Optimization of Non-Thermal Treatment Methods and Extrusion Temperature on Quality of Rice Pasta Enriched with *Cirina butyrospermi*

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ABSTRACT: Food security remains a critical global challenge, necessitating the exploration of sustainable and nutrient-rich food alternatives such as edible insects. This study investigated and optimized the effect of treatment methods (boiling, ultrasound, and a combined boiling and ultrasound treatment) on *Cirina butyrospermi* and extrusion temperature (70°C, 80°C and 90°C) on some quality (crude protein, in-vitro protein digestibility, calcium, zinc, iron, cooking time, water uptake ratio, lightness, and colour change) of rice pasta. The effect of treatment methods on *Cirina butyrospermi* powder and extrusion temperature on crude protein ranged from 15.85 to 18.27%, in-vitro protein digestibility (80.42-88.55%), calcium (48.53-56.25 mg/100g), zinc (2.42-3.56 mg/100g), iron (3.34-5.13 mg/100g), cooking time (8.50 - 19.50 min), water uptake ratio (1.15 - 1.90), lightness value (4.19 - 50.73) and colour change (4.47 - 51.13), respectively. The combined boiling and ultrasound treatment on *Cirina butyrospermi* powder and higher extrusion temperature gave rice pasta the highest protein, calcium, zinc, and iron content while lower extrusion temperature along with boiling treatment, increased in-vitro protein digestibility. Optimum conditions for desirable rice pasta were achieved at 80°C extrusion temperature with combined boiling and ultrasound treatment. Conclusively, exploring edible insects like *Cirina butyrospermi* under an accurate treatment method and extrusion condition could aid in the development of nutrient-rich rice pasta.

KEYWORDS: Edible insect, *Cirina butyrospermi,* Ultrasound, Gluten-free, Extrusion, Rice Pasta.

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I. INTRODUCTION

Pasta is a cereal-based food product that has become popular and widely consumed as a staple food due to its convenience, high digestibility and ease of cooking. Pasta can be produced in a variety of unusual sizes and shapes. Durum wheat semolina is the preferred raw material for pasta manufacturing due to the unique characteristics of its protein and gluten as well as its high concentration of yellow pigment (Meena *et al.*, 2019; Carpentieri *et al.,* 2024). The demand for gluten-free products, especially pasta, is rising because of the rise in gluten intolerances and consumer awareness of celiac disease. Rice pasta accounts for a higher value of the gluten-free pasta market share among gluten-free pasta due to its bland flavour, high digestibility, and hypoallergenic properties (Taddei *et al.*, 2021; Marana *et al.,* 2023).

Rice pasta is a popular gluten-free alternative to traditional wheat-based pasta. However, compared to wheat, rice flour has low protein content and a relatively poor ability to develop a cohesive network, which impairs its technological performance (Marengo et al., 2018; Suo et al., 2024). Several studies have recently emphasized the need to improve rice pasta's nutritional composition, highlighting its lower values when compared with its wheat-based counterparts (Marengo et al., 2018; Suo et al., 2024). One possible solution to this problem is to incorporate edible insects into the pasta, as they have been regarded as an alternative food due to their rich nutrients.

Edible insects have gained great relevance as a food source due to their high nutritional value and the creation of alternative food sources that align with sustainability goals for food production (Liang et al., 2024). Nevertheless, insects have low consumer acceptability due to social influences, aversion, cultural taboos and habits (Sun-Waterhouse et al., 2016; Orkusz and Orkusz, 2024). Thus, incorporating insects into common foods like pasta can enhance their nutritional value while also addressing consumer preferences. By using processing techniques that reduce the visibility of insect characteristics, such as their appearance or smell, this approach can promote greater acceptance among consumers. *Cirina butyrospermi*, commonly known as the Shea caterpillar, is a species of edible caterpillar found in West Africa (Boko *et al.,* 2024). It is known for its association with the Shea tree (*Vitellaria paradoxa*), from which it feeds. The shea caterpillar has garnered significant attention due to its nutritional value, culinary applications, and potential economic benefits. The shea caterpillar has been traditionally consumed by various ethnic groups in West Africa, where it is considered a delicacy.

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It is highly regarded for its high protein content, essential fatty acids, and mineral composition (Mbayahaga and Kouebou, 2018). The caterpillar is known by the name *Chitoumou* in Burkina Faso and as *Moni-Moni* in the Yoruba-speaking part of Nigeria. Rice pasta enriched with *Cirina butyrospermi* could present a nutritious and eco-friendly alternative to traditional pasta formulations and offer a promising opportunity to develop a sustainable and protein-rich food product.

Within the realm of food processing, two distinct but complementary technologies have gained prominence: ultrasound treatment and extrusion. Ultrasound treatment, a non-thermal processing method, utilizes high-frequency sound waves to induce structural and functional changes in food ingredients (Bermúdez-Aguirre *et al.,* 2011; Jafari and Koocheki, 2024). In the context of edible insects, ultrasound treatment could hold the potential to improve texture, reduce potential allergenicity, and enhance the bioavailability of essential nutrients found in edible insects (Kim *et al.*, 2019). In contrast, extrusion is a well-established technique in pasta production and is ideally suited for incorporating edible insects. This process involves forcing a mixture of flour and other ingredients through a die under controlled temperature and pressure (Sanusi *et al.,* 2023a; Sanusi *et al.,* 2023b; Sanusi *et al.,* 2023c). Extrusion temperature plays a critical role in shaping the final attributes of the pasta (Wang *et al.,* 2016). Suo *et al.* (2024) examined the effect of shape on nutritional and technological properties of rice-corn-chicken pea gluten free pasta while Marana *et al.* (2023), used high protein flour to develop and analysed gluten free rice pasta. However, the enrichment of rice pasta with edible insects could offer a unique opportunity to fine-tune the final product, catering to the demands of a modern food market that values both nutrition and sustainability. Carcea (2020) reported that enriching durum wheat with cricket powder enhances the quality and nutritional value of wheat pasta while Çabuk and Yılmaz (2020) found that fortifying traditional egg pasta with edible insects also improves its quality. Piazza *et al.* (2023) used silkworm pupae to fortify pasta. However, the effect of treatment methods (ultrasound, boiling and combined boiling and ultrasound treatment) on *Cirina butyrospermi* powder and extrusion temperature on the protein, in-vitro protein digestibility, mineral contents (iron, zinc and calcium), lightness, colour change, cooking time and water uptake ratio of rice pasta is not available in the literature. Therefore, this study investigates and optimizes the effect of treatment methods on *Cirina butyrospermi* and the extrusion temperature on some quality attributes of rice pasta.

II. THEORETICAL FRAMEWORK

This process flow diagram (Figure 1) represents the theoretical framework of this study on the optimization of non-thermal treatment methods and extrusion conditions on quality of rice pasta enriched with *Cirina butyrospermi.*

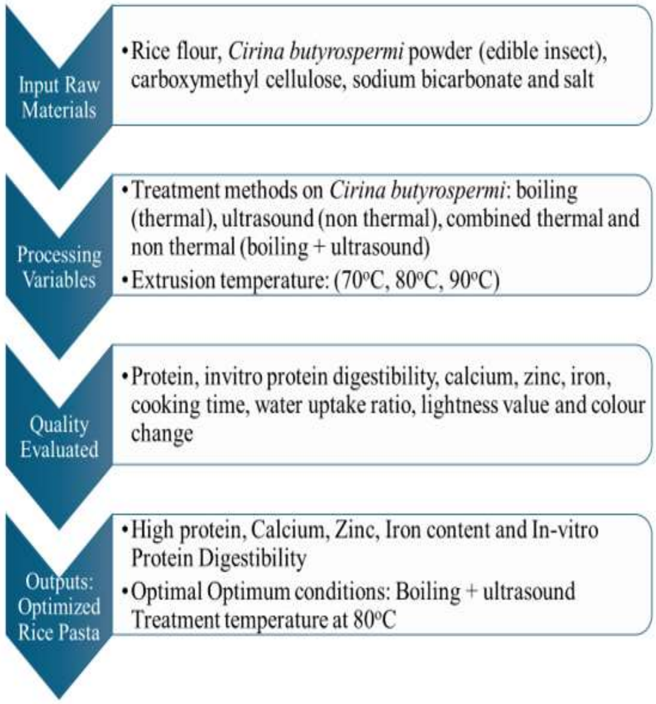

Figure 1. Theoretical framework for the optimization of non-thermal treatment methods and extrusion conditions on quality of rice pasta enriched with *Cirina butyrospermi*

III. MATERIALS AND METHODS

A. Materials

Broken grains of white rice (25kg) of FARO 44 were purchased from 3Q rice processing centre in Ilorin, Kwara State, Nigeria. The rice was milled into flour with a particle size of 0.30 mm using a developed hammer mill. Dried *Cirina butyrospermi* were obtained from Yeetiny Agro Foodies Ltd in Ilorin, Nigeria. Other ingredients such as sodium bicarbonate, carboxymethyl cellulose (CMC) and salt were bought from a grocery shop in Ilorin, Kwara State, Nigeria

B. Cirina butyrospermiPowder Preparation

The dried *Cirina butyrospermi* (6 kg) was soaked for 2 h in 12 litres of water. The soaked dried caterpillars were strained and divided into three equal portions (2 kg each). A portion was boiled at 100°C for 30 min. The second portion underwent ultrasound treatment for 30 min using an ultrasonic cleaner (Model CJ:008 China) with ultrasonic frequency and power set at 40 kHz and 50 W, respectively. The third portion of the *Cirina butyrospermi* underwent a combined treatment method (15 min apiece) beginning with 15 min boiling treatment followed by an ultrasound treatment. After the specified 30 min treatment time for each method, the respective batches of *Cirina butyrospermi* were wet milled using an electric food processor (Mr. Steel Model: SUS 304, China), dried at 50°C for 30 min and sieved to remove the exoskeleton. The resulting

Cirina butyrospermi was packed in a Ziploc bag until it was required for use.

C. Experimental Design

For the development of the rice pasta, Face Centre Composite Design of Response Surface Methodology (FCCD-RSM) was employed using design expert (Version 13) to study the interaction effect between the treatment methods for *Cirina butyrospermi* powder (ultrasound, boiling and combined ultrasound and boiling) and extrusion temperature (70°C, 80°C and 90°C) on the quality attributes of the rice pasta. The second-order polynomial model as shown in Equation 1 was used to model the interaction between the treatment methods and extrusion temperature.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_i X_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} \beta_{ij} X_i X_j \qquad (1)$$

where Y is the predicted response for the quality attributes (protein, in-vitro protein digestibility, iron, zinc, calcium, lightness, colour change, cooking time and water uptake ratio), X_i and X_j are the independent variables (treatment method and extrusion temperature), β_0 is the intercept, β_i represents the linear coefficient for X_i, β_{ii} represents the quadratic coefficient for X_i, and β_{ij} represents the interaction coefficient between X_i and X_j. The significance of extrusion temperature and treatment method on the quality attributes of the pasta were determined at 95%, 99% and 99.9% confidence levels using Analysis of Variance (ANOVA). The fitness of the models were determined using the coefficient of determinations (R^2 and R^2_{adj}).

D. Production of Rice Pasta

Figure 2 shows the flow chart for producing the rice pasta. The formula of the dry mix used for preparing the rice pasta were 1000 g of rice flour, 30 g of *Cirina butyrospermi* powder, 5 g carboxymethyl cellulose, 5 g sodium bicarbonate and 5 g salt, respectively. The blends were mixed with potable water at 60% of the entire mixture mass using a mixer (Sokany Stand Mixer, Model: Cx-6612, China) per sample. The extrusion cooking process was carried out using a co-rotating twin-screw extruder (Model: HN-65, Zhuoheng Product, Jinan City, Shandong Province, China) with a barrel with three electric band heaters, hopper, cutter and a die of 3 mm. The twin screw extruder was set at a temperature of 60°C for the first heating band, 70°C for the second heating band and the last heating band which is the extrusion temperature was varied at temperatures of 70°C, 80°C and 90°C. Each sample was fed through the hopper at a constant speed of 300 rpm and conveyed into the barrel screw at 300 rpm where the cooking took place. The cooked sample within the barrel passed through the orifice die of 3 mm and the extruded pasta was collected. The collected rice pasta was allowed to cool and dry in a fabricated oscillatory dryer at 50°C for 20 min, then packed in Ziploc bag till required for further quality analysis.

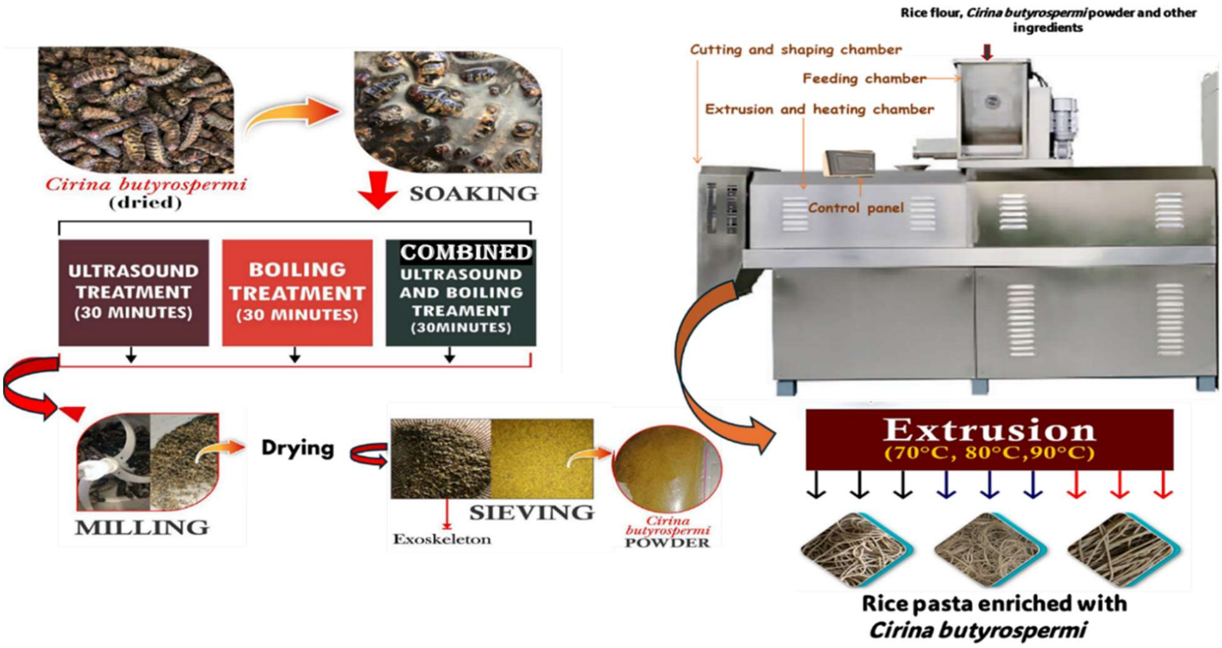

Figure 2. Flow diagram of rice pasta enriched with *Cirina butyrospermi* powder under different treatment methods and extrusion temperature

E. Quality attributes

(i) Crude protein

The crude protein content of the rice pasta was determined through the Kjeldahl method established by the Association of Official Analytical Chemists, AOAC (2012) method using a nitrogen-to-protein conversion of 6.25

B. In-vitro protein digestibility

, Rice pasta enriched with *Cirina butyrospermi* was milled, suspended in water, and the pH was adjusted to an initial value of 8.0 using 0.1 N NaOH. The samples were incubated with a multienzyme solution, and the pH was measured at 10 and 15 min to calculate in vitro protein digestibility (IVPD) using Equation 2, as described by Hsu *et al.* (1977) and L'Hocine *et al.* (2023). The variation in pH over time indicates the extent of protein hydrolysis, with a decrease in pH typically reflecting increased enzymatic activity and digestion.

$$IVPD = 210.46 - 18.10\,(x) \quad (2)$$

where x is the pH at 10 min.

(ii) *Mineral analysis*

One gram (1 g) of rice pasta was wet-digested using HNO_3-$HClO_4$, diluted to 100 mL, and analyzed for Ca, Zn, and Fe using a flame Atomic Absorption Spectrophotometer (VARIAN Model: AA240FS, United States)

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(iii) Lightness and colour values

The colour of the samples of rice pasta enriched was assessed using a Colorimeter (Model Konika Minolta, Sensing INC, Japan), which recorded colour variations in terms of CIELab values, including ΔL* (lightness), Δa* (redness-greenness), and Δb* (yellowness-blueness). Prior to measurements, the colorimeter underwent standardization using a provided white plate. For each sample, ten readings were taken. ΔE* was then computed using Equation 3 to gauge the visual colour difference between the pasta samples.

$$\Delta E* = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2} \quad (3)$$

(iv) Optimal cooking time (OCT)

A modified method of Tazrart *et al.* (2016) and Sanusi *et al.* (2017) was used to determine the optimal cooking time (OCT). In this method, 10.0 g of rice pasta was boiled in 100 mL of water, and the pasta was checked every 30 sec for the disappearance of the central white core using visual inspection. The central white core refers to the ungelatinized portion in the centre of the pasta, which remains visible until the pasta is fully cooked. The optimal cooking time (OCT) was recorded when the core completely disappeared.

(v) Water uptake ratio

Ten grams (10 g) of pasta was cooked in 100 mL of distilled water for the optimal cooking time (OCT), blotted to remove excess water, weighed, and its final weight recorded. The water uptake ratio (WUR) was calculated using Equation 4, as described by Sanusi *et al.* (2017).

$$WUR = \frac{WCRP - WRRP}{WRRP} \quad (4)$$

where WCRP is the weight of cooked rice pasta and WRRP is the weight of raw rice pasta.

(vi) *Optimization*

The numerical optimization of the responses was done using Design-Expert version 13. The optimization was done by maximizing the protein, in vitro protein digestibility and mineral contents (iron, zinc and calcium). The effectiveness of the optimization was determined using the overall desirability function (D) as shown in Equation 5. The validation of the optimization was determined by estimating the percentage variation (PV) between the experimental data and predicted data as described by Sanusi *et al.* (2022a) using Equation 6.

$$D(x) = \prod_{i=1}^{n}[d_i(x)]^{w_i} \quad (5)$$

where *D* is the overall desirability function, *di*(*x*) is the desirability function for the ith response (where $i = 1,2,\ldots n$), w_i is the weight assigned to the ith response (where $\sum_{i-1}^{n} w_i = 1$) to ensure the weights are normalized) and *x* is the vector of input variables.

$$PV = \frac{ED - PD}{PD} \quad (6)$$

where ED is the experimental data and PD is the predicted data.

(vii) Statistical analysis

Each sample was measured in triplicate, except for colour and lightness analysis, which was conducted with ten replicates. Results are presented as calculated means and standard deviations. Statistical analyses were conducted using the SPSS version 20.0 for Windows programme (SPSS Inc., Chicago, IL, USA) to ascertain significant differences between means ($p \leq 0.05$) using a one-way ANOVA test.

IV. RESULTS AND DISCUSSION

A. *Effect of Treatment Methods and Extrusion Temperature on some Quality of Rice Pasta Enriched with Cirina butyrospermi*

(i) Crude protein content

The effect of treatment methods and extrusion temperature on the crude protein content of rice pasta ranged from 15.85% to 18.27% as shown in Table 1. The lowest crude protein content (15.85%) was observed at 70°C extrusion temperature with combined ultrasound and boiling treatment while the highest (18.27%) was observed at 80°C extrusion temperature with combined ultrasound and boiling treatment. However, it was observed that there was no significant difference at $p<0.05$ between the crude protein of rice pasta extruded at 80°C when boiling treatment and combined ultrasound and boiling treatment were used. The reason could be that both treatments might have induced similar protein denaturation and starch-protein interactions, resulting in comparable crude protein in the rice pasta. Table 2 shows that the extrusion temperature, treatment methods, and the quadratic interaction of extrusion temperature and treatment methods significantly affected the crude protein content of rice pasta. The quadratic model for crude protein content demonstrated a strong fit, with a coefficient of determination (R^2) of 0.86 and an adjusted R^2 (R^2_{adj}) of 0.82. These high values indicate the model's effectiveness in describing the impact of extrusion temperature and treatment methods on the protein content of Cirina butyrospermi-enriched pasta. The F-value and the P-value of the polynomial model were 18.69 and 0.0001, respectively. Figure 3 shows that optimum protein content could be obtained at 80ºC when combined ultrasound and boiling treatment were used. At 80ºC, the extrusion process might induce optimal protein denaturation and aggregation, leading to an improved ability to retain proteins in the final product while at 70ºC, the temperature might be too low to cause sufficient denaturation and at 90ºC, excessive heat could lead to protein degradation or loss.

This result corroborates the findings of Rafiq *et al.* (2018) who reported that the increase in extrusion temperature leads to an increase in the protein content of pasta due to the formation of the starch-protein complex matrix during processing when studying the effect of extrusion on pregelatinized semolina pasta prepared using twin- screw extruder. According to Carcea (2020), enriching durum wheat with cricket powder increased the protein content of pasta from 10% to 17%. Rice pasta typically has lower protein content compared to other cereals (Romano *et al.,* 2021). This study demonstrates that incorporating Cirina butyrospermi into rice flour, along with applying the appropriate extrusion temperature of 80°C and utilizing effective treatment methods (such as boiling or a combination of ultrasound and boiling), can significantly enhance the protein content.

(ii) In-vitro protein digestibility

In-vitro protein digestibility (IVPD) is an important quality attribute that is used to assess the extent to which proteins are digested into smaller components under simulated gastrointestinal conditions (Orlien *et al.,* 2024; Li *et al.,* 2023). Table 1 shows that the IVPD of rice pasta under the influence of extrusion temperature and treatment methods ranged from 80.42 – 88.55%. The highest occurred at 70 ºC extrusion temperature with combined ultrasound and boiling method while the lowest occurred at 80 ºC extrusion temperature with combined ultrasound and boiling treatment, respectively. Table 2 indicates that extrusion temperature, quadratic interaction of extrusion temperature and treatment methods have a significant influence on the IVPD of rice pasta.

Table 1. Effect of treatment methods and extrusion temperature on some quality of rice pasta with *Cirina butyrospermi*

TM	ET	Crude Protein (%)	IVPD (%)	Calcium (mg/100g)	Zinc (mg/100g)	Iron (mg/100g)	Cooking Time (min)	Water uptake ratio	L	ΔE
1	70	16.05 ± 0.01^{g}	88.13 ± 0.00^{b}	48.60 ± 0.00^{h}	2.42 ± 0.00^{i}	3.34 ± 0.00^{i}	8.50 ± 0.02^{d}	1.90 ± 0.14^{a}	50.73 ± 11.62^{a}	4.47 ± 12.11^{e}
1	90	17.19 ± 0.03^{c}	87.15 ± 0.00^{f}	53.90 ± 0.00^{d}	3.14 ± 0.00^{c}	4.89 ± 0.00^{d}	19.50 ± 0.04^{a}	1.15 ± 0.07^{c}	4.19 ± 3.84^{e}	30.65 ± 6.12^{b}
3	70	16.43 ± 0.00^{f}	87.85 ± 0.00^{d}	52.04 ± 0.00^{g}	2.85 ± 0.00^{g}	3.76 ± 0.00^{g}	9.50 ± 0.00^{d}	1.75 ± 0.07^{a}	29.88 ± 7.36^{b}	13.90 ± 7.48^{de}
3	90	17.03 ± 0.00^{d}	85.61 ± 0.00^{g}	55.27 ± 0.00^{c}	3.13 ± 0.00^{d}	5.10 ± 0.00^{c}	18.50 ± 0.02^{a}	1.25 ± 0.07^{c}	12.61 ± 6.02^{de}	51.13 ± 3.92^{a}
2	70	15.85 ± 0.02^{h}	88.55 ± 0.00^{a}	48.53 ± 0.00^{i}	2.70 ± 0.00^{h}	3.58 ± 0.00^{h}	8.50 ± 0.03^{d}	1.55 ± 0.07^{b}	26.95 ± 13.70^{b}	19.31 ± 14.21^{cd}
2	90	17.86 ± 0.00^{b}	82.52 ± 0.00^{h}	56.06 ± 0.01^{b}	3.32 ± 0.00^{b}	5.12 ± 0.00^{b}	18.50 ± 0.06^{a}	1.35 ± 0.07^{c}	12.75 ± 7.35^{de}	30.59 ± 7.39^{b}
1	80	16.87 ± 0.02^{e}	87.25 ± 0.00^{e}	52.43 ± 0.00^{f}	2.90 ± 0.00^{f}	4.82 ± 0.00^{e}	12.50 ± 0.02^{c}	1.15 ± 0.07^{c}	23.76 ± 6.99^{bc}	26.68 ± 7.19^{bc}
3	80	18.25 ± 0.02^{a}	88.01 ± 0.00^{c}	53.53 ± 0.00^{e}	3.10 ± 0.00^{e}	4.53 ± 0.00^{f}	16.50 ± 0.04^{b}	1.35 ± 0.07^{c}	21.68 ± 11.58^{bc}	23.83 ± 12.16^{bc}
2	80	18.27 ± 0.00^{a}	80.42 ± 0.00^{i}	56.25 ± 0.00^{a}	3.56 ± 0.00^{a}	5.13 ± 0.00^{a}	16.50 ± 0.02^{b}	1.55 ± 0.07^{b}	16.89 ± 10.53^{cd}	30.65 ± 10.57^{b}

TM – Treatment method, ET – Extrusion temperature, IVPD – In-vitro protein digestibility, 1 – Ultrasound treatment, 2 – combined ultrasound and boiling treatment and 3 – Boiling treatment. Values within columns with dissimilar superscript letters are significantly ($p \leq 0.05$) different from each other.

Generally, lower extrusion temperatures favour the IVPD of the rice pasta regardless of the treatment method as illustrated in Figure 3. This aligns with the study of Marti *et al.* (2013), who reported that extruding rice pasta at lower temperatures results in less denaturation of protein molecules. When rice pasta is extruded at lower temperatures, the protein molecules are subjected to less heat and therefore undergo less denaturation. This preservation of protein structure enhances the digestibility of the protein in the pasta. The extrusion process itself can cause protein denaturation, which can negatively impact digestibility. However, at lower extrusion temperature, the extent of denaturation is reduced, leading to improved protein digestibility. This is equally supported by the findings of Zhou *et al.* (2016) who observed that extrusion at higher temperature resulted in a complete denaturation of rice bran protein (RBP), while extrusion at lower temperatures increased the content of RBP and preserved its structure. Therefore, a decrease in extrusion temperature can enhance protein digestibility in rice pasta by minimizing protein denaturation. Similarly, the increase in protein digestibility under the influence of combined boiling and ultrasound treatment could be attributed to the fact that both treatment methods hold the potential to change the protein structure of *Cirina butyrospermi*, leading to increased protein digestibility.

Similarly, it can disrupt the protein secondary structures, such as β-sheet, and promote the formation of random coil structures, which are more easily digested. In addition to this, ultrasound treatment can disrupt the particle size of the powder, resulting in a larger surface area for enzymatic action during digestion. The quadratic model for in vitro protein digestibility (IVPD) achieved a coefficient of determination (R^2) of 0.76 and R^2_{adj} of 0.68. These values suggest that the model is adequately suited for predicting the IVPD of rice pasta, indicating it effectively captures the relationships among the relevant variables.

Table 2. Polynomial regression coefficients of treatment methods and extrusion temperature on some quality of rice pasta enriched with *Cirina butyrospermi*

Source	Regression coefficients Crude protein	In vitro rotein igestibility	Calcium	Zinc	Iron	Cooking time	Water uptake ratio	L	ΔE
A_0	18.14	81.760	55.42	3.45	5.04	15.82	1.45	17.07	29.89
A	0.6261***	-1.540**	2.67***	0.2747***	0.7318***	5.00***	-0.2417***	-13.00***	12.45***
B	0.2700*	-0.176	0.9929**	0.1023**	0.0577*	0.6667	0.0250	-2.42	4.51
AB	-0.1330	-0.315	-0.5075	-0.1088*	-0.0520	-0.5000	0.0625	7.32**	2.76
A^2	-1.13***	2.080*	-2.09**	-0.3151***	-0.5760***	-1.59**	0.1023	2.32	-3.05
B^2	-0.4200*	4.190***	-1.40*	-0.3186***	-0.2535**	-0.5909	-0.0977	5.19	-2.75
R^2	0.8617	0.7561	0.8601	0.8993	0.9543	0.9342	0.6880	0.93	0.81
R^2 adj	0.8156	0.6748	0.8135	0.8658	0.9391	0.9122	0.5839	0.87	0.68
F-value	18.69	9.30	18.44	26.80	62.69	42.58	6.61	17.56	10.88
P-value	0.0001	0.0003	0.0001	0.0001	0.0001	0.0001	0.0019	0.0008	0.0034

∗Significant at 95% confidence level. ∗∗Significant at 99% confidence level. ∗∗∗Significant at 99.9% confidence level, A_0 – Intercept, A – Extrusion temperature, B – Treatment methods

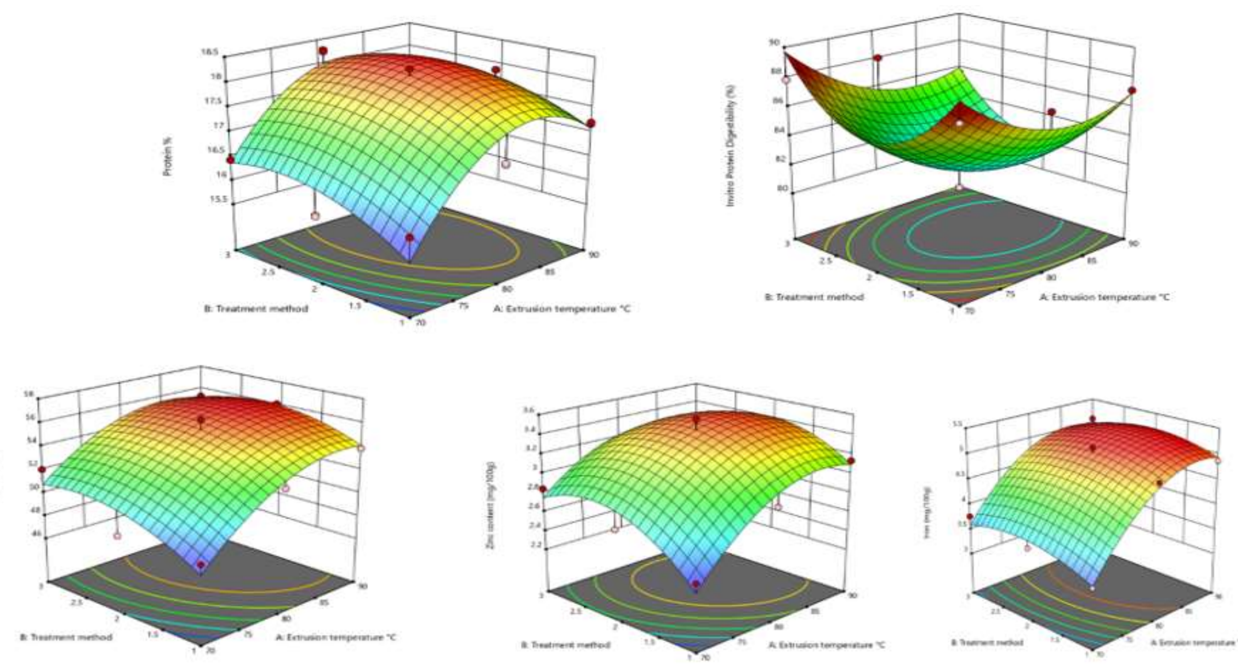

Figure 3. Effect of treatment methods on *Cirina butyrospermi* powder and extrusion temperature on the protein content, in-vitro protein digestibility, calcium, zinc and iron of rice pasta

(iii) *Mineral contents*

Mineral content plays a crucial role in the development and functioning of the human body (Abo-El-Saad and Shawir, 2024). Therefore, understanding and considering the mineral content of rice pasta is essential for assessing its nutritional value. Table 1 shows the influence of extrusion temperature and treatment methods on the mineral contents of the rice pasta. The mineral contents of the rice pasta include calcium, zinc, and iron, with calcium ranging from 48.53 to 56.25 mg/100g, zinc ranging from 2.42 to 3.56 mg/100g, and iron ranging from 3.34 to 5.13 mg/100g. The rice pasta was observed to have higher calcium content than iron and zinc. Also, combined boiling and ultrasound treatment at the extrusion temperature of 80°C gave the highest value for calcium, zinc and iron contents.

Table 2 indicates that extrusion temperature, treatment methods and the quadratic interaction of extrusion temperature and treatment methods have significant effect on the mineral contents, while the interaction of extrusion temperature and treatment method has a significant effect on the zinc content alone. Lazou (2022) highlighted the importance of considering the impact of extrusion temperature on mineral content to maintain the nutritional quality of the final product. From Figure 3, it was deduced that an increase in extrusion temperature favoured the mineral contents across all the treatment methods. This could be attributed to the changes in the starch structure of the rice dough at high extrusion temperature, thus, causing transformations and interactions that can lead to molecular changes in the size and distribution of the starch molecule resulting in improved mineral content. These results align with the findings of da Silva *et al.* (2016) on the quality assessment of pasta made from a blend of brown rice and cornmeal. The quadratic model for the mineral contents showed that the coefficient of determination (R^2) and R^2 adjusted have high value which are 0.86 and 0.81, 0.90 and 0.87, 0.95 and 0.94 for calcium, zinc and iron respectively; thus, showing their adequacy for predicting the mineral contents. The F-value and the P-value of the quadratic model were 18.44 and 0.0001 for calcium, 26.80 and 0.0001 for zinc, and 62.69 and 0.0001 for iron.

(iv) *Cooking time*

The cooking time directly affects how quickly the food reaches the desired texture and doneness. Shorter cooking times typically mean faster preparation. Rice that requires less cooking time is anticipated to be more valuable in the market and more appealing to consumers compared to rice that takes longer to cook (Sanusi *et al.,* 2022b). The cooking time of rice pasta produced by different extrusion temperatures and treatment methods ranged from 8.50 to 19.50 min as shown in Table 1. However, no significant difference exists at $p>0.05$ in the cooking time of the rice pasta produced at the extrusion temperature of 70°C when ultrasound treatment, boiling treatment and combined boiling and ultrasound treatment were used for the rice pasta. A similar trend was observed among the rice pasta produced at 90°C extrusion temperature. It was also observed that, regardless of the treatment method used, higher extrusion temperatures were associated with longer cooking times.

Table 2 shows that extrusion temperature and the quadratic interaction of extrusion temperature have significant influence on the cooking time of rice pasta. An increase in extrusion temperature generally increases the cooking time (Figure 3). The observed increase in cooking time could be attributed to the greater starch degradation caused by high extrusion temperature. This resulted in damage to starch granules thus allowing the cooking water to invade deeply into the granular interior which led to a slowing down of the hydration process and caused longer cooking time. Jalgaonkar *et al.* (2019) reported that increasing barrel extrusion temperature during the production of Pearl millet-based pasta increased the cooking time. de la Peña and Manthey (2017) reported similar findings in the cooking time of nontraditional spaghetti while Raji *et al.* (2024) also noted that pasta produced from Acha flour and defatted Moringa oleifera powder have longer cooking time at 110°C than 100°C and 90°C extrusion temperature. The polynomial model for the cooking time showed that the R^2 and R^2_{adj} have high values of 0.93 and 0.91 and this shows their adequacy for predicting the cooking time. The F-value and the P-value of the model were 42.58 and 0.0001 respectively.

(v) *Water uptake ratio (WUR)*

The water uptake ratio is a significant cooking characteristic preferred by consumers because it affects the weight of rice after cooking (Sanusi *et al.,* 2022b). The WUR of the rice pasta ranged from 1.15 to 1.90 as shown in Table 1. WUR was significantly higher at 70ºC extrusion temperature with ultrasound treatment. However, it was observed that lower extrusion temperature favoured higher water uptake ratio than higher extrusion temperature (Figure 4). The large water uptake for the rice pasta at 70°C could be attributed to the incomplete or limited gelatinization of starch granules that occurred at lower extrusion temperature.

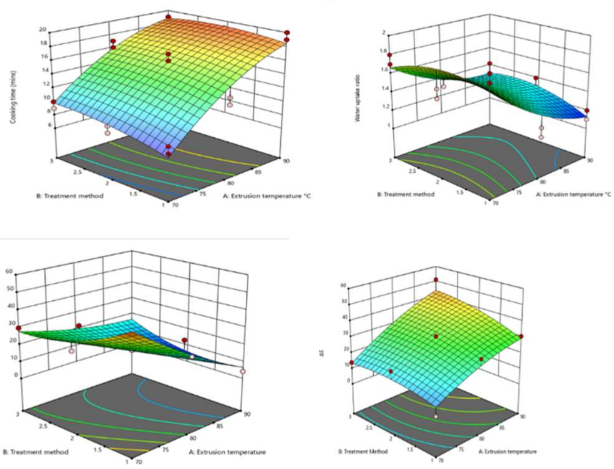

Fig. 4. Effect of treatment methods and extrusion temperature on cooking time, water uptake ratio, lightness value and colour change of rice pasta enriched with *Cirina butyrospermi*

Raji *et al.* (2024) reported similar trend as water uptake ratio of Nigerian pasta from Acha flour and defatted Moringa oleifera powder was higher at 90°C than 100°C and 110°C, respectively. The range of water uptake obtained in this study is similar to those reported by Hooper *et al.* (2023). Table 2 shows that extrusion temperature significantly affects the water uptake ratio (WUR) of the rice pasta, with a significance level of $p<0.001$. The polynomial model for the WUR showed that the R^2 and R^2_{adj} were 0.69 and 0.58, respectively. The F-value and the P-value of the quadratic model were 6.61 and 0.0019, respectively. In general, rice pasta extruded at lower temperatures absorbed more water compared to those extruded at higher temperatures.

(vi) Colour

The measurement of lightness (L) and colour change (ΔE) in pasta is important because it is one of the sensory indices that can be used to assess the quality of the final product by consumers before purchasing. The lightness profile of the rice pasta ranged from 4.19 to 50.73, and the color change ranged from 4.47 to 51.13, as indicated in Table 1. The maximum lightness value was observed at 70ºC extrusion temperature with ultrasound treatment while the maximum colour change occurred at an extrusion temperature of 90ºC with boiling treatment (Figure 4). The elevated L value noted when using a low extrusion temperature during ultrasound treatment may be ascribed to the capacity of the lower extrusion temperature process to inhibit the formation of darker specks in the final product, consequently enhancing the overall lightness value. Additionally, high extrusion temperature of the rice could promote Maillard reactions and account for the low lightness values observed at 80ºC and 90ºC extrusion temperature. Cavazza *et al.* (2013), Hooper *et al.* (2023), and Raji *et al.* (2024) found that higher extrusion temperatures decrease the lightness values of wheat pasta, dry beans pasta, and Acha pasta, respectively. Table 2 indicates that both extrusion temperature and the linear interaction of extrusion temperature with treatment methods significantly affect the lightness of the rice pasta, with p-values of <0.001 and <0.01, respectively. Ultrasound treatment can improve the retention qualities of the original product integrity, giving the pasta a better lightness value. Because of this, the interaction of low extrusion temperature and ultrasound treatment contribute to the high lightness value in the rice pasta. This validates the findings of Yaver and Bilgiçli (2021) regarding the development of quality pasta enriched with lupin flour and resistant starch type 4. For the colour change, high extrusion temperature at 90°C and boiling treatment resulted in rice pasta with the highest colour change. This aligns with earlier findings from Rafiq *et al.* (2018) on the impact of pregelatinizating on the rheology, cooking properties, and antioxidant activity of pasta. They noted that higher extrusion temperatures lead to greater starch degradation and increased molecular entanglement during processing, resulting in higher colour changes in pasta. Table 2 further showed that extrusion temperature significantly influenced the colour change of the rice pasta at $p<0.001$. The polynomial model for rice pasta lightness had high R-squared ($R^2 = 0.93$) and adjusted R-squared ($R^2_{adj} = 0.87$) values, indicating its reliability in predicting lightness. Furthermore, the polynomial model exhibited an F-value of 17.65 with a significant p-value of 0.0008. For colour change, the quadratic model yielded an R-squared (R^2) value of 0.81 and an adjusted R-squared (R^2adj) value of 0.64, indicating that the model is suitable for predicting colour change. Additionally, the model had an F-value of 10.88 and a p-value of 0.0034, which further supports its significance.

(vii) Optimization of extrusion temperature and treatment methods of the rice pasta

For process optimization, the protein, in vitro protein digestibility, calcium, zinc and iron were considered as the important nutritional quality indices. The optimization was done through numerical optimization of treatment methods and extrusion temperature (Figure 5).

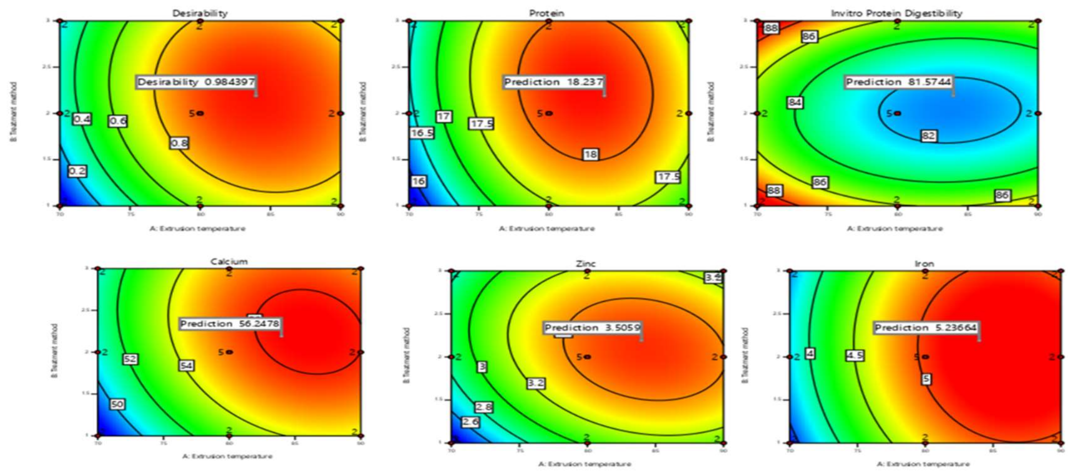

Fig. 5. Numerical optimization of treatment methods on *Cirina butyrospermi* powder and extrusion temperature on nutritional quality of rice pasta

During the optimization, assumptions were made to develop rice pasta with higher protein, in-vitro protein digestibility, calcium, zinc, and iron content. The optimization analysis result showed that at combined treatment method (2) and extrusion temperature of 80°C an optimized rice pasta with a predicted protein content of 18.24%, In-vitro protein digestibility value of 81.57%, calcium content of 56.25 mg/100g, zinc content of 3.51 mg/100g and iron content of 5.24 mg/100g could be achieved. The experimental values based on the optimum conditions were 18.26%, 82.90%, 57.12 mg/100g, 3.71 mg/100g and 5.60 mg/100g for protein, in-vitro protein digestibility, calcium, zinc, and iron content, respectively. The percentage variation between the experimental and predicted varied from 0.11%, 1.63%, 1.55%, 5.70% and 6.87%, respectively. An optimal desirability of 0.98 was achieved, indicating the effectiveness of the optimization process. According to Sanusi *et al.* (2022a), a desirability value closer to one signifies higher accuracy in achieving the optimal conditions. Therefore, the optimum range of variables obtained in Figure 4 can be used to produce desirable rice pasta enriched with *Cirina butyrospermi*

V. CONCLUSION

The study investigated the transformation of *Cirina butyrospermi* into powder using three methods and evaluated the impact of extrusion temperatures on the quality of rice pasta. The findings demonstrated that both extrusion temperature and treatment methods significantly influenced the crude protein, calcium, zinc, and iron content of the pasta. Additionally, extrusion temperature alone affected in-vitro protein digestibility, cooking time, water absorption, and color change, while the interaction between extrusion temperature and treatment methods impacted pasta lightness.

The optimal conditions for producing rice pasta with high protein and mineral content were found at an extrusion temperature of 80°C, with a combination of boiling and ultrasound treatments. A lower extrusion temperature of 70°C, along with boiling treatment, improved protein digestibility. The statistical models developed in this study are robust, offering valuable insights for improving rice pasta quality through the incorporation of *Cirina butyrospermi* powder. These findings contribute to advancing sustainable food production and innovation by promoting the use of edible insects in food systems. Recommendations include expanding the application of edible insects in food product development.

AUTHOR CONTRIBUTIONS

M.S Sanusi: Conceptualization, Methodology, Software, Validation, writing – original draft, Writing – review & editing. **A.B. Bello:** Writing – review & editing, Methodology **O. L. Oke:** Writing – review & editing, Methodology, **R. M. Sholabomi:** Writing – review & editing, Methodology **I.B. Adedeji**: Writing – review & editing, Methodology **S.A. Olaleye**; Writing – review & editing, Methodology **M. O. Idowu:** Writing – review & editing, analysis **M.A. Imam:** Writing – review & editing, **A. A. Tajudeen:** Writing – review & editing, **S.O. Alasi**: Writing – review & editing, **T. B. Olaniran**: Writing – review & editing, **F. Henshaw**: Supervision, reviewing & editing, **M.O. Sunmonu:** Supervision, Writing – review & editing.

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REFERENCES

Association of Official Analytical Chemists AOAC (2012). Official methods of analysis of the Association of Analytical Chemists International, 19th edition. AOAC, Gaithersburg, Maryland.

Abo-El-Saad, M. and Shawir, M. S. (2024). Nutritional and Medicinal Value of Mineral Elements in Dates. The Egyptian Science Magazine, 11(1), 43-51.

Bermúdez-Aguirre, D.; T. Mobbs and G. V. Barbosa-Cánovas. (2011). Ultrasound applications in food processing. Ultrasound Technology for Food and Bioprocessing, 1: 65-105.

Boko, A. C. E., A. C. Koko; S. H. Blei; D. L. Yao and D. M. Angaman. (2024). Nutritional enhancement of sprouted cereal flours with *Macrotermes subhyalinus* and *Cirina butyrospermi*: a strategy for combating malnutrition. African Journal of Food, Agriculture, Nutrition and Development, 24(4).

Çabuk, B. and Yılmaz, B. (2020). Fortification of traditional egg pasta (erişte) with edible insects: Nutritional quality, cooking properties and sensory characteristics evaluation. Journal of Food Science and Technology, 57:2750-2757.

Carcea, M. (2020). Quality and nutritional/textural properties of durum wheat pasta enriched with cricket powder. Foods, 9(9): 1298.

Cavazza, A.; C. Corradini; M. Rinaldi; P. Salvadeo; C. Borromei and R. Massini. (2013). Evaluation of pasta thermal treatment by determination of carbohydrates, furosine, and color indices. Food and Bioprocess Technology, 6:2721-2731.

Carpentieri, S.; D. Larrea-Wachtendorff and G. Ferrari. (2024). Influence of semolina characteristics and pasta-making process on the physicochemical, structural, and sensorial properties of commercial durum wheat spaghetti. Frontiers in Food Science and Technology, 4, 1416654.

da Silva, E. M. M.; J. L. R. Ascheri and D. P. R. Ascheri. (2016) Quality assessment of gluten-free pasta prepared with a brown rice and corn meal blend via thermoplastic extrusion. LWT-Food Science and Technology, 68:698-706

de la Peña, E. and Manthey, F. A. (2017). Effect of formulation and dough hydration level on extrusion, physical and cooked qualities of nontraditional spaghetti. Journal of Food Process Engineering, 40(1), e12301.

Hooper, S.D.; A. Bassett; J. A. Wiesinger; R. P. Glahn; and K. A. Cichy. (2023). Extrusion and drying temperatures enhance sensory profile and iron bioavailability of dry bean pasta. Food Chemistry Advances, 3: 100422.

Jalgaonkar, K.; S. A. Jha; S. K.; M. K. Mahawar and D. N. Yadav. (2019). Pearl millet-based pasta: Optimization of extrusion process through response surface methodology. Journal of Food Science and Technology, 56(3): 1134-1144.

Jafari, M. and Koocheki, A. (2024). Impact of ultrasound treatment on the physicochemical and rheological properties of acid hydrolyzed sorghum starch. International Journal of Biological Macromolecules, 256, 128521.

Kim, T. K.; H. I. Yong; Y. B. Kim; H. W. Kim and Y. S. Choi. (2019). Edible insects as a protein source: A review of public perception, processing technology, and research trends. Food Science of Animal Resources, 39(4): 521.

Lazou, A. E. (2022). Food extrusion: An advanced process for innovation and novel product development. Critical Reviews in Food Science and Nutrition, 64(14), 4532–4560. https://doi.org/10.1080/10408398.2022.2143474

Liang, Z.; Y. Zhu; W. Leonard and Z. Fang. (2024). Recent advances in edible insect processing technologies. Food Research International, 114137.

Li, M.; J. Wang; J. Zhang; Y. Lv; S. Guo and P. Van der Meeren. (2023). In vitro protein digestibility of different soy-based products: effects of microstructure, physico–chemical properties and protein aggregation. Food and Function, 14(24), 10964-10976.

L'Hocine, L.; A. Achouri; E. Mason; M. Pitre; D. Martineau-Côté; S. Sirois and S. Karboune. (2023). Assessment of protein nutritional quality of novel hairless canary seed in comparison to wheat and oat using in vitro static digestion models. Nutrients, 15(6), 1347.

Marengo, M.; I. Amoah; A. Carpen; S. Benedetti; M. Zanoletti; S. Buratti and S. Iametti. (2018). Enriching gluten-free rice pasta with soybean and sweet potato flours. Journal of Food Science and Technology, 55, 2641-2648.

Marti, A. and Pagani M.A. (2013). What can play the role of gluten in gluten free pasta? Trends in Food Science and Technology, 31(1):63-71.

Mbayahaga, J. and Kouebou, C.P. (2018). Edible caterpillars of the Shea tree caterpillar (*Cirina butyrospermi*): Traditional knowledge, nutritional value and potential for sustainable development in Burkina Faso. International Journal of Agricultural and Biological Science, 14(4):101-109.

Marana, A.I.S.; A. Morris; W. Prinyawiwatkul; Z. Xu and J. M. King. (2023). High-protein rice flour in the development of gluten-free pasta. Journal of Food Science, 88(4), 1268-1279.

Meena, G.S.; A. Dewan A.; N. Upadhyay; R. Barapatre; N. Kumar and A. Singh. (2019). Fuzzy analysis of sensory attributes of gluten free pasta prepared from brown rice, amaranth, flaxseed flours and whey protein concentrates. Journal of Food Science and Nutrition Research, 2(1):22-37.

Marana, A. I. S.; A. Morris, W. Prinyawiwatkul; Z. Xu and J.M. King (2023). High-protein rice flour in the development of gluten-free pasta. Journal of Food Science, 88(4), 1268-1279.

Orkusz, A. and Orkusz, M. (2024). Edible Insects in Slavic Culture: Between Tradition and Disgust. Insects, 15(5), 306.

Orlien, V.; K. Aalaei; M. M. Poojary; D. S. Nielsen; L. Ahrné and J. R. Carrascal. (2023). Effect of processing on in vitro digestibility (IVPD) of food proteins. Critical Reviews in Food Science and Nutrition, *63*(16), 2790-2839.

Piazza, L., S. Ratti; F. Girotto and S. Cappellozza. (2023). Silkworm pupae derivatives as source of high value protein intended for pasta fortification. Journal of Food Science, 88(1), 341-355.

Raji, A. O.; I. M. Olaitan; M. Y. M. Omeiza and M. S. Sanusi. (2024). 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. Food Physics, 1, 100007.

Rafiq, A.; S. Sharma and B. Singh. (2018). Effect of pregelatination on rheology, cooking and antioxidant activity of pasta. Journal of Food Science and Technology, 55:1756-1766.

Romano, A.; P. Ferranti; V. Gallo and P. Masi. (2021). New ingredients and alternatives to durum wheat semolina for a high-quality dried pasta. Current Opinion in Food Science, 41, 249-259.

Sanusi, M. S.; R. Akinoso and N. Danbaba. (2017). Evaluation of physical, milling and cooking properties of four new rice (*Oryza sativa L.*) varieties in Nigeria. International Journal of Food Studies, 6(2).

Sanusi, M.S.; M. Sunmonu; A. Abdulkareem and A. Alaka. (2022a). Modelling and optimization of the quality indices to produce ingredient-mix based dried chicken product (chicken kilishi). Journal of Meat Technology, 63(1): 33-50. https://doi.org/10.18485/meattech.2022.63.1.4

Sanusi, M.S.; R. Akinoso; N. Danbaba and J. B. Hussein. (2022b). Comparative studies of the effect of processing conditions on cooking and sensory properties of selected rice varieties. African Journal of Food, Agricultural, Nutrition and Development, 22(10), 21785-21806.

Sanusi, M.S.; M. O. Sunmonu; S. O. Alasi; A. A. Adebiyi and A. A. Tajudeen. (2023). Composition, bioactive constituents and glycemic index of brown rice-watermelon seeds extruded snacks as stimulated by extrusion conditions. Applied Food Research, 3(1), 100287.

Sanusi, M.S.; M. O. Sunmonu and S. O. Alasi. (2023). Influence of extrusion conditions on functional and textural properties of brown rice-watermelon seeds extruded snacks. Acta Periodica Technologica, (54), 81-91.

Sanusi, M.S.; M. O. Sunmonu; S. O. Alasi; A. A. Adebowale; I. T. Esho and A. A. Tajudeen. (2023). Modification of some quality attributes of brown rice-bambara nuts-pineapple peels extruded snacks through extrusion conditions. In conference proceedings, 1st Faculty of Engineering and Technology Conference, University of Ilorin, Nigeria (FETiCON 2023).

Suo, X., M. Dall'Asta; G. Giuberti; M. Minucciani; Z. Wang and E. Vittadini (2024). Effect of "shape" on technological properties and nutritional quality of chickpea-corn-rice gluten free pasta. *LWT*, *192*, 115661.

Sun-Waterhouse, D, G. I. Waterhouse; L. You; J. Zhang; Y. Liu; L. Ma and Y. Dong. (2016). Transforming insect biomass into consumer wellness foods: A review. Food Research International, 89:129-151.

Suo, X.; M. Dall'Asta; G. Giuberti; M. Minucciani; Z. Wang and E. Vittadini. (2024). Effect of "shape" on technological properties and nutritional quality of chickpea-corn-rice gluten free pasta. LWT-Food Science and Technology, 192, 115661.

Taddei, F.; E. Galassi; F. Nocente and L. Gazza. (2021). Innovative milling processes to Improve the technological and nutritional quality of parboiled brown rice pasta from contrasting amylose content cultivars. Foods, 10(6): 1316.

Tazrart, K.; C. Lamacchia; F. Zaidi and M. Haros. (2016). Nutrient composition and in vitro digestibility of fresh pasta enriched with Vicia faba. Journal of Food Composition and Analysis, 47:8-15

Wang, L.; W. Duan; S. Zhou; H. Qian; H. Zhang and X. Qi. (2016). Effects of extrusion conditions on the extrusion responses and the quality of brown rice pasta. Food Chemistry, 204:320-325

Yaver, E. and Bilgiçli, N. (2021). Effect of ultrasonicated lupin flour and resistant starch (type 4) on the physical and chemical properties of pasta. Food Chemistry, 357:129758

Zhou, L., Y. Yang; H. Ren; Y. Zhao; Z. Wang; F. Wu and Z. Xiao. (2016). Structural changes in rice bran protein upon different extrusion temperatures: A Raman spectroscopy study. Journal of Chemistry, 2016. doi: 10.1155/2016/6898715