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Process optimization and influence of processing conditions on physical, thermal and textural characteristics of Nigerian pasta produced from acha flour and defatted *Moringa oleifera* powder

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A R T I C L E I N F O

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A B S T R A C T

The consumption of Nigerian lesser known crops has been advocated by many researchers. Replacement of wheat flour with acha (*Digitaria exilis*) and de-fatted *Moringa oleifera* cake in pasta production at a laboratory scale was investigated to determine their suitability in functional pasta production. Optimization process of pasta production from acha flour (AF) and defatted *Moringa oleifera* powder (DMP) carried out using standard method, with the objectives of determining optimum processing condition by applying hybrid of Taguchi Orthogonal Array Design and Response Surface Methodology of Design Expert version 6.0. The independent variables were barrel temperature (90 – 110 °C), barrel speed (240 – 360 rpm) and moisture content (30–40%). The responses ranged as follows: hardness (18.96 – 27.83 N), springiness (0.41 – 0.71), adhesiveness (0.09 – 0.59 N/m^2), cohesiveness (0.35 – 0.64), chewiness (3.85–11.89 N/m^2), gumminess (9.23 – 17.63 N/m^2), colour characteristics (L^* [0.07 – 2.20], a^* [0.32 – 1.07] and b^* [0.21 – 2.11]), cooking time (4.00 – 6.00 min), cooking loss (5.66 – 8.05 g/100 g), water uptake (95.27–137.27%), elongation ratio (0.82 – 1.08), specific heat capacity (Cp) (177.31 – 196.45 kJ/kg/K), thermal conductivity (27.31–29.64 W/m/K) and thermal diffusivity (8.17 – 8.81 $\times 10^{-6}$ m^2/s). The variation in processing conditions significantly ($P < 0.05$) influenced all the responses. However, the principal component analysis (PCA) of the physical, thermal and instrumental textural characteristics of pastas showed positive correlations except for adhesiveness and overall acceptability. Conclusively, dough moisture content of 39.85%, barrel speed of 240 rpm and barrel temperature of 110°C gave the optimal extrusion process condition for the production of high-quality pasta.

1. Introduction

Pasta is an age-old food that is still popular today and it is a key component of the Mediterranean diet [1]. Water, eggs, and other optional ingredients may be added to the wheat flour that is primarily used to make pasta [2]. Pasta is made from coarse semolina

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milled from durum wheat, combined with water, and then forced through a metal die under pressure [3]. Durum wheat can also be used to make dried and filled products like ravioli, tortellini, and spaghetti and macaroni [4].

The annual crop "*Digitaria exilis*", which is also known as "fonio" or "hungry rice" or "acha", is a native to West Africa and it is regarded as an underutilized crop [5]. Fonio is rich in carbohydrate and crude fibre, it also contains about 7.0% crude protein that is high in leucine (9.8%), methonine (5.6%) and valine (5.8%) [6].The high fiber content of acha is helpful for weight loss, it makes you feel full, because it can absorb water and contains no calories [7].

Moringa oleifera belongs to the genus *Moringaceae* and it is a fast growing, aesthetically pleasing tree [6]. Many studies have reported that *M. oleifera* is among the cheapest and most reliable sources of nutrients [8]. The seeds are sometimes consumed fresh as peas or pressed to produce sweet and non-desiccating oil. The pressed seed cake that possesses polypeptides is used as natural coagulant for water treatment [6]. The seeds of the *Moringa oleifera* plant are antipyretic, acrid, and bitter, and they also have antimicrobial properties [9]. The seed is a good source of protein, vitamins, beta-carotene, amino acids, and different phenolics [10]. However, despite the richness of moringa seed cake in protein, minerals and vitamins, information about its utilization for the enrichment of low proteins food products is scanty [6].

Traditional pastas lack other essential nutritional components such as dietary fiber, vitamins and minerals, which are lost during wheat flour refinement [11]. The nutrient content of pastas varies widely depending on the type, quality and quantity of constituent materials as well as processing method [12,13]. Whole replacement of wheat flour with acha and defatted moringa seed flour will reduce dependence on wheat flour for manufacturing pastas, lower cost of production and increase pastas variety. It will create variety and also increase the nutritional quality of commonly consumed pastas. Raji *et al.* [6] reported that fonio starch enriched with defatted moringa seed flour had a better nutrient quality. Hence, this study determined the optimization process and influence of processing condition on physical, thermal and textural characteristics of pasta produced from acha flour and moringa seed cake powder.

2. Materials and methods

2.1. Materials

Moringa seed and acha were purchased from retailers in Ilorin, Kwara State, Nigeria, and they were brought to the Department of Food Science and Technology, Kwara State University for processing.

2.2. Methods

2.2.1. Production of acha flour

The method described by Raji *et al.* [6] was used for acha flour production. Acha seeds were manually cleaned and sorted to remove chaff and foreign objects. The clean seeds were repeatedly washed with clean tap water to remove adhering dust and sand. The wet seeds were dried in an oven at 70°C for 6 hours, milled into flour using an attrition mill, sieved using 500 µm mesh size and eventually kept in airtight polyethylene bags at room temperature (28–32°C).

2.2.2. Production of moringa seeds flour

Raji *et al.* [6] method was used to produce moringa seed flour. Moringa seeds were subjected to de-hulling, weighed and roasted at 160 °C for 30 minutes. The roasted seeds were eventually cooled and milled into powder using a blender.

2.3. De-fattening of moringa seed flour

The moringa seeds were defatted using Ismael and Yee [14] procedure with the following modifications. The roasted moringa seed powder was subjected to fat extraction using cold ethanol extraction method. After being soaked in ethanol for 15 minutes and vigorously stirred, the powdered roasted moringa seeds/ethanol mixture was kept for 48 hours at room temperature. The solvent layer which contained the extract was collected and the remaining cake was further washed with ethanol. Both the washing and extract were filtered through Whatman filter paper (No. 44) into a beaker. The residual cake was spread thinly on a tray and dried in an oven already set at 80 °C for 30 min in order to evaporate the adhering solvent. The dried cake was ground into powder, sieved using 500 µm mesh size and kept in a clean bowl prior to further processes. (Table 1)

Table 1
Experimental design for the basic processing condition of pasta from acha flour with moringa powder.

Variables	S1	S2	S3	S4	S5	S6	S7	S8	S9
Barrel temperature (°C)	110	110	110	100	100	100	90	90	90
Barrel speed (rpm)	240	300	360	240	300	360	240	300	360
Moisture content (%)	40	30	35	30	35	40	35	30	40

Table 2
Ingredient for pasta production.

Ingredients	Percentage (%)
Acha flour	87.97
Defatted moringa powder	12.03
Bicarbonate of soda	0.48
Salt	1.90
Carboxyl methyl cellulose	0.79

2.4. Production of pasta

The process described by Bui and Small [15] was adopted for pasta production. Dough was produced through well-combined mixtures as presented in Table 2. The formed dough was kneaded and rolled with a rolling pin to form sheets after resting for 20 minutes. A twin-screw extruder (Model: HN-65, Zhuoheng Product, China.) and a 4 mm die were used to extrude the sheets at a laboratory scale. The pastas were laid out in thoroughly cleaned aluminum trays to cool at room temperature. The pasta samples were further dried at 60 °C for 6 hours to a safe moisture level.

2.5. Analyses

2.5.1. Physical properties determination

2.5.1.1. Cooking time and cooking loss. The cooking time and cooking loss were evaluated according to the method described by Chillo *et al.* [16]. Optimal cooking time was evaluated by observing the time of disappearance of the core of the pasta strand during cooking (every 30 s) by squeezing the pastas between two transparent glass slides, while the cooking loss was determined by measuring the amount of solid substance lost to cooking water.

2.6. Water uptake percentage (%)

The percentage weight difference between cooked and uncooked pasta is expressed as the water uptake [17].

2.7. Elongation ratio

Elongation ratio was calculated based on the difference between the height/width ratio of cooked and uncooked pasta [17].

2.8. Pasta colour

The colour of the pasta samples were measured with a Chroma-meter (Minolta, Tokyo, Japan) equipped with a D 65 illuminant using the CIE $L^*a^*b^*$ system. The L^*, a^* and b^* readings were obtained directly from the instrument and provided readings of lightness, redness and yellowness, respectively. All measurements were performed in triplicate.

2.9. Pasta texture

Each sample was optimally cooked and cooled for 1 min under running distilled water. The excess water was drained and the drained sample was stored for exactly 10 min at 28°C as described by Kruger *et.al.* [18] and submitted for textural testing using the TA-XT2i texture analyzer. Instrument settings were extension mode; trigger type, auto-0.5 g; pretest speed 2.0 mm/s; post test speed 10 mm/s; test speed 3.0 mm/s; and trigger distance 80 mm. From force-distance curves, seven textural parameters were obtained, which were hardness, springiness, adhesiveness, cohesiveness, chewiness, gumminess, and energy peak.

2.10. Thermal properties

The specific heat capacity, thermal conductivity and thermal diffusivity of the pastas were determined as a function of their proximate compositions by applying additivity principles [19]. Specific Heat Capacity (Cp), Thermal Conductivity (K) and Thermal Diffusivity (D) of the pastas were determined based on weight fraction of water, fat, ash, protein and carbohydrate component of food using the equations stated below:

$$C_p = 1.424X_c + 1.549X_p + 1.675X_f + 0.837X_a + 4.187X_w$$

$$K = 0.25X_c + 0.155X_p + 0.16X_f + 0.135X_a + 0.58X_w$$

$$D = 0.146 \times 10^{-6}X_w + 0.10 \times 10^{-6}X_f + 0.0075 \times 10^{-6}X_p + 0.082 \times 10^{-6}X_c$$

X was the fraction of food component, and the subscripts; w, f, p, c and a represented water, fat, protein, carbohydrate and ash respectively.

2.10.1. Sensory evaluation of pasta samples

Trained panel of fifty judges were selected from the students and staff of the Department of Food Science and Technology, Kwara State University, Ilorin, Kwara State, Nigeria, who were familiar with pasta organoleptic properties. The panelists were further given orientation on the pasta characteristics to check for during assessment. Exactly 100 g each pasta sample was cooked for 10 min to allow for the free water to be absorbed by the pasta. Cooking was done in a pot containing 500 mL of water and presented to the panelists. The sensory evaluation (colour, texture, aroma, taste and overall acceptability) of the pasta samples were carried out using A 9 point hedonic scale in a well-ventilated sensory evaluation room at 28 °C. The hedonic scale was ranked as: like extremely to very much (9–8 scores), like moderately to like slightly (7–5 scores), neither like nor dislike to dislike slightly or dislike moderately (4–2 scores) and dislike extremely to dislike very much (1–0 score).

2.11. Statistical analysis

Data obtained were expressed as means and standard deviations, and were analysed for ANOVA and regression ($P < 0.05$). Taguchi was used for the experimental design, while Response Surface Methodology of Design Expert version 6.0 was used for process optimization and XLSTAT was used for principal component analysis.

3. Results and discussion

3.1. Cooking quality of pasta from acha flour and defatted moringa powder

The cooking characteristics of pasta sample are shown in Table 4. This also includes the amount of water absorbed during cooking, the cooking loss, and the ratio of elongation of the pasta samples. It was observed that the processing conditions significantly influenced the cooking characteristics ($P < 0.05$). The cooking time of the pasta products ranged from 4.0 to 7.0 min with pasta from 110:300:30 having the highest value (7.0 min), while the least cooking time (4.0 min) was observed in pasta from 100:300:35. Shorter cooking time exhibited by pasta from 100:300:35 might be attributed to fast-paced swelling, quicker gelatinization and faster rehydration due to increased dough moisture content and temperature [20]. The values of optimal cooking time of some pasta samples (110:300:30, 90:300:30, 90:360:40) was in tandem with the optimal cooking time (6.5 min) of pasta reported by Piwińska *et al.* [21]. Cooking loss represents the amount of solid substance lost in the cooking water [16]. However, high-quality pasta is characterized by low cooking loss [22]. There was significant difference ($P < 0.05$) in the cooking loss of the samples. Pasta from 100:360:40 had the highest cooking loss (8.05 g/100 g), while pasta from 100:240:30 had the lowest cooking loss (5.65 g/100 g). The cooking loss ranged from 5.65 to 8.05 g/100 g. Cooking loss of ≤ 6.0 g/100 g is the best for a good quality pasta product [22]. The higher cooking loss (8.05 g/100 g) observed in pasta from 100:360:40 might be caused by the pasta's weakened protein network [23]. However, limited starch damage has a direct relationship to lower cooking loss in pasta processing [24]. Interestingly, lower cooking losses observed in pastas from 100:240:30 and 90:240:35 suggested that they might have limited starch damage. How well pasta products react to cooking can be determined by their water uptake [23]. Pasta samples' water uptake values ranged from 95.27% to 137.27%, Pasta from 110:240:30 had the lowest value (95.27%), while pasta from 90:360:40 had the highest water uptake (137.27%). It was reported that there is a direct correlation between cooking time and water uptake, implying that as the cooking time increases the water uptake also does [21]. Similar finding was noticed in this study and it also in tandem with the report of Kaur *et al.* [25]. The pasta's capacity to maintain its shape in the presence of tensile forces is measured by its elongation ratio [26].The elongation ratios of the pasta samples varied significantly ($P < 0.05$), with the values ranging from 0.82% to 1.11%. In comparison to other pasta samples, the pasta from 100:360:40 had the best elongation ratio. The processing conditions significantly influenced the elongation ratios of the samples, and similar trend was observed by Kumalasari *et al.* [25] who worked on gluten-free pasta using single-screw extruders. The elongation ratios values observed in this study were below the values reported by Sholichah *et al.* [27] for pasta made from modified cassava, rice, and corn flour enriched with seaweed and Mayasti *et al.* [28] for a commercial gluten-free pasta. (Table 3 and 4).

Table 3
Cooking qualities of pastas produced from acha flour and defatted moringa powder.

Sample	Cooking time (min)	Cooking loss (g/100 g)	Water uptake (%)	Elongation ratio
110:240:30	5.00 ± 0.00^{c}	8.03 ± 0.00^{a}	95.27 ± 0.13^{g}	1.05 ± 0.00^{bc}
110:300:35	7.00 ± 3.54^{a}	6.46 ± 0.00^{bc}	95.64 ± 0.00^{g}	1.08 ± 0.00^{ab}
110:360:40	5.00 ± 0.00^{c}	7.54 ± 0.00^{a}	113.54 ± 0.00^{d}	1.01 ± 0.00^{c}
100:240:30	5.00 ± 0.00^{c}	5.65 ± 0.00^{c}	98.65 ± 0.00^{fg}	1.06 ± 0.00^{abc}
100:300:35	4.00 ± 0.00^{d}	6.05 ± 0.00^{bc}	104.08 ± 0.00^{f}	0.82 ± 0.00^{e}
100:360:40	5.00 ± 2.83^{c}	8.05 ± 0.00^{a}	120.38 ± 0.08^{b}	1.11 ± 0.00^{a}
90:240:30	5.00 ± 0.00^{c}	6.55 ± 0.00^{a}	112.35 ± 0.00^{e}	1.04 ± 0.00^{bc}
90:300:35	6.00 ± 0.00^{b}	5.66 ± 0.00^{c}	118.00 ± 0.00^{c}	1.05 ± 0.00^{bc}
90:360:40	6.00 ± 0.00^{b}	7.25 ± 0.00^{ab}	137.27 ± 0.00^{a}	0.89 ± 0.00^{d}

Data are means of triplicates ± Standard deviation. Data with different superscripts in the same column are significantly different at $P < 0.05$. Samples extrusion conditions are represented as first digit = barrel temperature in °C, second digit = barrel speed in rpm and third digit= moisture content in %.

Table 4
Colour characteristics of pastas produced from acha flour and defatted moringa powder.

Sample	L*	a*	b*
110:240:30	1.07 ± 0.03[d]	0.57 ± 0.02[a]	0.21 ± 0.04[b]
110:300:35	2.20 ± 0.03[a]	0.40 ± 0.03[b]	0.24 ± 0.01[b]
110:360:40	0.07 ± 0.02[g]	0.44 ± 0.04[b]	0.27 ± 0.02[b]
100:240:30	2.11 ± 0.00[b]	0.89 ± 0.01[a]	0.53 ± 0.03[b]
100:300:35	1.24 ± 0.00[c]	0.32 ± 0.04[b]	0.72 ± 0.04[b]
100:360:40	0.67 ± 0.03[f]	0.42 ± 0.03[b]	0.67 ± 0.00[b]
90:240:30	0.86 ± 0.01[e]	0.39 ± 0.02[b]	2.03 ± 0.01[a]
90:300:35	1.05 ± 0.00[d]	1.07 ± 0.00[a]	1.86 ± 0.04[a]
90:360:40	0.64 ± 0.00[f]	0.87 ± 0.03[a]	2.11 ± 0.03[a]

Data are means of triplicates ± Standard deviation. Data with different superscripts in the same column are significantly different at $P < 0.05$. Samples extrusion conditions are represented as first digit = barrel temperature in °C, second digit = barrel speed in rpm and third digit = moisture content in %.

3.2. Colour characteristics of pasta from acha flour and defatted moringa powder

Colour is an imperative parameter that gives outright impression to consumers determining acceptance or rejection of a product, which is influenced by the ingredients [26], however the picture of the pastas produced from acha flour and defatted moringa powder is in Plate 1. Table 4 presents the results for the colour characteristics of uncooked pasta products. There were significant differences ($P < 0.05$) in the lightness (L^*), redness (a^*) and the yellowness (b^*) for the pasta products. The colour attributes of the acha defatted moringa pasta in terms of L^*, a^*, b^* ranged from 0.07 to 2.20, 0.32–1.07, and 0.21–2.11 respectively (Table 3). However, increase in the barrel speed and dough moisture subsequently led to a decrease in the L^* and increase in the b^* of the pastas except for samples110:300:30 and 90:300:35 that exhibited contrary behaviour. The result obtained in this study is not in agreement with the findings of Sobowale *et al.* [29] who reported on the process optimization of extrusion variable and its effects on colour characteristics of extruded cocoyam pastas in term of L^*, a^* and b^*(29.38–77.18, 9.43–25.49, and 2.18–23.44 respectively).

3.3. Instrumental texture profiling of pasta from acha flour and defatted moringa powder

Table 5 shows the findings for the instrumental texture profiling of pasta in terms of hardness, springiness, adhesiveness, cohesiveness, chewiness, gumminess, energy peak and stringiness. The pasta samples ranged in hardness from 18.96 to 27.83 N, with pasta from 100:300:35 being the noticeably hardest and pasta from 90:360:40 having the lowest value. The processing conditions had significant influence of the hardness of the samples. Higher pasta hardness readings from 100:240:30 and 100:300:35 could have been influenced by temperature changes. Similar findings were reported by Sozer *et al.* [23] who researched on thermal, textural and cooking properties of spaghetti enriched with resistant starch. The hardness of the pasta measured in this investigation are in agreement with Khatkar and Kaur's [20] study on steam boiled and steam-fried instant pasta (18.10–23.02 N) and El-Sohaimy *et al.* [30] who reported the hardness of chickpea-fortified cooked pasta (9.00–22.13 N), but contrary to the findings of Sozer *et al.* [23] who investigated the hardness (23.52–92.72 N) of cooked spaghetti and Kumalasari *et al.* [26] who conducted research on gluten-free pastas for two different extruders (264.05–275.49 N and 158.70–327.29 N). The springiness of the pastas ranged from 0.41 to 0.71, with sample 90:300:30 having the lowest value and sample 110:240:40 having the highest value. The springiness of the pasta samples varied significantly. Pastas extruded at a high temperature (110°C) displayed an overall higher springiness than others; this might be linked to quicker swelling and gelatinization of starch at elevated temperature [20]. Since the chewy effect of food when bitten is directly related to springiness or elasticity, therefore the degree of springiness is an indicator of the product's elasticity when chewed [31,32]. It is expected that sample 110:240:40 may have good elastic behavior during processing and better chewiness because of its high springiness value. The values reported in this reported in this study is slightly lower than the values of springiness Kumalasar *et al.* [26] reported for gluten-free pastas from two different extruders, but higher than the springiness values (0.30–0.59) reported by Sholichah *et al.* [27] for gluten-free pasta produced from edible red seaweed supplemented tempeh flour. Pasta samples ranged in adhesiveness from 0.09 to 0.59 N/m^2, with pasta from 90:300:30 being significantly the most adhesive (0.59 N/m^2), while pasta from 110:300:30 had the least adhesiveness (0.09 N/m^2). The adhesiveness of the samples varied significantly. However, lower

Plate 1. Pastas produced from acha flour and defatted moringa powder.

Table 5
Instrumental texture profiling of pastas produced from acha flour and defatted moringa powder.

Textural Properties	110:240:30	110:300:35	110:360:40	100:240:30	100:300:35	100:360:40	90:240:30	90:300:35	90:360:40
Hardness (N)	25.84 ± 0.93^{b}	20.89 ± 0.04^{cd}	23.94 ± 5.23^{c}	27.76 ± 0.49^{a}	27.83 ± 2.36^{a}	23.79 ± 2.29^{c}	$22.63 \pm 1.98^{\mathbf{d}}$	27.10 ± 2.99^{a}	18.96 ± 0.93^{e}
Springiness	0.71 ± 0.06^{a}	0.69 ± 0.04^{a}	0.64 ± 0.04^{ab}	0.47 ± 0.02^{c}	0.67 ± 0.01^{a}	0.41 ± 0.06^{c}	$0.47 \pm 0.05^{\mathbf{c}}$	0.41 ± 0.04^{c}	0.58 ± 0.93^{b}
Adhesiveness (N/m^2)	0.36 ± 0.32^{d}	0.09 ± 0.03^{g}	0.19 ± 0.04^{ef}	0.48 ± 0.16^{b}	0.16 ± 0.08^{f}	0.43 ± 0.03^{c}	$0.35 \pm 0.11^{\mathbf{d}}$	0.59 ± 0.02^{a}	0.22 ± 0.93^{e}
Cohesiveness	0.62 ± 0.06^{ab}	0.59 ± 0.07^{bc}	0.57 ± 0.05^{cd}	0.35 ± 0.03^{f}	0.64 ± 0.05^{a}	0.38 ± 0.07^{ef}	$0.41 \pm 0.03^{\mathbf{e}}$	0.39 ± 0.07^{e}	0.54 ± 0.04^{d}
Chewiness (N/m^2)	11.50 ± 2.30^{a}	8.56 ± 1.24^{b}	8.56 ± 0.61^{b}	4.66 ± 0.03^{d}	11.89 ± 0.47^{a}	3.85 ± 1.53^{d}	$4.40 \pm 0.88^{\mathbf{d}}$	4.39 ± 1.03^{d}	6.13 ± 1.05^{c}
Gumminess (N/m^2)	16.07 ± 2.06^{b}	12.46 ± 1.32^{d}	13.43 ± 1.76^{c}	9.79 ± 0.87^{ef}	17.63 ± 0.70^{a}	9.23 ± 2.68^{f}	$9.31 \pm 0.77^{\mathbf{f}}$	10.57 ± 1.93^{e}	10.53 ± 1.55^{e}

Data are means of triplicates ± Standard deviation. Means with different superscript on the same row are significantly different at $P < 0.05$. Samples extrusion conditions are represented as first digit = barrel temperature in ^{o}C, second digit = barrel speed in rpm and third digit = moisture content in %.

Table 6
Thermal properties of pastas produced from acha flour and defatted moringa powder.

Samples	Cp (kJ/kg/K)	K (W/m/K)	D x 10^{-6} (m^2/s)
110:240:30	196.45 ± 0.02^{a}	29.64 ± 0.01^{a}	8.81 ± 0.01^{a}
110:300:35	187.06 ± 0.08^{c}	28.51 ± 0.00^{c}	8.65 ± 0.01^{c}
110:360:40	185.67 ± 0.02^{d}	28.28 ± 0.01^{e}	8.48 ± 0.04^{d}
100:240:30	168.78 ± 0.01^{h}	26.03 ± 0.04^{i}	8.17 ± 0.01^{f}
100:300:35	180.61 ± 0.00^{f}	27.79 ± 0.01^{g}	8.41 ± 0.01^{e}
100:360:40	183.41 ± 0.57^{e}	27.92 ± 0.02^{f}	8.49 ± 0.02^{d}
90:240:30	177.31 ± 0.01^{g}	27.31 ± 0.01^{h}	8.52 ± 0.02^{d}
90:300:35	186.93 ± 0.04^{c}	28.47 ± 0.01^{d}	8.63 ± 0.01^{c}
90:360:40	190.92 ± 0.02^{b}	29.11 ± 0.01^{b}	8.72 ± 0.03^{b}

Data are means of triplicates ± Standard deviation. Data with different superscripts in the same column are significantly different at $P < 0.05$. Samples extrusion conditions are represented as first digit = barrel temperature in °C, second digit = barrel speed in rpm and third digit= moisture content in %.

Table 7
Sensory properties of properties of pastas produced from acha flour and defatted moringa powder (N = 50).

Pasta Samples	Taste	Colour	Texture	Aroma	Overall Acceptability
110:240:30	6.06 ± 0.77^{ab}	5.74 ± 0.83^{b}	5.16 ± 1.48^{b}	5.70 ± 0.89^{c}	6.02 ± 0.59^{b}
110:300:35	5.48 ± 0.91^{b}	5.04 ± 1.18^{b}	5.16 ± 1.35^{b}	5.54 ± 0.95^{c}	5.44 ± 1.03^{c}
110:360:40	5.20 ± 1.53^{b}	5.30 ± 1.20^{b}	5.28 ± 1.34^{b}	5.58 ± 1.13^{c}	5.82 ± 1.08^{bc}
100:240:30	5.76 ± 1.17^{b}	6.04 ± 1.21^{a}	5.67 ± 1.36^{b}	7.24 ± 1.40^{a}	6.34 ± 1.30^{b}
100:300:35	6.78 ± 1.22^{a}	6.30 ± 1.27^{a}	6.16 ± 1.23^{a}	5.80 ± 1.31^{bc}	6.20 ± 1.37^{b}
100:360:40	6.82 ± 1.30^{a}	6.22 ± 1.48^{a}	5.98 ± 1.20^{ab}	5.76 ± 1.31^{c}	7.08 ± 1.28^{a}
90:240:30	4.26 ± 1.55^{c}	5.08 ± 1.47^{b}	5.52 ± 1.40^{b}	6.24 ± 1.10^{b}	6.34 ± 0.90^{ab}
90:300:35	6.12 ± 1.42^{ab}	6.60 ± 1.30^{a}	6.56 ± 1.22^{a}	6.58 ± 1.13^{b}	6.96 ± 1.23^{a}
90:360:40	4.18 ± 1.69^{c}	5.54 ± 1.30^{b}	5.88 ± 1.12^{ab}	5.84 ± 1.10^{bc}	5.90 ± 1.25^{b}

Data are means of 50 panelists' scores ± Standard deviation. Data with different superscripts in the same column are significantly different at $P < 0.05$. Samples extrusion conditions are represented as first digit = barrel temperature in °C, second digit = barrel speed in rpm and third digit= moisture content in %.

Table 8
Correlation loading of physical, thermal properties and overall acceptability of pastas produced from acha flour and defatted moringa powder.

	F1	F2	F3	F4	F5
Cp (J/kg.k)	0.99	0.04	-0.03	-0.09	0.11
K (W/m.k)	0.99	0.07	0.01	-0.11	0.06
D (m^2/s)	0.92	0.07	0.25	-0.13	0.24
L	-0.45	-0.61	0.21	-0.40	0.08
A	-0.15	-0.13	0.86	0.15	0.06
B	0.12	0.62	0.66	0.29	0.05
Cooking time(min)	-0.44	0.43	0.21	-0.61	0.44
Cooking loss (%)	-0.06	0.76	-0.54	-0.17	0.21
Water uptake (%)	-0.30	0.91	0.16	-0.20	-0.12
Elong ratio(%)	-0.11	-0.36	-0.07	0.10	0.90
Overall acceptability	-0.25	0.28	-0.16	0.81	0.31

adhesiveness observed in some samples (110:240:40, 110:300:30, and 110:360:35) might be related to high temperature, as it was postulated that high temperature reduced the adhesiveness of pasta [21]. The values obtained in this study is higher than the values reported by Khatkar and Kaur's [20] on the adhesiveness (-3.94 to -7.13 N) of instant pastas. The adhesiveness of 0.59 N/m^2 in sample 90:300:30, suggesting that it might have lesser cooking loss and better nutrient retention, as higher cooking loss implying leaching of starch from pasta surface into cooking water, thereby contributing to a less adhesive texture. The pasta samples` cohesiveness ranged from 35 to 64, the processing conditions significantly influenced the cohesiveness of the pasta samples. Sample 110:240:30 had the highest cohesiveness, while sample 100:240:30 had the lowest cohesiveness. It was observed that the cohesiveness of the sample decreased as both the barrel speed and temperature decreased. Similar trend was reported for spaghetti made from resistant starch by Sozer *et al.* [23]. Cohesiveness is the amount of direct effort needed to break down a food's internal bonds [33]. Interestingly, product's ability to withstand a second deformation in comparison to how it responded to the first deformation is another way to describe the term "cohesiveness" [34]. This shows that higher cohesiveness values observed in this study, implying that the products might have strong ability to withstand deformation. The chewiness of the pasta samples ranged from 3.85 to 11.89 N/m^2. Pasta from 100:300:35 required the most force (11.89 N/m^2) to masticate, while the least value (3.85 N/m^2) was observed in 100:360:40. The values obtained for the chewiness of the samples varied significantly at 95% confidence level. Chewiness is the number of chews to masticate a known amount of sample at a constant rate of force application to reduce it to a consistency ready for swallowing [23].

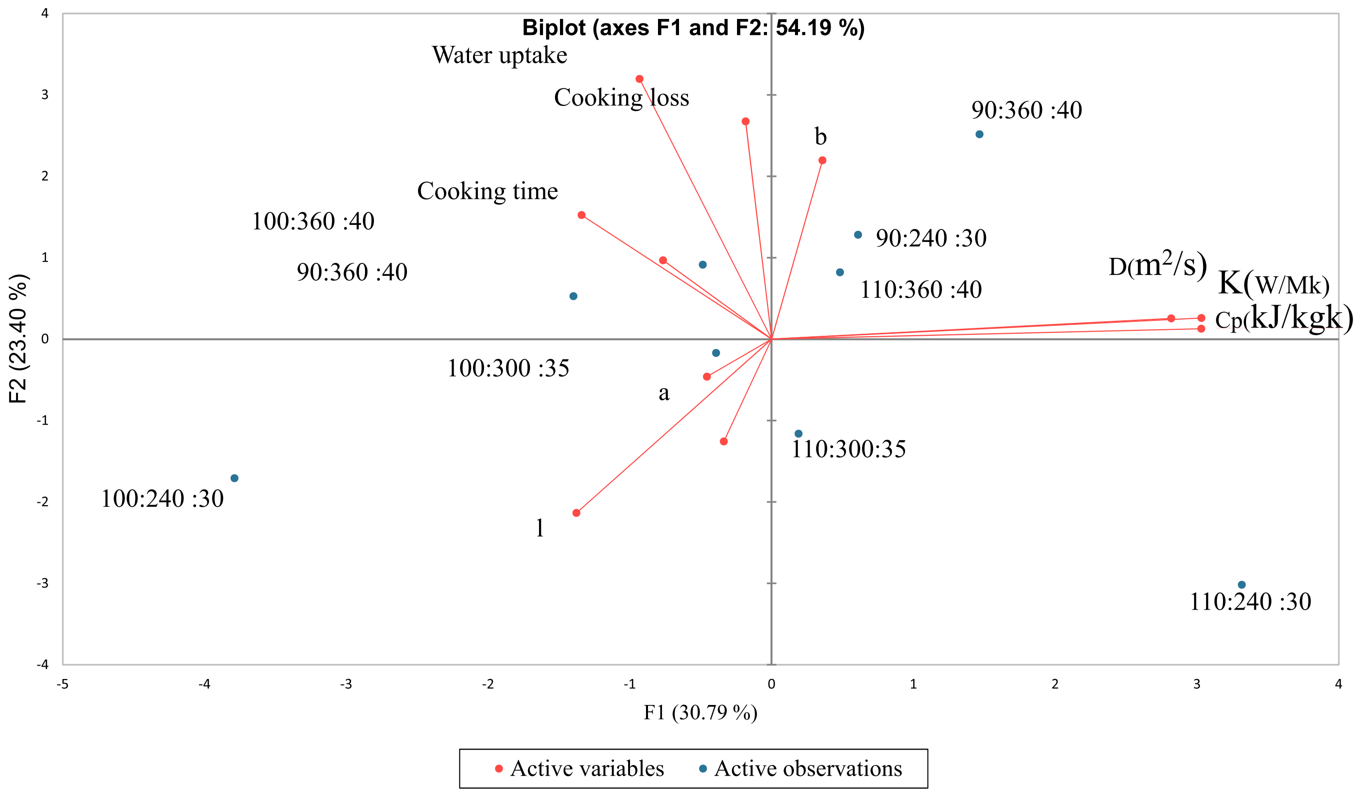

Fig. 1. Principal component biplot of the physical and thermal properties of acha- defatted moringa powder pasta produced from different at different conditions. Samples extrusion conditions are represented as first digit = barrel temperature in °C, second digit = barrel speed in rpm and third digit= moisture content in %.

Table 9
Correlation loading of instrumental textural profiling and overall acceptability of pastas produced from acha flour and defatted moringa powder.

	F1	F2	F3	F4	F5
Hardness	-0.15	0.93	0.24	-0.22	-0.11
Springiness	0.99	0.06	-0.09	0.12	0.03
Adhesiveness	-0.85	0.42	-0.02	-0.08	0.30
Cohesiveness	0.98	-0.02	0.06	0.08	0.14
Chewiness	0.93	0.32	0.15	0.07	0.09
Gumminess	0.85	0.45	0.26	-0.01	0.09
Overall acceptability	-0.76	0.04	0.59	0.26	-0.07

Increase in dough moisture content of the respective pasta products resulted in reduced level of chewiness. The values obtained in this study are lower than the values both reported by Sozer *et al.* [23] for cooked spaghetti products (25.32 – 52.45 N/m^2) and Khatkar and Kaur [20] for instant pastas (14.69 – 21.14 N/m^2). The amount of energy needed to break down semi-solid food so it can be swallowed is called it "gumminess" [31,32]. The pasta samples' gumminess ranged from 9.23 to 17.63 N/m^2. Pasta produced at 100:300:35 was noticeably gummier than other pasta products. The variation in the process conditions significantly influenced the gumminess of the pasta products. Lower values observed in this study, suggesting that the pasta samples might require lesser amount of energy to break down the pastas during mastication. The results obtained were in tandem with the report (7.13–21.34 N) of El-Sohaimy *et al.* [30] on cooked pasta fortified with chickpeas, but far lower than the values (189.38–256.18 N) reported by Kumalasari *et al.* [25] for gluten free pasta produced using single screw extruder.

3.4. Thermal properties of pasta from acha flour and defatted moringa powder

According to Akintunde [35] and Akinoso and Raji [19], thermal properties of foods are essentially the way that food materials behave when subjected to various heat treatments. These properties are crucial factors taken into account when developing processing and storage technologies as well as when performing heat transfer calculations. They are also helpful in modeling materials during thermal processing operations such as boiling, drying, baking, and frying [36,37]. The amount of heat energy needed to raise the temperature of pasta products by one-degree Kelvin (˚K) must be calculated using the specific heat capacity (Cp). The specific heat capacity values obtained in this study varied from 177.31 to 196.45 kJ/kg/K (Table 6). It was observed that the processing conditions significantly influenced the specific heat capacity (Cp) of the pasta products. Pasta from 110:240:40 had the highest specific heat capacity, while 90:240:35 had the lowest value. The values obtained in this study were higher than the values reported by Oke *et al.* [38] for yam cut and Barine and Victor [39] for plantain flour. Higher values obtained in this study could be attributed to the smaller surface area of the pasta which retained the absorbed moisture, as moisture raises a food's specific heat capacity [36]. The capacity of a food substance to carry heat inside itself is referred to as thermal conductivity (Usman *et al.*, 2019). The thermal conductivity of the pasta products ranged from 27.310.01 to 29.640.01 W/m/K, with pasta from 110:240:40 having the highest value and 90:240:35 having the lowest value. The pasta products' thermal conductivity varied significantly at 95% confidence level. It was observed that variation in temperature and moisture had significant influence on the thermal conductivity of the samples (Table 6). Increase in both results in increase in thermal conductivity of the samples as documented by Usman *et al.* [40]. However, the observed values in this study were far above the values (0.25–0.26 W/m/K) Barine and Victor's [39] reported for three cultivars of plantain flour and values (0.03–0.13 W/m/K) Usman *et al.* [40] reported for varieties of brown tigernut. Thermal diffusivity, according to Olayemi and Rahman [19] describes a material's ability to store thermal energy in relation to how well it conducts heat. The combined effects of specific heat capacity (Cp) and thermal conductivity (K) may explain the descending (110:240:40, 110:300:30, 110:360:35) and ascending (100:240:30, 100:300:35, 100:360:40) trends in the thermal diffusivity of the aforementioned samples. The observed values varied from 8.170×10^{-6}–8.81×10^{-6} m^2/s, there was a statistically significant difference in the thermal diffusivity of the pasta samples at $P < 0.05$. Pasta from 110:240:40 had the highest thermal diffusivity, while pasta from 100:240:30 had the lowest (Table 6). Higher values of thermal diffusivity of the samples at closed values suggest that the products might have greater potentials to transmit heat at a nearly identical rate. The results obtained in this study is far above the findings of Tunji *et al.* [41] who worked on thermal properties of soursop seeds and kernels and Olayemi and Rahman [19] who researched on thermal properties of various Nigerian soups.

3.5. Sensory properties of pasta from acha flour and defatted moringa powder

Colour is one of the major attributes of pasta, the sensory score for the colour of the samples varied from 5.04 to 6.60. Sample 90:300:35 had the highest mean value, while sample 110:300:30 had the least score. Taste is a sensation of flavor perceived in the mouth and throat on contact with a substance, and it is one of the most important attribute watched out for in a product. The taste of the samples ranged from 4.18 to 6.82. Highest value of taste was recorded in sample 100:360:40, while least score was recorded in sample 90:360:40. Aroma is regarded as a distinct typical pleasant smell of a substance perceived by the olfactory sense. The aroma of the samples ranged from 5.54 to 7.24. The highest aroma value was recorded in sample 100:240:30, while the lowest value was found in sample 110:300:30. However, the evaluation of the texture was based on the hand feeling and it is an important discriminative

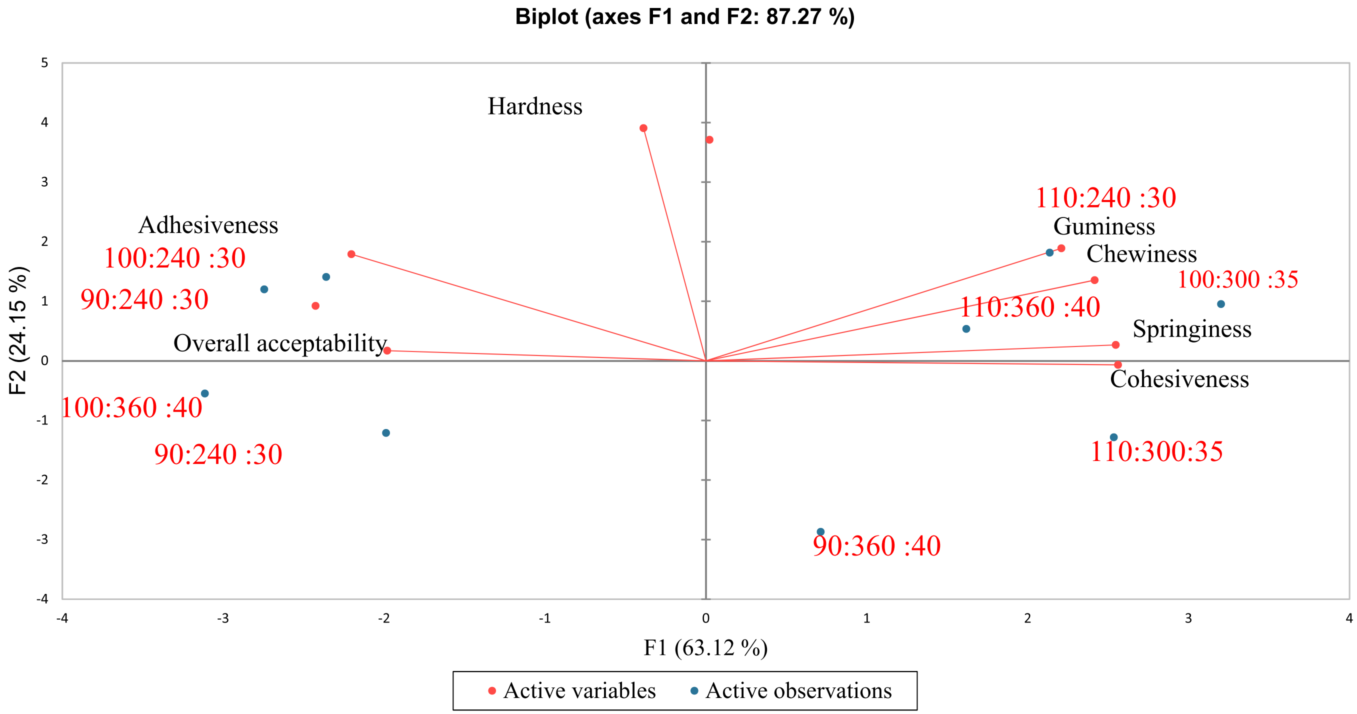

Fig. 2. Principal component biplot of the instrumental textural profiling and overall acceptability of acha- defatted moringa powder pasta produced from different at different conditions. Samples extrusion conditions are represented as first digit = barrel temperature in °C, second digit = barrel speed in rpm and third digit= moisture content in %.

Table 10
Predictive optimal process conditions for pastas produced from acha flour and defatted moringa powder.

Parameter/sample	100°C:240 rpm:39.85%	90°C:312.65 rpm:31.15%	107°C:260 rpm:31.07%
Hardness (N)	25.43	26.72	25.01
Adhesiveness (N/m^2)	0.42	0.45	0.15
Chewiness	10.54	7.92	11.18
Springiness	0.69	0.5	0.02
Guminess (N/m^2)	15.16	14.1	15.35
Cohesiveness	0.6	0.53	0.63
Cooking time (sec)	143.38	311.35	274.65
Cooking loss (g/100 g)	4.51	5.49	5.12
Elongation ratio (%)	1.05	0.89	0.89
L^*	1.06	0.77	2.07
a^*	0.83	1.09	0.72
b^*	0.64	1.89	0.33
Cp (KJ/k	195.22	181.67	178.98
K (w/m.k)	29.6	27.46	27.76
D (m^2/s)	8.79	8.74	8.43
Overall Acceptability	6.96	7.03	6.40
Desirability	0.68	0.48	0.44
Status	Desirability		

attribute of pastas, as it affects the mouth feel of the product. The texture of the samples varied from 5.16 to 6.16, with both samples 110:240:40 and 110:300:30 having the least score and sample 90:300:35 having the highest score.

The scores for overall acceptability ranged from 5.44 to 7.08. Sample 110:300:30 had the least score, while sample 100:360:40 had the highest score. However, samples were all rated above 5.4 in terms of acceptability, indicating that they were acceptable by the panelists. Sanni *et al.* [42] reported similar results for pasta produced from cassava/wheat flour (Table 7).

3.6. Correlation loading of the physical, thermal and of pasta from acha flour and defatted moringa powder

Table 8 shows the correlation loading of the physical, thermal and overall acceptability of the pasta. The result depicts that the principal component 1 (PC1) was positively correlated with the specific heat capacity (r = 0.99), thermal conductivity (r = 0.99) and thermal diffusivity (r = 0.92). The PCA biplot, as shown in Fig. 1 allowed for the separation of the samples based on the physical, thermal and the overall acceptability of the pasta. The result showed a data variance of about 54.19%, with principal component 1 contributing 30.79% and principal component 2 contributing 23.40%. The pastas made from 100ºC: 360 rpm: 40% MC and 90ºC: 240 rpm: 35% MC were in the same quadrant with the water uptake, cooking loss and cooking time of the pasta. Similarly, the 90ºC: 360 rpm: 40% MC, 90ºC: 240 rpm: 35% MC and 110ºC: 360 rpm: 35% MC were in the same quadrant with the specific heat capacity, thermal conductivity and thermal diffusivity. The preference for the pastas produced from 100ºC: 360 rpm: 40% MC and 90ºC: 240 rpm: 35% MC might be attributed to the water uptake, cooking time and cooking loss.

3.7. Correlation loading of instrumental texture profiling and overall acceptability of pasta from acha flour and defatted moringa powder

Table 9 shows the correlation loading of the instrumental textural profiling and overall acceptability of the pasta. The result depicts that the principal component 1 (PC1) was positively correlated with the springiness (r = 0.99), cohesiveness (r = 0.98), chewiness (r = 0.92), and gumminess (r = 0.85), but negatively correlated with adhesiveness (r = - 0.85) and overall acceptability (r = - 0.76). The PCA biplot, as shown in Fig. 2 allowed us to separate the samples based on the instrumental textural profiling and the overall acceptability of the pasta. The result showed a data variance of about 87.27%, with PC1 contributing 63.12% and PC2 contributing 24.15%. The pastas made from 100°C: 240 rpm: 30% MC and 90°C: 240 rpm: 35% MC was in the same quadrant with the adhesiveness, hardness and the overall acceptability of the pasta. Similarly, the pastas made from 110°C: 240 rpm: 30%, 100°C: 300 rpm: 35% and 110°C: 360 rpm: 35% were in the same quadrant with the gumminess, chewiness and springiness. In addition, samples 110°C: 300 rpm: 30% MC and 90°C: 360 rpm: 40% MC was in the quadrant with the response cohesiveness. Therefore, the preference for the pastas produced from the 100°C: 340 rpm: 30% MC and 90°C: 240 rpm: 35% MC might be attributed to the hardness and adhesiveness.

3.8. Predictive optimal process conditions for pasta produced from acha-defatted moringa composite flour blends

Based on the overlay plot of the responses using the hybrid of taguchi orthogonal array for experimental design and response surface methodology for process optimization, pasta produced from the combined effect of dough moisture content at 39.85 percent, barrel speed of 240 rpm, and barrel temperature of 110°C gave the best conditions for the extrusion process for producing high-quality pasta from acha-defatted moringa cake powder (Table 10) with a desirability of 68% (Fig. 3).

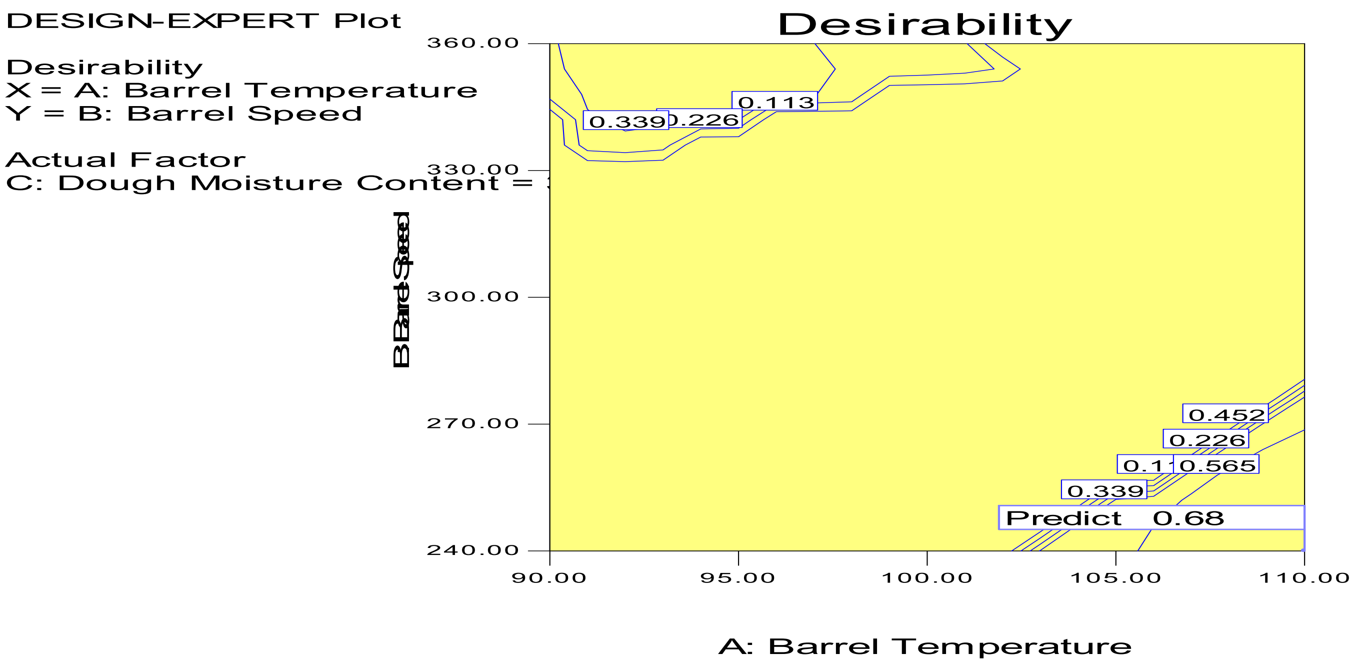

Fig. 3. Overlay plot of the response variables for the pasta produced from acha-deffated moringa cake powder.

4. Conclusion

The results of the study generally showed that dough moisture content, the barrel temperature, and the barrel speed significantly influenced the thermo-physical, colour, and textural properties of pasta made from acha flour and deffated moringa cake powder. For the correlation loading results, the principal component analysis (PCA) of the physical, thermal and instrumental textural characteristics of pastas showed positive correlation for gumminess, chewiness, springiness, cohesiveness, thermal diffusivity, thermal conductivity and specific heat capacity, but negatively correlated with adhesiveness and overall acceptability. Thus, the drivers of the overall acceptability of the 90°C: 240 rpm: 35% and 100°C: 240 rpm: 30% was influenced by the hardness, adhesiveness, water uptake, cooking loss and cooking time. After process optimization, the overlay plots of the responses revealed that the ideal extrusion process condition for the production of pasta with optimum quality would be from a dough moisture content of 39.8 percent, a barrel speed of 240 rpm, and a barrel temperature of 110°C (Fig. 3).

Authors contributions

AOR is the principal investigator, and was involved in the design concept, data acquisition, analysis, interpretation and manuscript drafting. His contribution to the work is rated 30%. **IMO** is a co- investigator, and was involved in the data acquisition, analysis, interpretation and manuscript drafting. His contribution to the work is rated 25%. **MYM** is a co- investigator and the corresponding author, he was involved in the design concept, data analysis, interpretation and manuscript drafting. His contribution to the work is rated 25%. **MSS** was involved in the design concept, data analysis, interpretation and thesis write up. His contribution to the work is rated 20%.

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CRediT authorship contribution statement

Akeem Raji: Writing – review & editing, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Isiaka Mubarak Olaitan:** Writing – original draft, Methodology, Data curation, Conceptualization. **Maxwell Yemmy Mitchel Omeiza:** Writing – review & editing, Validation, Investigation. **Mayowa Saheed Sanusi:** Writing – review & editing, Visualization, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare no conflict of interest.

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