

Article

Application of Edible Insect Flour as a Novel Ingredient in Fortified Snack Pellets: Processing Aspects and Physical Characteristics

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Abstract: The aim of the study was to develop a suitable recipe for wheat-corn snack pellets fortified with insect flour addition and to evaluate the relevant processing aspects and physical characteristics of the developed products. Varying levels of edible insect flour (10, 20, and 30%) were incorporated into a new type of fortified snack pellet as a half product for further expansion. The effects of the edible insect flour level, as well as processing variables (moisture levels 32, 34, 36% and screw speeds 60, 80, 100 rpm), were analyzed on the extrusion stability and on selected snack pellets' physical properties processed via single-screw extrusion cooking. This research indicated that an increasing amount of edible insect flour significantly affected the processing output and energy consumption. The incorporation of insect flour in blends significantly increased the specific mechanical energy and efficiency of pellet extrusion, especially at a high moisture level and high screw speed during processing. Moreover, the addition of insect flour in the snack pellets significantly reduced the bulk density and pellet durability. Principal component analysis confirmed that approximately 76.5% of the data variance was explained by the first two principal components, and significant correlations were noted between the properties of the tested snack pellets. It can be concluded that up to 20% of insect flour in newly developed extruded snack pellet formulations has no negative effect on processing and physical properties.

Keywords: edible insect flour; snack pellets; extrusion cooking; physical properties



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1. Introduction

Feeding a growing global population with increasingly demanding consumers will necessitate an increase in food production [1–3]. The production of feed contributes significantly to the environmental impact of animal production systems. Insects are able to efficiently convert feed to body mass and thus form a more sustainable food source [4–6]. As a result, in recent years, insects have been proposed as the food of the future. There are over 1.900 edible insect species worldwide, with crickets (*Acheta domesticus*), black soldier fly larvae (*Hermetia illucens*), and mealworms (*Tenebrio molitor*) being the most common. Insects are primarily composed of protein and fat in high concentrations, are harmless, and some have functional properties, such as antimicrobial peptides, making them a viable alternative for human food and animal feed [7].

Aside from the basic nutrient composition, efforts are being made to estimate the potential health effects of eating insects. Crickets contain chitin and other fibers that may benefit gut health, in addition to high levels of protein. The results of patient studies show that consuming 25 g of powdered crickets is tolerable and non-toxic at the tested dose. *Bifidobacterium animalis*, a probiotic bacteria, increased 5.7-fold in response to powdered cricket intake. Consumption of crickets was also linked to lower plasma tumor necrosis factor (TNF) levels. According to these findings, eating crickets may improve gut health and reduce systemic inflammation [8].

A comparison of the properties of cricket flour with other cereals or pseudocereals (wheat, oats or quinoa) showed that cricket flour with comparable techno-functional properties is characterized by much higher content of protein (62.68–67.48%) and fat (19.32–24.9%) and significantly higher antioxidant properties. Therefore, it can be used as a food ingredient in the development of novel foods [9], and increased research is being conducted towards the use of cricket flour in food products. The researchers concluded that cricket flour could be considered as low-carb, high-protein and sustainable all-purpose flour substitute for muffins [10]. Other results confirm that cricket flour can be used to obtain protein-enriched bread [11]. Bread supplementation studies have shown that a 10% share of cricket flour is acceptable and contributes to a significant improvement in the nutritional composition of wheat bread. Fortification with insect flour in this amount causes an increase in the amino acid index (AAS) for lysine from over 40% to almost 70% as compared to wheat bread [12]. Moreover, research demonstrated that cricket flour used as an addition to millet flour in the production of pasta significantly increased the protein content and antioxidant properties of these products [13]. Replacing part of the wheat flour with cricket flour in chapatti baking has been proposed in other investigations, which noted that the amount of cricket flour added cannot be greater than 5%, because a larger proportion deteriorates the texture of the product [14]. Another study evaluated the effect of replacing soy flour with cricket flour and observed that this supplementation improved the nutritional value and in vitro protein digestibility of the flours, but reduced the viscosity, bulk density, water absorption capacity and water solubility of the flours, making them quite suitable for feeding children [15].

Taking into account legal considerations, food products containing flour based on house cricket (*Acheta domesticus*) were approved on 3 January 2023 by the Commission Implementing Regulations for trading in the European Union [16]. Previously, the novel food had been thoroughly investigated by scientists at the European Food Safety Authority (EFSA). Regulation 2023/5 follows the EFSA opinion of May 2022 [17]. According to the regulation, crickets may be eaten in frozen, dried or powdered form. Flour from these insects can be added, e.g., to baking, pasta, biscuits, chocolate, sauces, meat analogues and other food products, including snacks. The addition of cricket flour must be appropriately labeled on food labels for products containing this ingredient, which must indicate that the ingredient may cause allergic reactions in consumers who are known to be allergic to crustaceans, molluscs and products derived therefrom and to house dust mites.

During the thermal processing of cricket flour, there are significant changes in physicochemical properties and an increase in antioxidant capacity and protein bioavailability in the digestive tract. This warrants further research into industrial processes that can be used to produce palatable and nutritious insect-based products [18]. For example, extrusion texturization for the preparation of meat analogues with soy protein isolate and cricket flour was investigated. As a result of the conducted research, with the addition of 30% low-fat cricket flour, it was possible to obtain fibrous meat analogues with high anisotropic indices [19]. The other findings indicate that incorporating edible insects into extruded corn snacks can be a good alternative to market snacks because incorporation retains the appropriate physicochemical properties (especially when formulated at low temperatures), while the protein content with extrusion at 165 °C is enhanced when using the recommended percentages of 5 and 10% house cricket [20]. Other authors confirmed that it is possible to obtain corn snacks enriched with 12.5 and 15.0% of cricket flour classified as a “protein

source"; however, in order to maintain the typical parameters for market products, it is recommended to use 7.5% of cricket flour [21]. Sensory evaluations of extruded rice snacks with added cricket flour at levels of 10 and 15% showed that these products were well accepted based on color, smell, taste and mouthfeel [22].

Due to their attractiveness, snacks are an element of the everyday diet for many consumers. It is estimated that one third of all Poles eat them between main meals during the day [23]. Among the snacks available on the market, those obtained using the extrusion technique deserve special attention [24]. The extrusion process is a high-temperature short-time (HTST) treatment, during which there is continuous mixing, heating, pressure and shear forces on the processed biological material. In addition, it is an energy-saving technique that allows for obtaining a high-quality final product with relatively low energy and water inputs. The introduction of the extrusion technique in the food industry has increased the production of not only ready-to-eat snacks, but also pellets, breakfast cereals, baby porridges, meat analogues or cheese [25]. The extrusion process is carried out using extruders, the working element of which is a screw rotating in a profiled cylinder (single-screw extruders), a pair of screws (twin-screw extruders) or many screws (planetary extruders) [26]. The working part of the device is responsible for transporting, compacting, plasticizing and pressing the processed material through the die located at the end of the cylinder [27]. The technological aspect of the extrusion process requires control of many process parameters, e.g., humidity, composition and particle size of the material, temperature in individual sections of the device, rotational speed of the extruder screw(s), geometry of the plasticizing system and the size and shape of the forming matrix. These factors determine the range of transformations at the macromolecular level during extrusion, also affecting the rheological properties and structures of extrudates. Among the physical characteristics that are determined for extruded products, the expansion index, density and texture are some of the relevant parameters affecting the recipient acceptability [28,29].

The aim of the research was to test the processing possibilities and chosen physical properties of wheat-corn snack pellets fortified with various levels of edible insect flour.

2. Materials and Methods

2.1. Raw Materials

The basic raw materials for snack pellet processing were wheat flour type 450 and corn flour (50:50), sugar and salt. Insect flour containing powdered house cricket (*Acheta domestica*), which is widely available on the market, was purchased from SENS Foods (London, UK) and was used as a replacement for flour components in the amounts of 10, 20 and 30%. The basic composition of cereal components included the following: wheat flour—moisture 11.9%, protein 12.3%, fat 0.98%, ash 0.45%, fiber 1.3%; corn flour—moisture 9.6%, protein 5.1%, fat 1.4%, ash 0.45%, fiber 2.0% (producers' data in dry mass). The chemical composition of cricket flour was the following: moisture 2.5% protein 70.0%, fat 20.0% (of which saturated 5.2%), fiber 9.5%, carbohydrates 0.5% (of which sugars 0%), salt 0.8%, energy value 1939 kJ/463 kcal (producers' data in dry mass).

2.2. Snack Pellet Processing

Snack pellet preparation and processing variables (temperature, moisture content and screw speed) were selected on the basis of a preliminary study and our previous work [30–33]. Dry components (wheat flour, corn flour and cricket flour) with a particle size below 500 μm were mixed in a laboratory ribbon mixer for at least 15 min to achieve the uniform homogeneity of blends, moistened to 32, 34 and 36% of water content by the addition of a proper amount of tap water and mixed once again to equalize the moisture in the blend mass [34]. Control snack pellets and extrudates supplemented with insect flour were processed with a single-screw prototype modular extruder, EXP-45–32 (built by Zamak Mercator, Skawina, Poland) (Figure 1A). The temperature range was set at 50–110 °C in four sections of the extruder with a configuration of L/D = 20. Snack pellets were extruded at screw speeds of 60, 80 and 100 rpm and formed with a flat forming die

to 0.6 mm × 30 mm, followed by an external cutting device for 30 × 30 mm squares. The snack pellets were dried at 25 °C for 24 h (moisture content below 11%) and then stored in hermetically sealed plastic bags (Figure 1B).

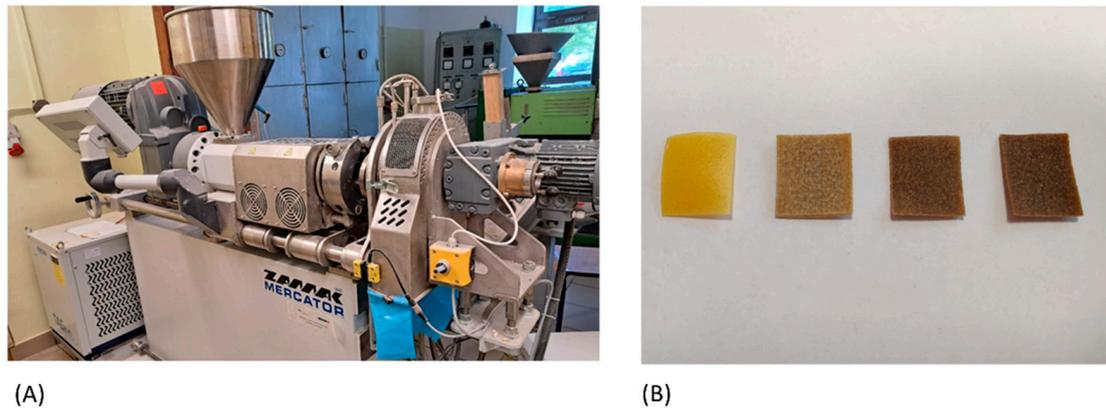


Figure 1. The single-screw prototype modular extruder EXP-45-32 (A) with L/D = 20 configuration design for snack pellet processing, and samples of the obtained snack pellets (B). From left: control and supplemented with 10, 20 and 30% of edible cricket flour.

2.3. Evaluation of Selected Physical Properties of Snack Pellets

For pellets, the efficiency (Q) of the extrusion process was determined as the mass of extrudate obtained in the appropriate time unit [34].

The specific mechanical energy (SME) was calculated taking into account the screw speed, engine load, electric power and process efficiency [34].

The expansion ratio (EI) was calculated as the ratio of the snack diameter to the diameter of the forming die. The calculation was replicated 10 times for each type of snack [35].

The bulk density (BD) of the snack pellets was determined as the weight of a specific volume of the extrudates. The test was performed in triplicate [30].

Pellets' durability was tested according to Chevanan et al. [36], where extrudates were tumbled inside a Pfast durability tester for 10 min and, after screening, the amount of uncrushed extrudate was expressed as the pellet durability.

2.4. Statistical Analysis

Data were subjected to one-way analysis of variance (ANOVA), followed by Fisher's least significant difference (LSD) post hoc test to compare means at the 0.05 significance level using the Statistica 10.0 software (StatSoft, Inc., Tulsa, OK, USA). Principal component analysis (PCA) was used to establish the dependencies between the degree of addition of flour from edible crickets and the physical parameters describing the obtained products. The Statistica software (version 12.0, StatSoft Inc., Tulsa, OK, USA) was used for statistical analyses. The PCA data matrix was composed of 8 columns and 36 rows. The optimal quantity of important components was determined after applying the Cattell criterion. The input matrix was scaled automatically. PCA and correlations were determined at $\alpha = 0.05$ significance level.

3. Results

Based on the content of the main components, it is clear that the application of nutritionally valuable ingredients may be used to improve the nutritional quality of extruded products but can also have an effect on the processing stability and extrudates' physical attributes. Téllez-Morales et al. [37] found significant differences in directly expanded corn-based snacks with cricket flour enriched at up to 40%, both during processing and in the physical properties. The LIDER project, the origin of the presented research, is focused on practical aspects of processing snack pellets according to the direct possibility

of implementing the research results in production practice. The presented research aimed to determine the most suitable practical processing aspects, including the desired amount of additive, initial moisture content and processing intensity (the applied screw speed). Knowledge about the optimal conditions and product characteristics is needed to scale up the process of snack pellet extrusion to industrial levels. Snack pellets are half-products for further expansion; hence, producers of snack pellets are more interested in the pellet characteristics and properties than those of the final product, because they are responsible for the best quality of pellets. Ready-to-eat snacks expanded from these pellets should be tested according to the method used for expansion, e.g., frying in hot oil, microwaving or hot air toasting, as the quality and properties, as well as sensory characteristics, are dependent on the expansion method [32].

3.1. Processing Aspects of Snack Pellets

During the study, selected processing aspects of the snack pellets as half-products were evaluated. It was observed that increasing the amount of insect flour improved the protein and fiber content in the snack pellet recipe, making it possible to produce more nutritionally valuable snacks with higher content of insect flour. It was also found that the composition may have an effect on the extrusion process. In Figure 2, the processing efficiency during the extrusion cooking of wheat-corn snack pellets with added insect flour and treated at various screw speeds and initial moisture levels is demonstrated. Both the highest (37.20 kg h^{-1}) and the lowest (12.08 kg h^{-1}) efficiency of the snack pellet extrusion process were noted for samples extruded from blends with 10% of insect flour addition. The highest efficiency was determined during the processing of samples at a 32% initial moisture level and at an extruder screw speed of 100 rpm. If the amount of cricket flour was higher (20 and 30%), the process was more stable and smaller differences were observed in the processing efficiency (depending on the applied variables). This could be the result of the increased amount of protein and fat content in the recipe as replacements for starchy cereal components. This provided more stable processing at the applied variables and may have been the effect of the increased amount of fat in the cricket flour recipes in samples with 20 and 30% of additive, because fat acts as a lubricant during extrusion, generating an easier flow through the extruder barrel. We also observed the lowering of the process efficiency with increasing water amounts in the processed material, especially when a low screw speed was applied. A similar range of processing efficiency was noted during the extrusion of snack pellets with the addition of fresh vegetable pulp from onion, kale, leek and carrot [34]. As reported by Lisiecka et al. [34], lower extrusion cooking efficiency of snack pellets processing can be obtained when vegetable ingredients are used, as compared to potato-based recipes. These could be related to the gelatinization temperature, which is much lower for starchy potato components, and increased efficiency may be achieved by faster starch gelatinization in the presence of water and a proper temperature. Similar observations were made by Combrzyński et al. [38] in the comparison of the pasting properties and gelatinization temperature of corn-wheat-based blends and ingredients supplemented with 10 and 30% of cricket flour.

During the extrusion process, the energy consumption was determined in the entire range of applied process variables (additive level, initial moisture level and rotational screw speed). Figure 3 reveals the results of the specific energy consumption of the extrusion process of snack pellets with the addition of various amounts of insect flour. The lowest SME ($0.086 \text{ kWh kg}^{-1}$) was observed if control samples were processed using the lowest extrusion variables. The highest SME ($0.197 \text{ kWh kg}^{-1}$) characterized the extrusion of blends with 10% addition of insect flour using the highest level of initial moistening and an 80 rpm screw speed. Similarly as for the results of processing efficiency, an increased quantity of insect flour (20 and 30%) in the recipes resulted in the better stability of the SME at variable moisture content and applied screw speeds, and the SME results differed only slightly between these samples. This may be connected with the increased amount of fat in the recipe coming from cricket flour (20%), which acts as a lubricant during extrusion

and enhances material slip during processing. The results presented by Lisiecka and Wójtowicz [34] showed that the content of plant additives had a slight effect on the SME for all tested pellet samples, probably due to the same level of hydration of the raw materials, in contrast to the important effect of the speed of the screw. In their work, the SME ranged from 0.08 (pellets with 30% of onion pulp extruded at 60 rpm) to 0.25 kWh kg⁻¹ (pellets with 10% of carrot pulp produced at a speed of 80 rpm). During the extrusion of compositions supplemented with vegetables, the effect of the screw speed was more significant than the effect of the additive content. This conclusion was confirmed by higher values in the F-test results [34]. In the wheat-corn tested snack pellets that we produced, a similar tendency was observed only for control samples. When insect flour was added, the SME increased, particularly if low amounts of water addition and slow screw speeds were applied, as compared to control samples. This outcome may be the result of the increased protein content coming from the insect flour and thus the need for more energy input to transform the blend with the addition of edible insects. Prior research by Kręcis [39] demonstrated the significant impact of an increased screw speed in creating higher SME values during corn gruel extrusion cooking processing.

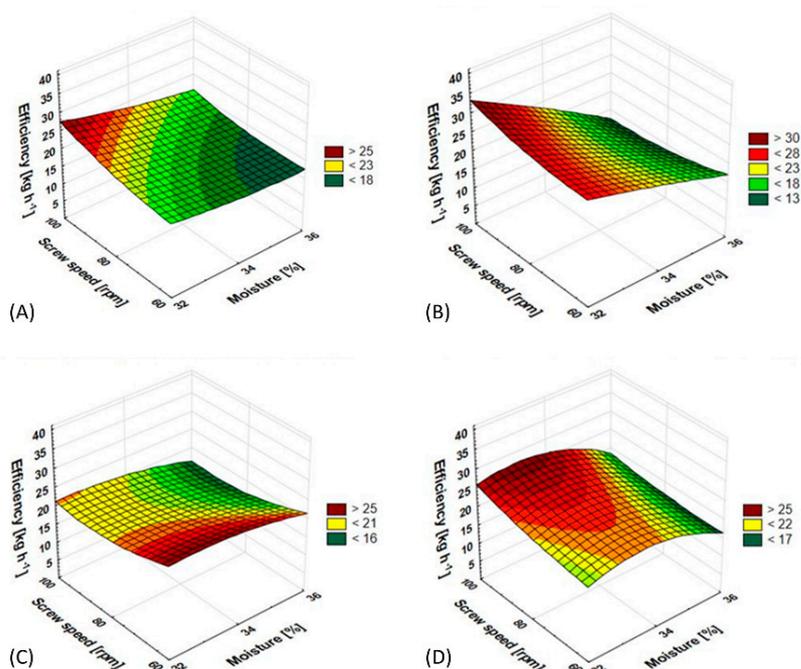


Figure 2. Results of snack pellet processing efficiency assessment of the tested blends without and with the addition of insect flour depending on initial moisture content and applied screw speed: (A) control, (B) 10% insect powder, (C) 20% insect powder, (D) 30% insect powder.

3.2. Physical Properties of Snack Pellets

After the extrusion process, the obtained pellets supplemented with edible insect flour were subjected to the evaluation of selected physical properties. Firstly, the expansion index of the achieved products was tested (Figure 4). The lowest expansion results (1.1–1.3) were found for control samples extruded at 34 and 36% of initial moisture content independent of the applied screw speed. The application of 10% of insect flour significantly increased the expansion index (3.6) and the highest index value was noted for snack pellets with 10% of insect flour processed at a 32% of moisture level and a screw speed of 80 rpm. A further increase in insect flour lowered the expansion of pellets and the results were similar for samples processed at 20 and 30% of the applied additive (Figure 4C,D). When insect flour was incorporated into the recipe in amounts of 20 and 30%, we noted no significant effect of the extrusion variables of moisture content or screw speed. The results of pellet expansion may have a significant influence on ready-to-eat snack product expansion, but this effect is connected with the applied expansion method (i.e., frying, microwaving or hot air toasting);

low expansion may be desired if frying or microwave treatment will be applied due to the very fast transformation of water into steam through very thin walls [32].

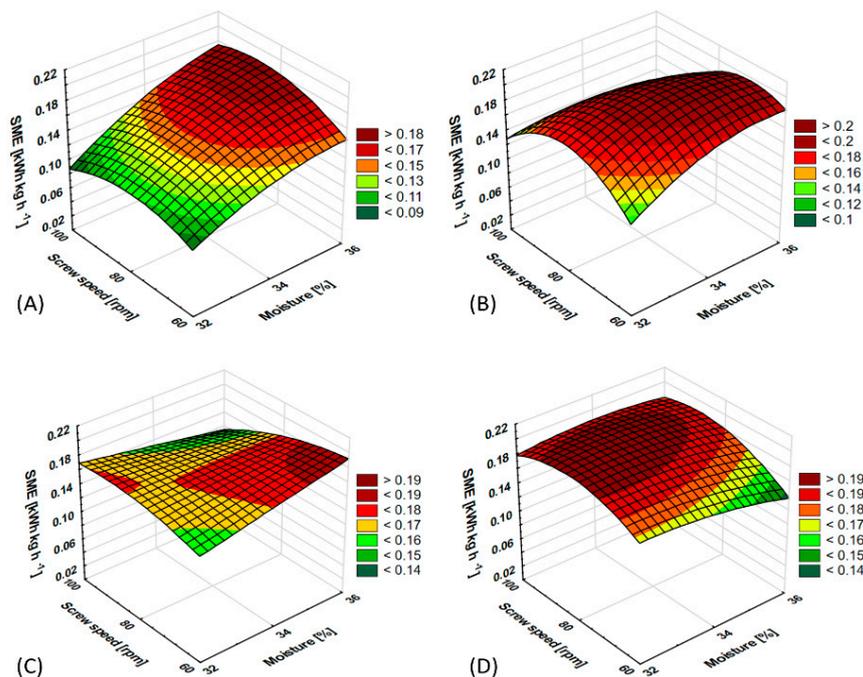


Figure 3. Results of SME testing during processing of snack pellets without and with the addition of insect flour, depending on initial moisture content and applied screw speed: (A) control, (B) 10% insect powder, (C) 20% insect powder, (D) 30% insect powder.

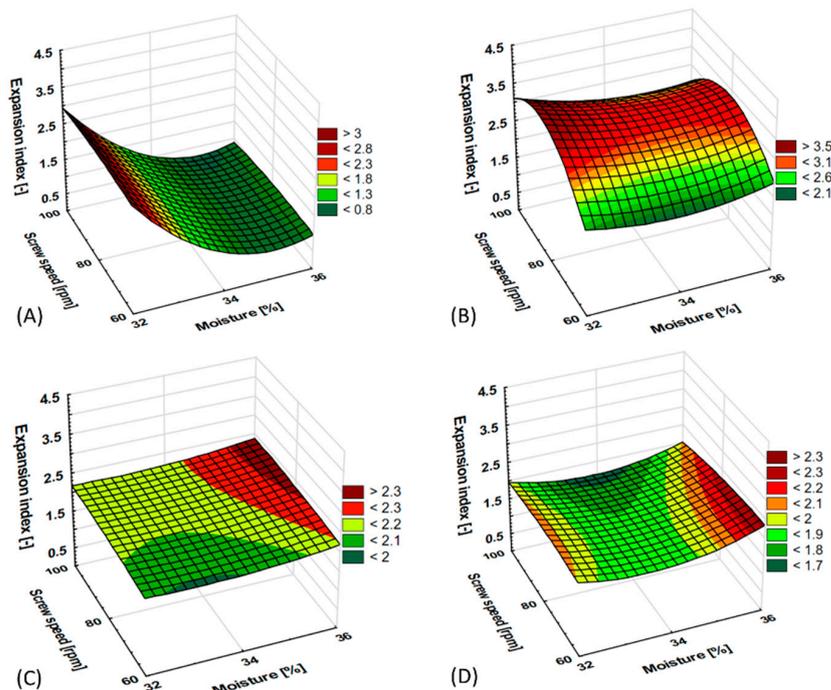


Figure 4. Results of expansion index testing of snack pellets without and with the addition of insect flour, depending on initial moisture content and applied screw speed: (A) control, (B) 10% insect powder, (C) 20% insect powder, (D) 30% insect powder.

Figure 5 shows the results of measurements of the bulk density of pellets. Both the highest and the lowest measurements of the bulk density of pellets were obtained when a 34% level of hydration was applied. The lowest results (180 kg m^{-3}) were determined

for pellets with a 30% of additive level when processed at an extruder screw speed of 80 rpm, while the highest bulk density (403.63 kg m^{-3}) was found for the control sample with any additive and subjected to extrusion at the highest screw speed. Increasing the addition of cricket flour brought about a lowering in the bulk density, which was also the effect of the low expansion index of the snack pellets, especially when 20 and 30% of insect flour was added. Lisiecka and Wójtowicz [30] reported that the fortification of snack pellets at the level of 10–30% with fresh beetroot, especially during single-screw extrusion at screw speeds of 60 and 100 rpm, significantly affected the values of the bulk density of pellets, in comparison with control samples. The increase in the content of vegetable pulp induced a significant decrease in density due to the introduction of fresh vegetables to the recipe. The bulk density of pellets was higher when the rotational screw speed increased during processing. Moreover, slightly higher ranges of bulk density for pellets supplemented with fresh onion and leek pulp pellets were noted (216.6 to 466.5 kg m^{-3}) by Lisiecka et al. [31]. In our work, we observed a decrease in bulk density in the whole range of additives applied, as compared to the control samples (Figure 5). Téllez-Morales et al. [37] also found that a high concentration of house cricket in mixtures with corn grits resulted in low expansion. The lowered bulk density of pellets supplemented with various additives may be the effect of the limitation of the carbohydrate content in potato- or cereal-based recipes due to the presence of fruits, vegetables or other additives replacing starch and thus restricting the possibility of forming a continuous gelatinized dough matrix, with low starch causing less compacted dough sheets after processing [33,36].

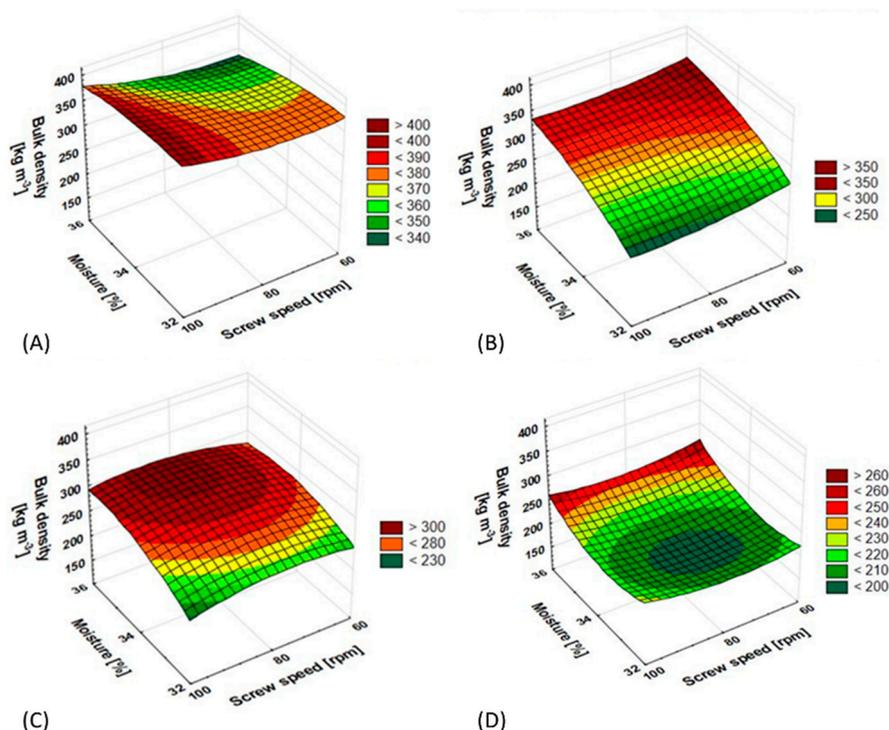


Figure 5. Results of bulk density testing of snack pellets without and with the addition of insect flour, depending on initial moisture content and applied screw speed: (A) control, (B) 10% insect powder, (C) 20% insect powder, (D) 30% insect powder.

The control snack pellets were characterized by having a strong structure. This was confirmed by these demonstrating the highest bulk density and durability, as tested by tumbling. As presented in Figure 6, test snack pallets showed high durability if the amount of additive was up to 20% when tested utilizing a Pfast apparatus. This feature is very important for snack pellet producers during situations of transportation, packaging and storage, as the shape is not lost before delivery to the final recipient. The snack pellets produced under the proposed conditions were stable and were not crushed very easily.

However, an increase in the amount of insect flour produced snack pellets that were more delicate and more susceptible to mechanical damage due to the lowered amount of transformed and gelatinized starch responsible for their solid structure. Starch is the dominant polymer in most grain compositions and plays an important role in the expansion of extrudates, while other ingredients (proteins, sugars, fats and fiber) act as diluents [40], making the internal structure less compact. The lowest bulk density was determined for pellets with a 30% additive level. Moreover, for these samples, the lowest durability results were noted. Such a level of high-protein additive significantly lowered the starch content and thus limited the possibility of formation of a starch-based matrix. Hence, on the basis of this test, we can recommend the incorporation of insect flour at 20% so as to achieve snack pellet products with high durability.

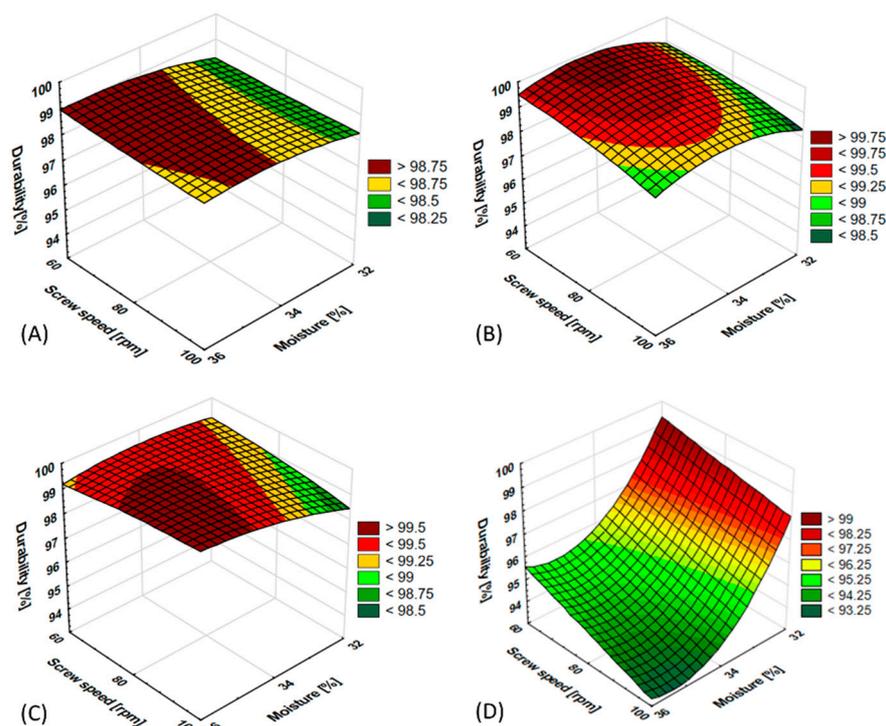


Figure 6. Results of durability testing of snack pellets without and with the addition of insect flour, depending on initial moisture content and applied screw speed: (A) control, (B) 10% insect powder, (C) 20% insect powder, (D) 30% insect powder.

3.3. Principal Component Analysis

All the results of the processing and physical properties were analyzed via principal component analysis. Principal component analysis (PCA) is applied to reduce the number of variables describing phenomena, or to discover regularities between variables. It consists of determining the components as a linear combination of the variables examined. A thorough analysis of the principal components makes it possible to identify those initial variables that have a large impact on the appearance of individual principal components, i.e., those that form a homogeneous group. The principal component (in which the variance is maximized) is then representative of this group. Further components that are mutually uncorrelated are defined so as to maximize the variability that is not explained by the previous component. Each principal component explains some part of the variability of the initial variables. The main applications of principal component analysis are as follows: a reduction in the number of variables, structure detection in relationships between variables, the verification of detected regularities and connections and the classification of objects in new spaces defined by the created factors. It is not always possible to define new variables, but it is always possible to determine their impact on the system's variability.

Upon performing principal component analysis (PCA), three variables were found that addressed 76.52% of the variability in the whole system. The first two main components, PC1 and PC2, described 58.83% of the system variability. The parameters contained between the two red circles showed the largest impact on the variability of this system (Figure 7A). In this analysis, the first principal component (PC1) determined the amount of additive. It was not possible to precisely define the remaining variables for which an impact on the system variability was seen. Parameters such as the bulk density and expansion ratio demonstrated the greatest impact and could explain the PC2 component, the slightly smaller SME and efficiency and the minimal durability. We particularly noted a strong positive correlation between the expansion ratio and efficiency. In addition, a strong and positive correlation between durability and SME was obtained. It was also found that the bulk density was strongly and negatively correlated with the SME and durability. Correlations between bulk density, processing efficiency and the expansion ratio were not, however, obtained.

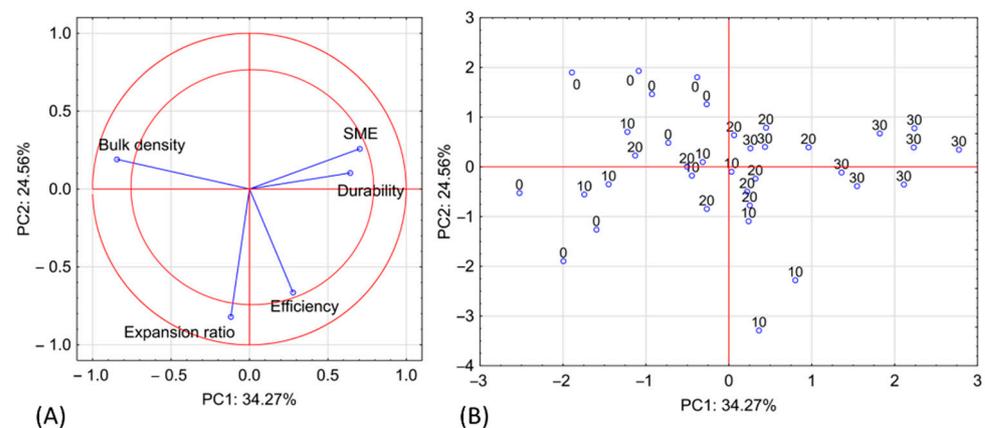


Figure 7. Loading plot (A) and score plot (B) of the principal component analysis (PC1 and PC2) carried out for addition of edible crickets and tested parameters.

The PCA analysis showed that the first component of PC1 described the use of an additive from edible insect flour to 34.27% (Figure 7B). In the figure, the positive PC1 principal component values show the results of using a higher amount of the insect flour, and the negative PC1 principal component values describe the results of not using the edible insect additive or the use of the additive but at low content. The lack of edible crickets is characterized by its expansion ratio and efficiency parameters. In turn, the highest content of the additive correlates with the SME and durability parameters.

We observed a similar relationship for the first (PC1 = 34.27%) and third (PC3 = 17.69%) principal components as a result of the PCA analysis (Figure 8A,B). These two principal components (PC1 and PC3) described 51.96% of the variability in the system, which is also more than 50%, as in the case of the principal components PC1 and PC2. However, only three parameters in this system had a strong influence on its variability (PC3). These were the bulk density, durability and SME. Additionally, these three parameters were not correlated with each other. The process efficiency, as well as the expansion ratio, had very little influence on the system variability in this arrangement. Here, no addition of edible crickets correlated with pellet bulk density. The durability and SME parameters correlated with the highest content of this type of additive (Figures 7A and 8A).

However, minor differences between snack pellets with 10 and 20% of additive were found, compared to the control sample and when 30% of insect flour was used. This is clearly visible in Figures 7B and 8B from the location of the samples in the component space.

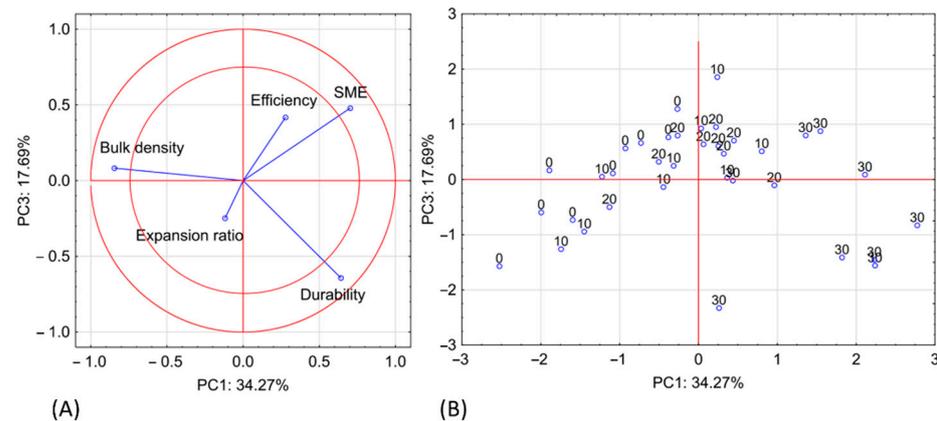


Figure 8. Loading plot (A) and score plot (B) of the principal component analysis (PC1 and PC3) carried out for addition of edible crickets and tested parameters.

4. Conclusions

Based on the obtained results, it was found that the fortification of snack pellets with 10 to 30% of insect flour leads to an increase in processing SME. Moreover, the amendment of pellet recipes with insect flour up to 20% is a successful compromise between processing requirements and acceptable physical features due to stable efficiency and SME, a low expansion index and high durability. Such attributes are very important in half-products intended for subsequent expansion processing. Snack pellets supplemented with insect flour can be a new and attractive alternative to current high-protein snacks and are readily expanded via various tried and effective methods, e.g., frying, microwaving or hot air toasting.

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Data Availability Statement: Data supporting the reported results can be found in the corresponding author’s department.

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