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Comparative analysis of the effect of cricket powder and spirulina in model meat systems as substitutes for soy in raw pork products

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This study focused on comparing and assessing the effects of substituting soy protein in raw semi-finished pork products with alternative protein sources, such as cricket powder and spirulina powder. Changes in the physicochemical, technological, and microbiological properties of the model meat systems were examined. The inclusion of spirulina powder resulted in reduced hardness along with increased springiness and cohesiveness, while the addition of cricket powder led to lower adhesiveness and improved chewiness and gumminess. The experimental samples exhibited good emulsion stability, albeit with slightly lower values compared to those containing soy protein. Incorporating the studied protein sources, either individually or in combination, as replacements for soy protein, enhanced the nutritional profile of the model meat systems by increasing fiber content and improving oxidative stability.

Keywords: Meat products, protein, color, textural traits, emulsion stability

INTRODUCTION

The global population's steady increase has brought about a heightened demand for protein-dense foods, compelling the food industry and researchers to explore sustainable approaches to meet this need [1-4]. Meat products are a well-known source of high-quality protein with a favorable balance of amino acids [5]. However, the continuation of current trends in meat consumption is projected to double the demand for animal proteins, intensifying the strain on environmental resources and ecosystems. In addition to this challenge, crises such as the COVID-19 pandemic, geopolitical conflicts, climate change, and pollution have further driven efforts to identify alternative food sources as part of the solution to global food insecurity. Plant-derived proteins have gained popularity as replacements for meat proteins in various food applications. Their health benefits, absence of cholesterol, and cost-effectiveness make them attractive for use in meat products [6-8]. Among these, soy protein is the most extensively utilized in the food sector due to its superior protein content and functional properties, including excellent water retention and emulsification, which enhance the technological quality of meat products [9-11]. Algae have also emerged as an intriguing alternative protein source, attracting attention for their nutritional benefits [12]. They contain all essential amino acids required by humans and, in some cases, surpass traditional sources such as meat, dairy, soy, and grains in protein quality [13]. Beyond their protein content, algae are rich in bioactive compounds that offer potential health-promoting effects [14, 15]. Spirulina, a blue-green alga, is particularly noteworthy due to its high protein concentration-ranging from 60% to 70%/-and its ease of cultivation and processing [16-18].

Edible insects represent another emerging protein source, known for their abundance in essential nutrients such as protein, fiber, fatty acids, vitamins, and minerals [19-21]. Insects are increasingly seen as a sustainable option to alleviate the environmental pressures caused by traditional livestock farming [22]. For instance, the house cricket (*Acheta domesticus*), widely consumed in Southeast Asia, provides a protein content of 20–25 g per 100 g of fresh weight, comparable to that of conventional meat. Crickets are often processed into protein-rich flour, containing 50% - 60% protein, which can be incorporated into various food formulations [23, 24].

This study investigates the potential of substituting soy protein in raw semi-finished pork products with alternative protein sources, namely cricket flour and spirulina powder. The research examines the effects of these replacements on the physicochemical, technological, and micro-biological characteristics of model meat systems.

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MATERIALS AND METHODS

The following recipe was used in the experiment: lean pork meat (shoulder blade): 500 g/kg; semi-fat pork: 500 g/kg; water: 200 g/kg; soy protein: 10 g/kg, and sodium chloride: 18 g/kg. Seven experimental samples were prepared for the study with different concentrations of soy, spirulina and cricket powder protein according to Table 1. Before their addition, they had been hydrated in water in a 1:3 w/v ratio. The protein additives (soy and spirulina) were purchased from retail shops, the cricket powder was supplied by EntoSynergy Ltd. (Balgarevo, Bulgaria), and the meat raw materials by the Lovech Meat Processing Company within Boni Holding, Bulgaria.

Table 1. Modeled substitution composition in the raw meat systems

Sample name	Ingredient ratios, g/kg^{-1}		
	Soy protein, (X1)	Spirulina powder, (X2)	Cricket powder, (X3)
S	10.0	0.0	0.0
Sp	0.0	10.0	0.0
CP	0.0	0.0	10.0
SSp	5.0	5.0	0.0
SCP	5.0	0.0	5.0
SpCP	0.0	5.0	5.0
SSpCP	3.33	3.33	3.33

Note: Samples: S- (control sample with soy protein); Sp- (sample with spirulina powder); CP- (sample with cricket powder); SSp- (sample with soy protein and spirulina powder); SCP- (sample with soy protein and cricket powder); SpCP- (sample with spirulina powder and cricket powder); SSpCP- (sample with soy protein, spirulina powder and cricket powder).

The samples were prepared as follows: the meat was ground on a meat grinder with a grid diameter of 6 mm, and then divided into seven equal parts. After that, the necessary salting materials, water, and a protein supplement, respectively, were added to each part in a mixer; 60 g meatballs were formed from the meat batter obtained and then packed on PVC plates and stored at 0±4 °C. At the 24th hour, the raw meatballs were analyzed according to the following parameters: overall chemical composition, pH, water activity (a_w), oxidative and emulsifying capacity, and textural and microbiological characteristics.

Proximate composition

The water content was determined by drying the samples at 104±1 °C to constant weight using a KERN MLS-A moisture balance (Kern & Sohn GmbH, Germany). The protein content was determined by the Kjeldahl method [25]; the fat content by the Soxhlet method [26]; and the mineral, carbohydrate and dietary fiber contents were analyzed according to [27-29]. The sodium chloride content was determined by Mohr's method [30]. The energy value was calculated using arithmetic mean values of the overall chemical composition according to European Parliament and Council Regulation (EU) No 1169/2011 of 25 October 2011 on the provision of food information to consumers.

pH, a_w and color

The pH determination was carried out on an aqueous extract of the sample (1:9 w/v), using a pH meter (Milwaukee MW102 PRO+ 2-in-1 pH and temperature meter with ATC). The water activity (a_w) was measured using HygroPalm – HP23 at 22-25 ºC. The color parameters were determined spectrophotometrically using a Minolta chroma meter (model CR 410, Osaka, Japan) in the CIELab system.

Emulsion stability

For determination of the emulsion stability, the method described by Zorba and Kurt [31] was used. Thirty grams of each sample were weighed into a centrifuge tube and heated on a water bath at 70 °C for 30 min. Immediately after heating, the tubes were centrifuged at 2000 min^{-1} for 10 min, and the separated water and oil were weighed and used to calculate the emulsion stability (ES).

Texture profile analysis (TPA)

A TA-XT Plus texture analyzer (Stable Micro Systems, Surrey, GB) was used for the analysis of the texture profile of the samples, under the following measurement conditions: sample size: 40±2 mm in diameter and 25±2 mm in height; diameter of the compression cylinder: 50 mm, compression speed: 2 mm/s; degree of deformation: 8 mm; and relaxation time between two compressions: 5 s. The hardness, springiness, cohesiveness, gumminess, chewiness, and adhesiveness of the samples were calculated on the basis of the values obtained [32-34].

Oxidative stability (TBARS and antioxidant capacity)

The content of the thiobarbituric acid reactive substances was measured according to the method described by Cabral *et al*. [35].

The antioxidant capacity was determined and evaluated on the basis of the free radical scavenging activity (DPPH). The DPPH determination was based on the method described by Brand-Williams

et al. [36] and Petrova *et al.* [37] with the following modification: methanol solution of DPPH (6×10^{-5} M) in a 1:9 (v/v) ratio was added to 250 μL of water extract of the sample in a 1:3 ratio. After 20 min in the dark at room temperature, the 515 nm absorption of the prepared reaction mixture was measured (Evolution 201 UV Visible spectrophotometer, Thermo Scientific). A water-soluble vitamin E analogue was used as a standard, and the results obtained were presented as Trolox equivalents (TE) in μmol per 100 g sample.

Microbiological analysis

The total microbial load of the samples on the 1st and 5th day was studied through the following microbiological parameters: total bacteria count according to [38] and presence of molds and yeasts according to [38]. The samples were prepared in accordance with [40].

Statistical analysis

All the data obtained were statistically analyzed by one-way analysis of variance (ANOVA) using the Statgraphics 16 software product. Significant (P<0.05) differences between the treatments were determined using Duncan's post hoc test. All experiments were performed in triplicate, and the data presented in the tables and figures were expressed as means ± standard deviation (SD).

RESULTS AND DISCUSSION

Proximate composition

No significant differences (P>0.05) were found in the water content values between the experimental samples, except for sample SpCP, for which a higher value was reported compared to sample S (control sample) (P<0.05) (Table 2). Also, no significant differences were found in the protein, fat and carbohydrate contents between the control and experimental samples, which was probably due to the low concentration in which they were added. The results obtained were in agreement with data presented by other authors who used spirulina to replace soy protein in raw sausages and beef burgers [41, 42]. The higher dietary fiber content found in the experimental samples compared to the control sample (P<0.05) was related to the chitin contained in the cricket powder [43] and possibly, the polysaccharide composition of the algae. The mineral content of the studied samples also increased with the addition of spirulina and cricket powder and was the highest in the SpCP sample. Similar results were obtained by authors who investigated the possibility of including algae and insect powder in meat products with a view to improving their nutritional quality and reducing the sodium chloride content [44-47].

pH and water activity (a_w)

The data obtained showed statistically significant differences between the samples, both on the first day and on the fifth day of their cold storage (Table 3). On the first day, the control sample S had the lowest pH value (6.19), most probably owing to the higher pH values of the cricket and spirulina powders. The pH value of the cricket powder sample CP (6.21) was closest to the control sample S, and the highest pH was reported for sample Sp (6.37). A tendency to lower pH was observed in all samples on the 5th day of their cold storage, maintaining the established differences in the values between the individual samples.

Table 2. Proximate composition and energy value of the raw model meat systems

Samples	Parameter							
	Moisture content, %	Proteins, %	Fats, %	Carbo-hydrates, %	Dietary fiber, %	NaCl, %	Ash, %	Energy value, KJ/kcal
S	65.89±3.06^{a}	12.74±0.84^{a}	14.93±0.1^{a}	0.55±0.02^{a}	8.6±1.3^{a}	1.82±0.03^{a}	2.14±0.2^{a}	857/205
Sp	68.48±1.6^{ab}	13.42±0.59^{a}	14.42±0.56^{a}	0.45±0.03^{a}	10.3±0.42^{bc}	2.03±0.02^{f}	2.48±0.9^{ab}	867/207
CP	68.04±0.66^{ab}	13.1±0.1^{a}	14.72±0.05^{a}	0.53±0.06^{a}	9.42±0.47^{ab}	1.96±0.09^{bc}	3.06±0.8^{ab}	860/206
SSp	67.04±0.3^{ab}	12.98±0.79^{a}	14.68±0.31^{a}	0.49±0.04^{a}	10.38±0.4^{bc}	1.85±0.04^{ab}	2.32±0.6^{a}	864/207
SCP	66.69±0.55^{ab}	12.29±1.29^{a}	14.63±0.3^{a}	0.45±0.07^{a}	8.82±1.07^{a}	1.87±0.09^{ab}	2.26±0.7^{a}	837/200
SpCP	69.03±1.54^{b}	13.47±0.23^{a}	14.52±0.46^{a}	0.49±0.09^{a}	10.39±0.5^{bc}	1.92±0.8^{abc}	3.54±0.4^{b}	867/207
SSpCP	66.59±1.65^{ab}	13.31±0.25^{a}	14.8±1.12^{a}	0.58±0.07^{a}	11.04±1.15^{c}	1.92±0.08^{abc}	2.85±0.5^{ab}	881/211

Note: *The results are presented as mean values for the respective sample after triple measurements of the respective parameter. **$^{a-f}$: Values bearing the same superscripts are not statistically different (P>0.05). ***Samples: S- (control sample with soy protein); Sp- (sample with spirulina powder); CP- (sample with cricket powder); SSp- (sample with soy protein and spirulina powder); SCP- (sample with soy protein and cricket powder); SpCP- (sample with spirulina powder and cricket powder); SSpCP- (sample with soy protein, spirulina powder and cricket powder).

Table 3. Changes in pH and a_w in the model meat systems

Period (days)	pH						
	S	Sp	CP	SSp	SCP	Sp.CP	SSpCP
1	6.19±0.08^{a}	6.37±0.09^{b}	6.21±0.05^{a}	6.28±0.07a^{b}	6.23±0.05a^{b}	6.3±0.09a^{b}	6.24±0.05^{a}
5	6.03±0.03^{a}	6.3±0.09^{c}	6.18±0.06^{bc}	6.24±0.08^{c}	6.2±0.09^{bc}	6.22±0.03^{c}	6.08±0.08^{ab}
	a_w						
1	0.869± 0.001^{b}	0.872± 0.005^{b}	0.852± 0.001^{a}	0.87± 0.002^{b}	0.868± 0.015^{b}	0.872± 0.003^{b}	0.871± 0.003^{b}

Note: The results are presented as mean values for the respective sample after triple measurements of the respective parameter. $^{a-c}$: Values bearing the same superscripts are not statistically different (P>0.05). Samples: S- (control sample with soy protein); Sp- (sample with spirulina powder); CP- (sample with cricket powder); SSp- (sample with soy protein and spirulina powder); SCP- (sample with soy protein and cricket powder); SpCP- (sample with spirulina powder and cricket powder); SSpCP- (sample with soy protein, spirulina powder and cricket powder).

Table 4. Color characteristics of the model meat systems

Parameter	Sample						
	S	Sp.	CP	SSp.	SCP	SpCP	SSpCP
L*	55.08±8.33^{c}	36.19±6.36^{a}	52.13±12.52^{bc}	46.96±3.98^{abc}	59.35±5.98^{c}	40.96±2.54^{ab}	50.71±8.66^{bc}
a*	8.69±1.65^{bc}	-6.38±1.53^{a}	7.71±1.04^{b}	-4.99±2.75^{a}	11.6±3.46^{c}	-3.59±2.62^{a}	-4.3±0.76^{a}
b*	8.86±1.53^{bcd}	4.74±0.94^{a}	10.03±1.92^{cd}	8.19±2.88^{abc}	12.12±2.75^{d}	7.48±0.83^{abc}	6.3±2.82^{ab}
C	12.42±2.14^{bc}	6.95±2.65^{a}	12.72±2.03^{cd}	9.5±1.98^{abc}	16.8±4.32^{d}	8.45±0.54^{ab}	7.69±0.14^{a}
h	45.64±3.39^{a}	134.17±9.39^{c}	52.52±2.66^{a}	133.57±11.01^{c}	46.65±2.88^{a}	113.88±12.99^{b}	126.53±9.62^{bc}

Note: *The results are presented as mean values for the respective sample after five measurements of the respective parameter. ** $^{a-d:}$Values bearing the same superscripts aere not statistically different (P>0.05). ***Samples: S- (control sample with soy protein); Sp- (sample with spirulina powder); CP- (sample with cricket powder); SSp- (sample with soy protein and spirulina powder); SCP- (sample with soy protein and cricket powder); SpCP- (sample with spirulina powder and cricket powder); SSpCP- (sample with soy protein, spirulina powder and cricket powder).

From a technological point of view, it is important to point out that the use of additives that can increase the pH of the meat batter is desirable with a view to reducing losses during subsequent heat treatment and improving the consistency of the finished product.

As regards the water activity (a_w) values, no statistical differences were found between the samples (P>0.05), except for the sample prepared with complete replacement of the soy protein with cricket powder (P< 0.05), where a slightly lower value (0.852) was reported.

Color parameters

The L* color lightness values of the model meat systems ranged from 36.19 in sample Sp to 59.35 in sample SCP (Table 4). The experimental samples were statistically different (P<0.05) from the control sample as a result of both the type of additives used and their amount. The comparison of control sample S with cricket powder sample CP showed a decrease in the L* value, which was consistent with the data reported in [47]. The lower L* values of the spirulina samples were due to its dark green color, and a statistical difference was also observed between individual samples depending on the amount added. Lower color component values (L*, a* and b*) were also obtained by other authors [41], who investigated the possibility of soy protein substitution with various plant proteins and algae, including chlorella and spirulina. The negative values measured for a* in the spirulina samples were attributed to the pigments phycocyanin (blue color) and chlorophyll (green color) present in the composition of *Spirulina platensis* [42, 49, 50].

The cricket powder sample (CP) also showed a decrease in the red component a* compared to the control sample, which some researchers attributed to the greenish hues that cricket powder imparts to the meat batter [48, 51]. The comparison of the control sample with the cricket powder sample indicated that the use of cricket powder resulted in an increase in the yellow color component also reported by Kolev *et al*. [52].

The lowest h value was measured in the control sample S followed by the sample prepared with 50% soy protein and 50% cricket powder, i.e. SCP, with no statistical difference between them (P>0.05) (Table 4). In the samples made with spirulina powder, however, the opposite effect was observed:

the greater the amount of spirulina added to replace the soy protein, the higher was the value found for the color hue (h).

Oxidative stability (TBARS and DPPH)

Oxidative stability is one of the most important parameters determining the quality of meat products [53-55] and TBARS content, expressed as mg MDA/kg sample, is considered a parameter that can be used to measure the secondary products of lipid oxidation [56]. The TBARS data obtained (Table 5) on the first day of sample storage demonstrated oxidative changes ranging from 0.14 mg MDA.kg^{-1} in sample CP to 0.74 mg MDA.kg^{-1} in control sample S.

The comparison of the cricket powder samples with the control sample showed significantly ($P<0.05$) lower MDA results in the experimental samples, both on the first and on the fifth day of storage. The results obtained coincided with the data reported by other authors, according to which oxidative stability is a result of the antioxidant potential of edible insect powder [57-59]. Lower MDA values were also measured in the spirulina samples compared to the control sample ($P<0.05$). Similarly to these results, the authors of [60] also found lower lipid oxidation levels in raw sausages made with the addition of spirulina extracts.

The results of the antioxidant capacity (DPPH) analysis indicated that the values obtained for DPPH in the experimental samples were significantly ($P<0.05$) higher than those in the control sample (Table 5). The higher antioxidant activity in sample Sp could be attributed to the polyphenols, flavonoids, tannins and polysaccharides contained in spirulina [61, 62]. Similarly to the results obtained in this study, the authors of [63] observed an increase in the antioxidant potential and storage stability of pork meatballs made with insect powder addition. According to other authors [64, 65], the antioxidant capacity of edible insects is mainly due to the phenolic compounds they contain.

Table 5. Oxidative stability and antioxidant capacity (TBARS and DPPH) of the model meat systems

Period (days)	TBARS, mg MDA/kg^{-1}						
	S	Sp	CP	SSp	SCP	Sp.CP	SSpCP
1	0.74±0.09^{c}	0.34±0.06^{b}	0.14±0.04^{a}	0.4±0.03^{b}	0.19±0.04^{a}	0.35±0.08^{b}	0.38±0.09^{b}
5	0.83±0.06^{d}	0.48±0.04b^{c}	0.34±0.07^{a}	0.52±0.09^{c}	0.4±0.05^{ab}	0.4±0.06^{ab}	0.59±0.08^{c}
	DPPH, μmol TE 100 g						
1	30±3.2^{a}	74±3.1^{b}	136±2.2^{f}	125±2.8^{e}	106±2.1^{d}	98±1.9^{c}	176±3.6^{g}

Note: *The results are presented as mean values for the respective sample after triple measurements of the respective parameter. ** $^{a-g}$: Values bearing the same superscripts are not statistically different ($P>0.05$). ***Samples: S- (control sample with soy protein); Sp- (sample with spirulina powder); CP- (sample with cricket powder); SSp- (sample with soy protein and spirulina powder); SCP- (sample with soy protein and cricket powder); SpCP- (sample with spirulina powder and cricket powder); SSpCP- (sample with soy protein, spirulina powder and cricket powder).

Table 6. Texture parameters and emulsion stability of the model meat systems

Samples	Parameter						
	Hardness (N)	Springiness	Cohesiveness	Gumminess	Chewiness (N)	Adhesiveness (Nmm)	ES, %
S	18.02±0.73d	0.71±0^{ab}	0.48±0.03^{ab}	2.2±0.16^{b}	1.56±0.11^{b}	-1.56±0.1^{bc}	98.32±0.3^{d}
Sp	10.4±0.02^{a}	0.86±0.04^{c}	0.56±0.02^{c}	1.48±0.03^{a}	1.27±0.08^{ab}	-1.98±0.25^{ab}	98.02±0.5^{cd}
CP	15.77±2.53^{cd}	0.7±0.05^{ab}	0.47±0.02^{a}	1.94±0.3^{ab}	1.35±0.25ab	-1.17±0.09^{c}	97.58±0.27^{bcd}
SSp	13.43±1.79^{abc}	0.72±0.02^{ab}	0.5±0.01^{ab}	1.73±0.41^{a}	1.14±0.13^{a}	-2.46±0.65^{a}	97.15±0.7^{b}
SCP	13.01±0.73^{abc}	0.68±0.06^{a}	0.49±0.01^{ab}	1.7±0.1^{a}	1.16±0.08^{a}	-1.5±0.2^{bc}	97.05±0.32^{b}
SpCP	14.44±2.5^{bc}	0.72±0.03^{ab}	0.48±0.05^{ab}	1.81±0.41^{ab}	1.3±0.34^{ab}	-1.76±0.54^{abc}	97.47±0.5^{bc}
SSpCP	11.16±2.83^{ab}	0.76±0.05b	0.52±0.03^{bc}	1.59±0.18^{a}	1.21±0.2^{a}	-1.59±0.62^{bc}	96.13±0.14^{a}

Note: *The results are presented as mean values for the respective sample after three measurements of the respective parameter. ** $^{a-d}$: Values bearing the same superscripts are not statistically different ($P>0.05$). ***Samples: S- (control sample with soy protein); Sp- (sample with spirulina powder); CP- (sample with cricket powder); SSp- (sample with soy protein and spirulina powder); SCP- (sample with soy protein and cricket powder); SpCP- (sample with spirulina powder and cricket powder); SSpCP- (sample with soy protein, spirulina powder and cricket powder).

Emulsion stability and textural characteristics

The choice and quantity of protein sources used resulted in variations in emulsion capacity and alterations in the texture of the experimental samples (Table 6). All samples demonstrated high emulsion stability, two of them - control sample S and spirulina sample Sp - achieving values exceeding 98%. The excellent emulsion stability observed in algae-based samples can be attributed to their high protein content which provides emulsifying properties comparable to or better than those of whey proteins, soy proteins, and sodium caseinate [66-68]. In contrast, the cricket powder sample CP displayed a slightly lower emulsion stability than sample S, with a value of 97.58% ($P<0.05$). The lowest stability value was recorded for sample SSpCP at 96.13% ($P<0.05$). According to Pires *et al*. [69], when emulsion stability falls to 85–88% or below, issues related to consistency and structure can arise in the final sausage products.

The texture analysis revealed that control sample S exhibited the highest hardness value at 18.02 N. Incorporating various plant-based proteins and fibers, such as soy, wheat, and other cereals, tends to increase the hardness of meat matrices [70]. Similarly, the inclusion of cricket powder contributed to a rise in hardness, aligning with findings by Kim *et al.* [46], who studied the effects of cricket powder in sausages. Conversely, unlike soy and cricket powder, the addition of spirulina to raw semi-finished meat products resulted in reduced hardness (Table 6). Sample Sp, where spirulina entirely replaced soy protein, displayed the lowest hardness value ($P<0.05$) while achieving the highest springiness and cohesiveness values.

The highest gumminess and chewiness values, which are secondary parameters related to hardness, were reported for the control sample S (with soy protein) [71, 72]. The texture profile data obtained showed that control sample *S* (with soy protein) required the greatest chewing force when consumed, followed by the sample with complete replacement of soy protein with cricket powder (CP).

The highest adhesiveness was measured in the sample with equal soy protein and spirulina amounts (SSp), whereas lower values were found in the soy protein and cricket powder samples (SCP) (Table 6).

Microbiological characteristics

The microbiological characteristics of the samples of raw semi-finished products were monitored on the 1st and 5th day of their cold storage (Table 7).

Regarding the total bacteria count (TBC) on the 1st day of storage, no statistically significant difference ($P>0.05$) was observed between the individual samples. During their storage up to the 5th day, the bacteria count grew in all samples, with the lowest value recorded in sample Sp ($P<0.05$). Spirulina has been reported to have the ability to inhibit the growth of certain microorganisms, both pathogenic and food spoilage ones [73].

On the 1st day of storage, no presence of molds and yeasts was detected in experimental samples CP and SCP, while the highest number was reported in the control sample S (Table 7).

Table 7. Microbiological characteristics of the model meat systems on the 1st and 5th day of cold storage

Storage period (days)	S	Sp.	CP	SSp.	SCP	SpCP	SSpCP
TBC, log cfu/g							
1	3.12 ± 0.14^{aA}	2.96 ± 0.42^{aA}	3.11 ± 0.42^{aA}	3.85 ± 0.12^{bA}	3.2 ± 0.17^{aA}	3.86 ± 0.15^{bA}	4.20 ± 0.42^{bA}
5	5.08 ± 0.7^{bB}	4.18 ± 0.14^{aB}	4.67 ± 0.21^{abB}	6.11 ± 0.58^{cB}	5.23 ± 0.28^{bB}	6.11 ± 0.78^{cB}	6.04 ± 0.54^{cB}
Molds and yeasts, log cfu/g							
1	2.61 ± 0.12^{bA}	2.08 ± 0.68^{bA}	0.00 ± 0.00^{aA}	2.12 ± 0.84^{aA}	0.00 ± 0.00^{aA}	2.08 ± 0.98^{bA}	2.29 ± 0.67^{bA}
5	3.38 ± 0.88^{bA}	3.12 ± 0.78^{abB}	3.08 ± 0.41^{abB}	3.30 ± 0.64^{bB}	2.00 ± 0.65^{aB}	3.26 ± 0.25^{bB}	3.63 ± 0.82^{bB}

Note: *The results are presented as mean values for the respective sample after three measurements of the respective parameter. ** $^{a-c}$: Values in rows bearing the same superscripts are not statistically different ($P>0.05$). *** $^{A-B}$: Values in columns bearing the same superscripts were not statistically different ($P>0.05$). ****Samples: S- (control sample with soy protein); Sp- (sample with spirulina powder); CP- (sample with cricket powder); SSp- (sample with soy protein and spirulina powder); SCP- (sample with soy protein and cricket powder); SpCP- (sample with spirulina powder and cricket powder); SSpCP- (sample with soy protein, spirulina powder and cricket powder).

On the 5th day of storage, an increase in the number of molds and yeasts in the samples was observed, and, again, the lowest values were reported for samples CP and SCP. The difference in the number of molds and yeasts in the samples probably resulted from the microbiological status of the additives used, but this did not lead to any significant microbiological deficiencies.

CONCLUSION

The comparative analysis led to the conclusion that the use of spirulina and cricket powder, in combination or alone, as soy protein substitutes in model meat systems, resulted in products with a balanced nutritional composition and a higher fiber content. The experimental samples studied had good emulsion stability, although with slightly lower values compared to the control sample produced using soy protein, and significantly improved oxidative stability. The addition of spirulina caused a decrease in the hardness parameter and an increase in springiness and cohesiveness, whereas the addition of cricket powder led to a decrease in adhesiveness and improved chewiness and gumminess. The effect of the alternative protein sources used in the meat systems included pronounced changes in the color characteristics of the raw semi-finished products studied, but their perception and evaluation by consumers remain to be investigated in a complex sensory study of ready-to-eat semi-finished products in the context of the changing food ecosystem and innovations.

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