spotted discontinuous structure. These microstructural characteristics formed during puffing process determines the stability and texture of puffed grain cakes.

Conclusion

Quality puffed grain cakes could be produced with rice cake popping machine through appropriate selection of non-rice expanded mixed grain in the ingredient formulation. Although there were non-corn starches from bambara groundnut and cassava in all the mixed-grain puffed cakes but due to the high expansion capacity and in addition to high level of corn (50-60%) in the puffing ingredient formulation, corn starch conversion dominates the pasting and structural characteristic including air cell formation. Since there was no added binder to the mixed-grain puffing ingredients, the extent of formation of product structure depends on the re-arrangement of the grain during puffing. Due to the high nutrient density, the insect-based puffed cake would be an appropriate snack to meet the nutritional requirement of developing nations and special diet consumer. It is expected that the understanding of the structural changes in the single and mixed-grain ingredients during production of puffed cakes will enable food manufacturer to produce high quality products.

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