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Extruded Corn Snacks with Cricket Powder: Impact on Physical Parameters and Consumer Acceptance

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Abstract: Edible insects are more and more widely researched and presented as a good source of nutrients. Among the available raw materials, cricket powder (CP), obtained from roasted and crushed crickets, deserves attention because it can be used as an ingredient in many food products. The aim of this study was to determine the effect of CP addition on the physical and sensory properties of extruded corn snacks. In the extrusion process, five variants of corn snacks were produced with 2%, 4%, 6%, and 8% additions of CP, and with 8% CP and 2% baking powder. Snacks without CP addition were used as a control (R). The study also evaluated the storage life of the manufactured snack products based on their sorption properties. It was found that increasing the CP content in snacks has a significant effect on their characteristics, with a lower expansion ratio as the result of the higher CP content in the extrudates. CP increased the solubility and decreased the water absorption of the snacks. Color changes were also observed in the produced snacks. The more CP in the recipe, the darker the end product. In addition, the color parameters a* and b* were shifted towards red and blue in cross-sections of snacks with higher percentages of CP. According to the sensory analysis, CP additions up to 6% allow for obtaining sensory-attractive snacks. Statistical analysis of the results showed that the snack parameters, expansion ratio, and water absorption index are of the greatest importance for sensory acceptance. Therefore, when planning the incorporation of CP into this type of product, special attention should be paid to obtaining extrudates with appropriate parameters.

Keywords: *Acheta domesticus*; quality of extrudates; water sorption isotherm; storage stability

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1. Introduction

Changing socio-economic conditions mean that food producers face the challenge of providing nutritious food for the constantly growing population. According to the estimates of the Department of Economic and Social Affairs of the United Nations, the number of people on Earth will reach 9.8 billion in 2050 and 11.2 billion in 2100 [1]. Therefore, scientists are looking for new raw materials and food ingredients that, on the one hand, will provide appropriate nutrients and, on the other hand, will be easy and cheap to produce. According to the FAO/WHO [2], edible insects are one of the food ingredients to consider. Comparing insect farming with traditional animal husbandry shows several advantages: less impact on deforestation and reduced soil fertility, less water consumption, and lower greenhouse gas emissions. In addition, insects can be farmed using a wide variety of feeds, including food processing by-products and waste streams with a high impact on environmental degradation [3,4].

Entomophagy is not common in Western countries, but insects are commonly used as food in Africa, Latin America, and Asia [5]. Insect breeding is less harmful to the environment than breeding meat animals. Their breeding requires a smaller acreage of surface, much less water is used, and moreover, the waste of the agri-food industry can be used as fodder [6–8], which additionally corresponds to the current trends of "zero waste" and "circular economy". Most consumers still do not associate insects with food and do not accept their consumption. On the other hand, the use of processed (e.g., into powder) insects as a food ingredient is an alternative that can increase consumer acceptance [9–12]. Montowska et al. [13] indicated that cricket (*Acheta domesticus*) powder (CP) is a very good source of protein, fat, and minerals. In addition, Stull et al. [14] pointed to the health benefits of consuming crickets, which is why CP has been used to enrich many cereal products [15–19], but also meat products [20,21]. Despite the diverse chemical composition [13], the technological properties of commercially available CPs of different geographic origins are similar [22]. The available literature data also indicate that the use of CP in the recipe of products significantly improves their attractiveness by modifying the profile of volatile compounds [23,24].

Extrusion is gaining more and more popularity in many branches of the food industry. This technology is used for the production of, among others, breakfast cereals, baby food, crispbread, plant-based meat analogues, and even starch modification. Among the many products, however, extruded snacks play an important role [25]. The most commonly used raw materials for extrusion are cereal products containing starch and protein, such as corn, rice, and wheat. The parameters of the extrusion process (temperature, pressure, screw rotation speed, etc.) significantly affect the degree of degradation of thermolabile nutrients [26]. Correctly selected process parameters allow not only to maintain the nutritional value but also to ensure the appropriate structure of the obtained extrudates. Extruded snacks, due to their delicate and neutral taste as well as an attractive ready-to-eat form, are a matrix that is often used to incorporate nutrients and bioactive compounds [27–30]. The additives used, however, influence the texture properties of the snacks obtained [31,32]. Importantly, the texture and sensory properties of the extrudates are of key importance for consumer acceptance [33].

To date, many reports have been published on the impact of the CP additive on the extrusion process and the characteristics of the obtained extrudates [34–36]. However, there is no data indicating which of the analyzed quality determinants are the most important parameters responsible for the acceptance of new products by consumers. Bearing the aforementioned in mind, the aim of this study was to determine the effect of CP addition on the physical and sensory properties of extruded corn snacks. Moreover, a statistical analysis was performed in order to select the key parameters of the instrumental analysis results for final acceptance.

2. Materials and Methods

2.1. Materials

Corn grits, with a granulation of 0.36–0.65 mm, were purchased from Sante (Sobolew, Poland), baking powder (BP) from Dr. Oetker (Bielefeld, Germany), and CP from JR Unique Foods Ltd. (Moo, Thailand). According to the manufacturers' declarations, corn grits and CP contained: 75.9 and 8.3% protein, 11.4 and 72.2% carbohydrates, 5.47 and 2.30% fiber, and 6.76 and 1.70% fat, respectively.

2.2. Corn Snacks Preparation

The extruded corn snacks were obtained by extrusion in a S 45A-12-10U single-screw extruder manufactured by Metalchem (Gliwice, Poland), with screw length/diameter ratio 12:1 and compression ratio 3:1, and a die with a round hole of 4.5 mm. The following parameters of the extrusion process were used: screw rotation speed of 125 rpm, feed rate 25 kg/h, nominal cylinder diameter of 45 mm, motor power of 10,000 W, motor heating power of 2800 W, and head heating power of 300 W. Raw material with a water content of 13% was extruded. On the basis of preliminary experiments, the following temperature conditions for the process were selected: 105 °C (temperature of the first zone), 130 °C (temperature of the second zone), and 110 °C (head temperature). In the extrusion process, 5 variants of corn snacks were produced with 2%, 4%, 6%, and 8% addition of CP, denoted as E2CP, E4CP, E6CP, and E8CP, and with 8% addition of CP and 2% addition of BP, marked as E8CP2BP. The control samples (R) were extrudates obtained from 100% corn grits. Corn grits with CP were mixed using a Thermomix (Vorwerk International and Co. KmG, Wollerau, Switzerland). Following extrusion, the extrudates were packed in polypropylene pouches and stored at room temperature. Before the analyses, if necessary, the samples were ground in a laboratory mill (M20, IKA®-Werke GmbH and Co. KG, Staufen, Germany) and sieved using an analytical sieve shaker (AS200 basic, Retsch GmbH & Co. KG, Haan, Germany) to obtain particle sizes below 300 μm.

2.3. Physical Properties of Snacks

The water content of the products was determined by thermal drying to constant mass at 105 °C, under normal pressure [37]. Water activity (a_w) was determined using the AquaLab 4TE measuring instrument (version AS42.14.0 2017 from Decagon Devices, Inc., Pullman, WA, USA) with an accuracy of ±0.0003 at 20 °C ± 2.5 °C.

The expansion ratio (ER) of the extrudates was calculated based on the ratio of the extrudate diameter to the extruder die diameter.

The specific bulk density (BD) of the extrudates was determined by the weight-to-volume ratio of individual extrudates [38].

Water absorption index (WAI) and water solubility index (WSI) were determined based on the methodology of Anderson et al. [39]. For the determinations, an approximate 1.5 g grounded sample of extrudates was taken. The samples were topped up with 15 mL of distilled water and shaken. The finished solutions in the flasks were subjected to centrifugation at 12,000× *g*, for 10 min using a 3G load. The resulting filtrate was decanted from above the gel into Petri dishes and placed in a drying oven at 110 °C. The WAI (g/g) is expressed as the ratio of the weight of the gel after removal of the supernatant to the dry weight of the sample, while the WSI (%) is the weight of the dry substance in the supernatant expressed as a percentage of the original weight of the sample.

2.4. Sorption Characteristics of Extrudates

The study also evaluated the storage life of the manufactured snack products based on the characteristics of their sorption properties, based on the course of water vapor sorption isotherms. Extrudates were put into a hygrostat with an a_w in the range of 0.07–0.98 and stored for a period of 45 days at 25 °C. The mathematical descriptions of sorption isotherms were made based on the BET (Brunauer, Emmett, and Teller) equation in the range of a_w = 0.07–0.33. The extrudates' monomolecular layer capacity, sorption-specific surface, and energy constant were determined [40]. The results were analyzed using Jandel-Table Curve 2D software v. 5.01. The fit of the empirical data to the BET equation was characterized by the determination coefficient (R^2), the standard error estimation (FitStdErr), and the F_{stat} statistics.

2.5. Color Analysis

The color of snack cross-sections was measured with a digital image analysis set and expressed in the CIE L*a*b* color system [41] in 10 replicates. Images were acquired with a Nikon DXM-1200 (Nikon Inc., Melville, NY, USA) charge coupled device (CCD) color camera. The color parameters were designated using LUCIA G v. 4.8 software (Laboratory Imaging, Prague, Czech Republic). The light source was a Kaiser RB 5004 HF—high frequency daylight copy light set with 4 × 36 W fluorescent tubes of 5400 K (Kaiser Fototechnik GmbH and Co. KG, Buchen, Germany).

2.6. Sensory Study

Sensory analysis of the sensory quality of the extrudates was carried out in a sensory evaluation laboratory using a 5-point scale, where 1 point represented the lowest level of acceptance and 5 points was the highest [42]. The panel of 20 people evaluated five sensory attributes, including shape, color, aroma, taste, and crispness.

2.7. Statistical Analysis and Modeling

Analyses were performed in 2 independent production batches, in 3 replicates (n = 6), unless otherwise stated. The obtained results were analyzed using Statistica 13.3 PL software (StatSoft, Kraków, Poland). Fisher-Snedecor's F-test combined with a post hoc analysis using the least significant difference (LSD) test was used in the statistical analysis. These methods were used because all empirical distributions compared were close to a normal distribution (as verified by the chi-square test of concordance) [43]. Verification of all hypotheses was performed at the significance level $\alpha = 0.05$, based on the test probability value "p". It was assumed that $p \leq 0.05$ indicates a statistically significant difference in the dependent variable.

3. Results and Discussion

3.1. Physicochemical Properties of Snacks

Enriching food with new ingredients is a difficult process. On the one hand, the introduced ingredients improve the nutritional value or provide other valuable compounds, on the other hand, they significantly change the characteristic features of the final products [44]. Water content and a_w, ER, WAI and WSI, as well as BD were analyzed in the analyzed extrudates. The results of the analyses are presented in Table 1. The water content was highest in the E8CP2BP extrudates and then in E8CP. These snacks contained more water than R by 9.7% and 7.6%, respectively. The lowest water content was recorded in the E2CP and was 10.6% less than R. The snacks enriched with 4 and 6% CP were also characterized by lower water content. Similarly, as assumed, a_w was the highest in E8CP and E8CP2BP and was higher than in R. E2CP had the lowest a_w. Water content and a_w play an important role in the consistency of the extrudates as they directly affect crunchiness, a key factor in acceptability. Heidenreich et al. [45] showed that extrudates with an a_w below 0.5 have adequate brittleness. None of the extrudates analyzed in this study showed an a_w greater than 0.39; therefore, the obtained extrudates met the requirements for crispness. Tiwari and Jha [46] further indicated that a low a_w value (0.1 to 0.33) is advantageous for the microbiological stability of the snacks, which facilitates their storage and distribution.

Table 1. Physicochemical properties of control and CP-enriched corn snacks.

Parameter	R	E2CP	E4CP	E6CP	E8CP	E8CP2BP
Water content (%)	8.38 ± 0.01^{d}	7.49 ± 0.07^{a}	7.90 ± 0.04^{b}	8.29 ± 0.04^{c}	9.02 ± 0.06^{e}	9.19 ± 0.01^{f}
a_w (-)	0.339 ± 0.011^{c}	0.311 ± 0.005^{a}	0.329 ± 0.010^{b}	0.322 ± 0.003^{c}	0.386 ± 0.004^{e}	0.377 ± 0.005^{d}
ER (-)	4.02 ± 0.35^{d}	4.04 ± 0.20^{d}	3.91 ± 0.20^{cd}	3.84 ± 0.21^{c}	1.32 ± 0.09^{a}	1.72 ± 0.09^{b}
BD (g/cm)	0.11 ± 0.01^{a}	0.11 ± 0.01^{a}	0.13 ± 0.01^{a}	0.11 ± 0.01^{a}	0.64 ± 0.09^{c}	0.47 ± 0.03^{b}
WAI (g/g)	5.19 ± 0.02^{c}	5.37 ± 0.03^{c}	5.20 ± 0.03^{c}	5.11 ± 0.01^{c}	4.02 ± 0.04^{b}	3.42 ± 0.03^{a}
WSI (%)	9.36 ± 3.38^{b}	13.07 ± 0.61^{c}	13.37 ± 1.55^{c}	14.60 ± 0.48^{c}	10.46 ± 0.01^{b}	6.43 ± 0.02^{a}

Values (mean ± SD) marked with the same letter do not differ significantly ($p > 0.05$). R—control sample; E2CP, E4CP, E6CP, E8CP—snacks with 2%, 4%, 6%, 8% addition of cricket powder, respectively; E8CP2BP—snacks with 8% addition of cricket powder and 2% of baking powder; a_w—water activity; ER—expansion ratio; BD—bulk density; WAI—water absorption index; WSI—water solubility index.

ER and BD are interdependent physical properties of the extrudates. The higher the ER, the lower the value of BD, and vice versa [47]. Importantly, ER is one of the extrudate quality indicators. It is indicated that the higher the ER value, the better the perception of the snack by the consumer [48]. In short, the higher the ER of an extrudate is, the better it is perceived by a consumer. A decrease in the ER was observed with an increase in the CP addition (Table 1). Only in the case of 2% of the additive, there were no statistically significant changes in the ER compared to the control sample. The use of protein, fat, and fiber addition also resulted in a decrease in ER values in other studies [49–51]. CP is a rich source of all three above-mentioned ingredients [18], hence the observed decrease in the ER of snacks in enriched CP. Unexpectedly, only 8% of the CP addition caused an increase in BD. In the case of lower CP contents, no statistically significant differences were found.

The enrichment of corn extrudates with various components usually increases BD [49,52], although various literature sources also indicate the opposite relationship [26,50].

WAI measures the amount of water absorbed by starch and can be used as an indicator of starch gelatinization, while WSI is often used as an indicator of extrudate degradation [46]. The CP addition caused changes in the WAI and WSI values as well. The WAI value decreased from 5.19 for R to 4.02 (g/g) for E8CP, while the WSI value increased from 9.36 to 10.46, respectively (Table 1). The use of BP in E8CP2BP, on the other hand, reduced the WSI by 31.3% compared to R. WAI depends on the temperature of the extrusion process. Additionally, WSI depends on the parameters of the extrusion process, such as high mechanical shear, high pressure, and temperature [53,54]. In this study, all extrudates were produced with the same parameters of the extrusion process; the observed changes in WAI and WSI values are therefore strictly related to the modification of the raw material composition of the extrudates. Commercially available CPs are characterized by a low water-binding capacity [55], with a simultaneous high fat content [13], which may explain the observed changes in the WAI parameter of extrudates.

Despite the observed differences between the tested samples, on the basis of statistical analysis, it was found that in terms of physical properties, two clusters can be distinguished (Figure 1). The first group consists of the R and E8CP2BP samples, and the second group consists of the remaining CP-enriched snacks (E2CP, E4CP, E6CP, and E8CP). Thus, it can be concluded that although the CP additive changes the characteristics of the obtained snacks, the use of technological additives, in this case baking powder, improves their properties.

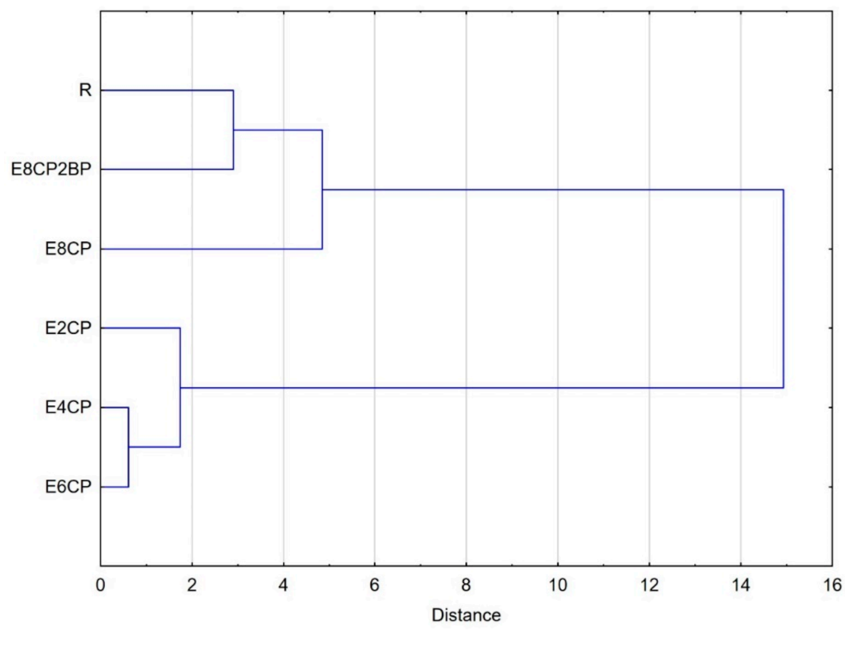

Figure 1. Dendrogram for hierarchical cluster analysis based on physical properties of corn snacks. R—control sample; E2CP, E4CP, E6CP, E8CP—snacks with 2%, 4%, 6%, 8% addition of cricket powder, respectively; E8CP2BP—snacks with 8% addition of cricket powder and 2% of baking powder.

3.2. Sorption Characteristics of Snacks

The characteristics of the course of sorption isotherms is a source of information on the state of water in snacks. Sorption isotherms represent the relationship between the amount of water adsorbed per unit mass of the product and the a_w at constant temperature and pressure [56]. Due to the low level of a_w, the snacks produced in the extrusion process should have constant physicochemical and sensory parameters during storage; however, the extrudates are characterized by high hygroscopicity [34,57]. The evaluation of the sorption properties of snacks allows, therefore, to determine the sensitivity to moisture and the degree of water absorption, as well as predict changes that may occur in the product during the storage process under changing environmental a_w conditions [37]. The sorption isotherms of the snacks produced were characterized by the continuity of the course in the entire range of environmental a_w (0.07–0.98). It was found that in the extrudates, there was no change in the structure of the arrangement of individual components of the starch-protein matrix of snacks produced in the extrusion process (Figure 2). When analyzing the course of sorption isotherms in detail, it was found that in E4CP, E6CP, and E8CP, in the range of a_w (0.07–0.22), the desorption process took place. In the case of R, E2CP, and E8CP2BP, the desorption process was carried out in a wider range of a_w (0.07–0.33).

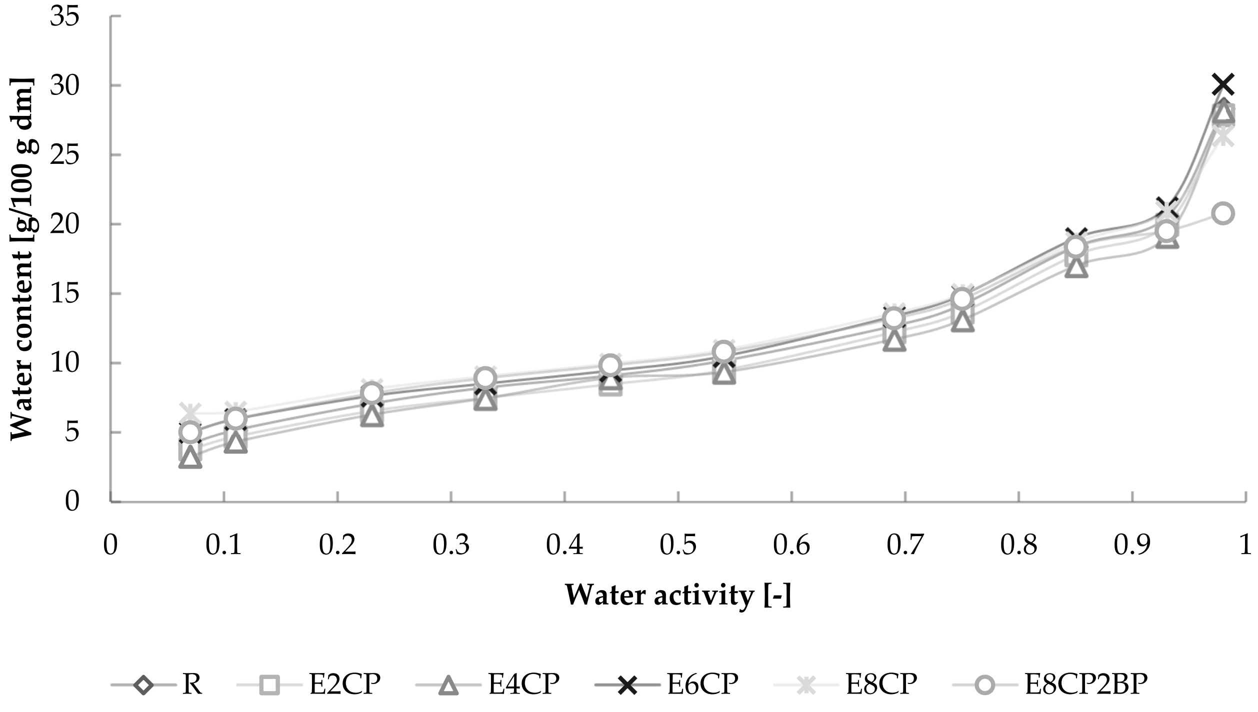

Figure 2. Sorption isotherm of corn snacks. R—control sample; E2CP, E4CP, E6CP, E8CP—snacks with 2%, 4%, 6%, 8% addition of cricket powder, respectively; E8CP2BP—snacks with 8% addition of cricket powder and 2% of baking powder.

In the range of a_w = 0.44–0.69, it was found that the more CP in the products (E6CP, E8CP, and E8CP2BP), the higher the hygroscopicity of snacks, which contributed to obtaining a higher equilibrium water content in these extrudates compared to R and E2CP and E4CP. Analyzing the further course of the mutual position of isotherms, it was found that in the snacks analyzed, the process of water absorption became clear after exceeding a_w = 0.75, which can be explained by the effect of the capillary condensation process [58,59]. The highest equilibrium water content in the CP-containing snacks after 45 days of storage in conditions of a_w = 0.98 was demonstrated by E6CP, reaching a water content of 30.108 g/100 g dm.

In order to determine the parameters of the surface structure of snacks, the empirical data describing the sorption isotherm was transformed according to the BET model, in the range of a_w = 0.07–0.33. The parameters of the BET equation, the monolayer capacity (v_m) and the energy constant (c_e), the sum of squared deviations of the theoretical from empirical values (SKO) along with the values of standard errors (RMS), are presented in Table 2.

The monolayer capacity v_m for R determined from the BET model was 6.01 g/100 g dm, and increasing the addition of CP in snacks E6CP, E8CP, and E8CP2BP influenced the development of the monomolecular layer (Table 2). From the storage point of view, E8CP and E8CP2BP (the highest v_m value) were characterized by the greatest durability and storage stability [60,61]. Therefore, it was found that with the applied parameters of the extrusion process and increasing the CP addition in snacks, it had a positive effect on the sorption properties. The evaluation of the surface microstructure of the snacks showed that increasing the CP addition in snacks increased the specific sorption surface. On the basis of the obtained microstructure parameters, it was found that the specific sorption surface, which is a derivative of v_m, was determined by the properties of the snack structure produced in the extrusion process and the interactions between starch and protein particles.

Table 2. Sorption characteristics of corn snacks.

Parameter	R	E2CP	E4CP	E6CP	E8CP	E8CP2BP
Parameters of BET equation						
v_m	6.01	5.51	5.71	6.01	6.16	6.34
c_e	26.00	25.20	15.98	56.77	44.79	40.78
R^2	0.993	0.985	0.990	0.982	0.982	0.981
SKO	0.99	0.68	0.84	0.54	1.60	0.54
RMS (%)	1.31	1.12	1.77	0.51	0.76	0.54
FitStdErr	0.180	0.221	0.240	0.249	0.224	0.214
F_{stat}	280.59	204.28	137.70	110.82	112.76	180.70
Sorption specific surface (m^2/g)	211.08	193.65	200.45	211.06	216.49	222.66

R—control sample; E2CP, E4CP, E6CP, E8CP—snacks with 2%, 4%, 6%, 8% addition of cricket powder, respectively; E8CP2BP—snacks with 8% addition of cricket powder and 2% of baking powder; v_m—monolayer capacity; c_e—energy constant; R^2—determination coefficient; SKO—sum of squared deviations of the theoretical from empirical values; RMS—values of standard errors; FitStdErr—standard error estimation; F_{stat}—f-statistics.

3.3. Color of Snacks

The color of ready-to-eat products, such as extruded snacks, plays an important role in consumer evaluation of the products [62]. It is therefore important to analyze the changes in the color parameters as a result of the CP additive used.

Significant color changes of the snacks were observed due to their enrichment in CP (Table 3). As expected, the more CP in a snack recipe, the darker the final product (a decrease in the L* parameter value). The color balance also shifted. The greater amount of CP increased the red saturation, from −2.94 for R to even 0.29 for E8CP. Surprisingly, it was found that the use of BP reduces the a* value, despite the same CP content in the snack food composition. Changes were also noted for the b* parameter, and its values indicate the blue orientation caused by CP. Among the foods consumed by adults, red and yellow colors are the most desirable [62–64]. Increasing the red saturation can, therefore, be seen as advantageous in terms of the attractiveness of the snacks.

Table 3. Color parameters of control and CP-enriched corn snacks.

Parameter	R	E2CP	E4CP	E6CP	E8CP	E8CP2BP
L* (%)	84.50 ± 0.04 ^{e}	81.26 ± 0.05 ^{d}	78.63 ± 0.28 ^{c}	76.76 ± 0.14 ^{b}	75.48 ± 0.02 ^{a}	77.02 ± 0.05 ^{b}
a* (-)	−2.94 ± 0.01 ^{a}	−2.12 ± 0.02 ^{b}	−1.11 ± 0.16 ^{c}	0.16 ± 0.05 ^{d}	0.29 ± 0.06 ^{e}	−0.21 ± 0.21 ^{de}
b* (-)	40.76 ± 0.02 ^{f}	35.77 ± 0.04 ^{e}	35.58 ± 0.55 ^{d}	30.43 ± 0.12 ^{c}	27.08 ± 0.03 ^{b}	26.44 ± 0.44 ^{a}
ΔE (-)	-	6.00	9.45	13.28	16.70	16.39

Values (mean ± SD) marked with the same letter do not differ significantly ($p > 0.05$). R—control sample; E2CP, E4CP, E6CP, E8CP—snacks with 2%, 4%, 6%, 8% addition of cricket powder, respectively; E8CP2BP—snacks with 8% addition of cricket powder and 2% of baking powder; L*—lightness; a*—redness; b*—yellowness; ΔE—total color difference.

The value of the total color difference (ΔE) indicates a significant effect of CP on the color of the snacks. The calculated color difference ranged from 6 for E2CP to almost 17 for E8CP. As indicated by Mokrzycki and Tatol [65], the higher the ΔE value, the more visible the color equations noticed by an inexperienced observer.

Additionally, in the case of color, a statistical analysis was performed in order to indicate the samples most similar to each other. In the presented Figure 3, it can be observed that there are no differences between E2CP and E4CP, which are similar to R; however, a further increase in the amount of CP causes significant color differences.

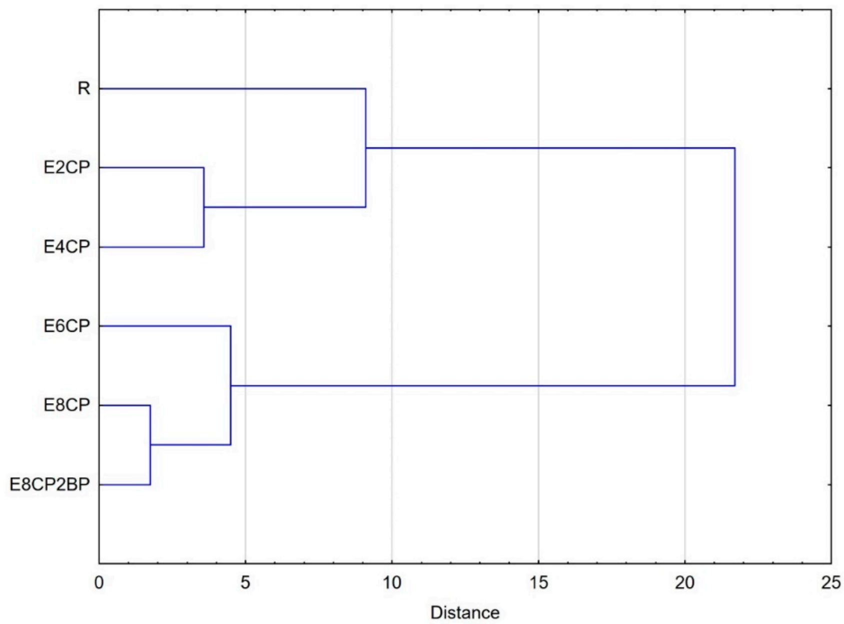

Figure 3. Dendrogram of clusters of tested products based on color parameters of corn snacks. R—control sample; E2CP, E4CP, E6CP, E8CP—snacks with 2%, 4%, 6%, 8% addition of cricket powder, respectively; E8CP2BP—snacks with 8% addition of cricket powder and 2% of baking powder.

3.4. Sensory Analysis

Although eating insects is entirely controversial, it is possible to incorporate them into traditional food products in the form of, e.g., powder [66]. The additives used may increase the nutritional value, but, as indicated in Sections 3.1–3.3, they also cause numerous changes to the final product compared to the conventional product. Different physicochemical properties and a color change may significantly affect the consumer appeal of a product [67]. The results of the sensory analysis, presented in Figure 4, indicate that the addition of CP in the range of 2–6% is fully acceptable by the respondents. The scores retained were not statistically significantly different from those given with the reference snacks. Yet, it is necessary to underline that the amounts of CP additive higher than 6% led to negative changes in physicochemical parameters, such as color and texture, which were reflected in lower consumer acceptability. The visual assessment of the color change was consistent with the results of the instrumental color measurement. Nevertheless, it is possible to obtain CP-enriched snacks on par with the control in terms of consumer acceptance. Additionally, the other literature sources indicated that the use of insects in a smaller amount results in obtaining sensorially attractive cereal products [68,69].

3.5. Statistical Considerations on the Influence of Analyzed Parameters on Sensory Attractiveness

In order to determine the strength and direction of the dependence of the results of the desirability assessment on the level of physical parameters and the colorimetric color measurement, the values of the Pearson's rectilinear correlation coefficient were calculated (Table 4). Then, the null hypothesis about the insignificance of the rectilinear correlation coefficient in the general population—"ρ" was verified, i.e., the hypothesis about the lack of a significant difference between the absolute value of the coefficient and the value of 0. This verification was performed using the Student's *t*-test with the assumed significance level of $\alpha = 0.05$.

The values of "r" and the analysis with the Student's *t*-test indicate that the attractiveness of the analyzed extrudates is determined by the water content and a_w (inversely proportional), ER and WAI (directly proportional), BD (inversely proportional), and the value of the b* parameter (directly proportional).

A mathematical model illustrating these relationships was established, and a multiple regression analysis was performed. A progressive stepwise regression procedure was used in the calculations. Due to the occurrence of the phenomenon of collinearity (the values of the tolerance index ranged from 0.2 to 0.4), the calculations were performed using the dorsal regression method (λ = 0.10) (Table 5). The analysis also included the calculation of the value of the multivariate determination coefficient (R^2) and the standard error of estimation (s_y).

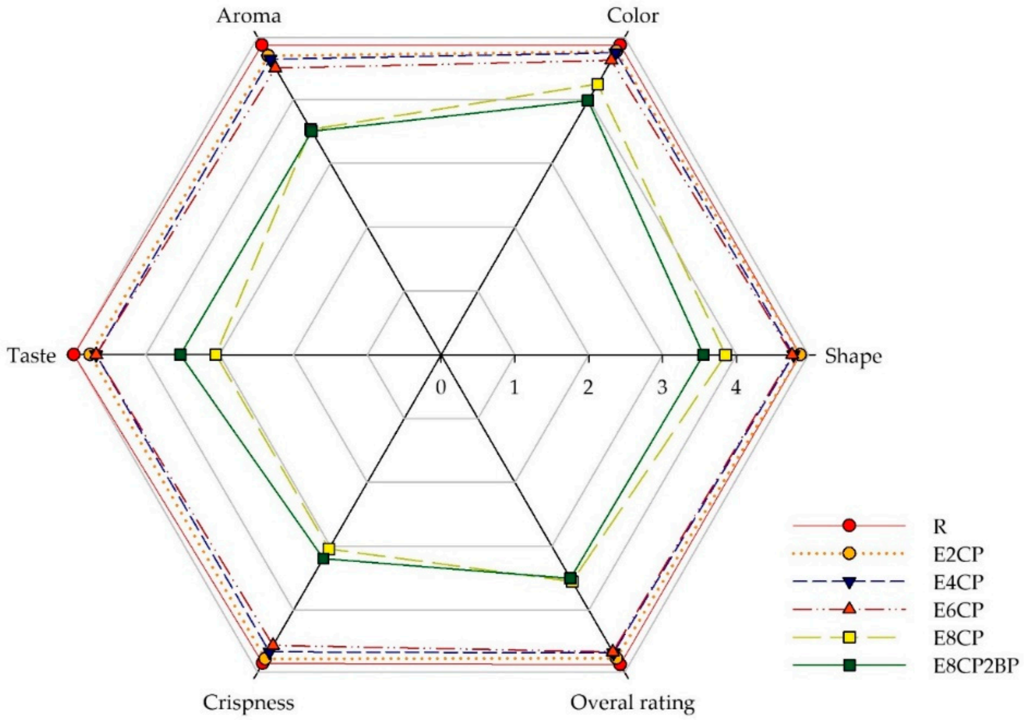

Figure 4. Radar chart showing the results of the sensory analysis of control and CP-enriched corn snacks. R—control sample; E2CP, E4CP, E6CP, E8CP—snacks with 2%, 4%, 6%, 8% addition of cricket powder, respectively; E8CP2BP—snacks with 8% addition of cricket powder and 2% of baking powder.

Table 4. Dependence of the results of the desirability assessment on the level of physical parameters and colorimetric color measurement (values of the Pearson's correlation coefficient).

	Water Content (%)	a_w (-)	ER (-)	WAI (g/g)	WSI (%)	BD (g/cm^3)	L* (%)	a* (-)	b* (-)
Attractiveness	−0.857 *	−0.929 *	0.990 *	0.969 *	0.648	−0.962 *	0.697	−0.681	0.868 *

The symbol * denotes a statistically significant value of the correlation coefficient (Student's *t*-test; α = 0.05). a_w—water activity; ER—expansion ratio; BD—bulk density; WAI—water absorption index; WSI—water solubility index; L*—lightness; a*—redness; b*—yellowness.

Table 5. Dependence of the attractiveness assessment results on the level of physical parameters (results of multiple regression analysis).

	R^2	s_y	b	Standard Error from b
y-intercept			1.947	0.646
ER	0.902	0.196	0.27	0.127
WAI			0.325	0.201

R^2—multivariate determination coefficient; s_y—standard error of estimation; ER—expansion ratio; WAI—water absorption index.

The multivariate determination coefficient indicates that the share of the determined model in the total variability of the results is 90.2%, so it is very high. The standard estimation error indicates that the accuracy of determining the Y variable in the adopted model is approximately 0.2 points. The model includes only those explanatory variables that have a significant impact on the dependent variable, i.e., ER and WAI. The regression equation takes the form:

$$Y = 1.947 + 0.270 \times ER + 0.325 \times WAI$$

where Y is the estimated attractiveness.

Therefore, it can be concluded that, from the point of view of the market success of new products, the focus should be on the above mentioned properties of extrudates, which mainly affect the assessment of the final product by consumers.

4. Conclusions

We described the effect of introducing CP into extruded corn snacks. It was found that the addition of CP caused a decrease in ER and WAI and an increase in WSI. Color changes were also observed, i.e., a decrease in brightness and a color balance shift. Moreover, the introduction of CP resulted in changes in the sensory attractiveness of the obtained extrudates. Nevertheless, on the basis of the obtained results, it was found that CP, in the amount of 2–6%, can be used to obtain sensorially attractive snacks, and the overall sensory perception is mostly influenced by ER and WAI. Further microbiological studies of snacks with CP, as well as snacks after simulated in vitro digestion, may provide valuable information on their nutritional safety and bioactivity in our body.

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