

Insect-based proteins in meat products: Evaluating the functional properties of *Locusta migratoria*

Et ürünlerinde böcek bazlı proteinler: *Locusta migratoria*'nın fonksiyonel özelliklerinin değerlendirilmesi

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To cite this article:

Dinçer, C. & Zungur Bastioğlu, A. (2025). Insect-based proteins in meat products: Evaluating the Functional properties of *Locusta migratoria*. Harran Tarım ve Gıda Bilimleri Dergisi, 29(4): 729-740.

DOI: 10.29050/harranziraat.1648366

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Received Date:

28.02.2025

Accepted Date:

03.11.2025

ABSTRACT

Due to global population growth and climate change, the demand for sustainable alternative protein sources is steadily increasing. Traditional animal protein production poses significant environmental sustainability risks as it requires high water and land usage and contributes to greenhouse gas emissions. Therefore, investigating alternative protein sources that have a lower environmental impact, are nutritionally rich, and economically viable is of great importance. This study examines the potential use of locust powder as a meat substitute in emulsified chicken patties and focuses on the effects of different locust powder ratios on the final product properties.

In this research, fully developed winged locusts of the *Locusta migratoria* species were used. The legs and wings were removed, and the locusts were dried and ground into a fine powder. For the emulsified chicken patties, chicken breast meat was divided into two portions: 75% of the meat was minced and mixed with beef fat, while the remaining 25% was homogenized alongside water, starch, a spice blend, and locust powder. Locust powder was incorporated at levels of 10%, 15%, and 20%. Both mixtures were emulsified and shaped into patties.

The study evaluated key characteristics such as emulsion stability, water-holding capacity, cooking loss, diameter reduction, and Hunter L*, a*, b* color parameters. The results demonstrated that the addition of locust powder had a statistically significant impact on these parameters.

This research highlights the feasibility of using locust powder as a sustainable alternative protein source in meat products. Moreover, it provides evidence that insect proteins can enhance the nutritional profile and sensory properties of food products, offering a promising solution to future food security and sustainability challenges.

Key Words: *Locusta migratoria*, alternative protein source, emulsified chicken meatball

ÖZ

Küresel nüfus artışı ve iklim değişikliği ile birlikte, sürdürülebilir alternatif protein kaynaklarına duyulan ihtiyaç giderek artmaktadır. Geleneksel hayvansal protein üretimi, yüksek su ve arazi kullanımı ile sera gazı emisyonlarına neden olarak çevresel sürdürülebilirlik açısından önemli riskler taşımaktadır. Bu nedenle, çevresel etkisi düşük, besleyici ve ekonomik açıdan uygulanabilir alternatif protein kaynaklarının araştırılması büyük önem arz etmektedir. Bu çalışma, emülsifiye tavuk köftelerinde çekirge tozunun et ikamesi olarak kullanım potansiyelini incelemekte ve farklı çekirge tozu oranlarının nihai ürün özellikleri üzerindeki etkilerine odaklanmaktadır. Araştırmada, *Locusta migratoria* türüne ait gelişimini tamamlamış kanatlı çekirgeler kullanılmıştır. Bacak ve kanatları ayrılmış çekirgeler kurutularak öğütülmüş ve toz haline getirilmiştir. Emülsifiye tavuk

köftesi için ise, Tavuk göğüs eti iki kısma ayrılmıştır; %75'lik kısmı kıyılarak kuyruk yağı ile karıştırılmış, kalan %25'lik kısım su, nişasta, baharat karışımı ve çekirge tozu ile homojenize edilmiştir. Çekirge tozu %10, %15 ve %20 oranlarında ilave edilmiştir. Her iki karışım emülsifiye edilerek köfte formu verilmiştir. Çalışmada emülsiyon stabilitesi, su tutma kapasitesi, pişirme kaybı, çap küçülmesi ve Hunter L*, a*, b* renk parametreleri gibi temel özellikler değerlendirilmiştir. Sonuçlar, çekirge tozu ilavesinin bu parametreleri istatistiksel olarak anlamlı düzeyde etkilediğini göstermiştir. Duyusal analizlerde ise özellikle %15 oranında çekirge tozu içeren köftelerin, kontrol grubuna kıyasla daha yüksek kabul edilebilirlik skorları elde ettiği tespit edilmiştir. Bu araştırma, çekirge tozunun et ürünlerinde sürdürülebilir bir alternatif protein kaynağı olarak uygulanabilirliğini ortaya koymaktadır. Ayrıca, böcek proteinlerinin gıda ürünlerinin besin profili ve duyusal özelliklerini iyileştirebileceğini kanıtlayarak geleceğin gıda güvenliği ve sürdürülebilirlik sorunlarına umut vaat eden bir çözüm önerisi sunmaktadır.

Anahtar Kelimeler: *Locusta migratoria*, alternatif protein, emülsifiye tavuk köftesi

Introduction

The rapid growth of the global population and the increasing demand for protein pose a significant pressure on food security, compounded by environmental factors such as excessive water consumption, land requirements, and greenhouse gas emissions associated with traditional protein production. These challenges highlight the urgent need for the exploration and adoption of alternative protein sources that are more sustainable and environmentally friendly. In this regard, insects have emerged as a highly promising alternative (Dinçer, 2024; Kim et al., 2019; Pandurangan and Kim, 2015). (Kurek et al., 2020) stated that insect proteins are significant emerging protein sources, and in the coming decades, approximately 40% of traditional meat consumption is expected to be replaced by alternative protein sources. Given this potential shift in protein consumption patterns, the role of insect-based foods in human diets becomes increasingly relevant. Entomophagy is a term that refers to the consumption of insects as food in human nutrition. While its role in food science remains a topic of debate, the potential of insects as an alternative protein source in diets is of critical importance in developing sustainable solutions to meet the increasing global food demand (Dinçer, 2024). Insects are consumed at various stages of their life cycle, including eggs, larvae, pupae, and adults (Sun-Waterhouse et al., 2016). Insects, characterized by their short life cycles and high reproduction rates, are generally regarded as ecological and environmentally friendly food alternatives, particularly because of their low greenhouse gas emissions (Dinçer, 2024;

Oonincx et al., 2010; Rumpold and Schlüter, 2013). Additionally, as ectothermic organisms, insects do not expend energy to regulate their body temperature, and their water and space requirements are considerably lower compared to conventional livestock farming (Akhtar and Isman, 2017). In addition to their environmental benefits, insects also provide a well-balanced nutritional profile when compared to conventional food sources. This profile is characterized by high protein content and a richness in unsaturated fatty acids (Cheseto et al., 2020; Kinyuru et al., 2009). The protein content of insects ranges from 40% to 75% on a dry matter basis and from 10% to 25% on a fresh weight basis (Bukkens, 1997; Rumpold and Schlüter, 2013). Insects such as grasshoppers and crickets from the Orthoptera order stand out as significant species due to their high protein content. The protein content of *L. migratoria* is generally reported to range between 50% and 65% (Barker et al., 1998). *Locusta migratoria* is among the most widely consumed edible insect species globally, representing 13% of total insect consumption worldwide (Mariod, 2020). The European Union (EU), under Regulation 2015/2283 on novel foods, has officially recognized *L. migratoria* as safe for human consumption. As a result, it has been introduced to the EU market in various forms, including frozen adult insects as well as dried and ground preparations (Dinçer, 2024). Insect-based ingredients, which are already available on the market and incorporated into products such as cookies, chocolates, tortilla-style chips, and other snacks, have gained attention as an alternative protein source (Melgar-Lalanne et al., 2019). In

addition, the use of insects in meat and meat products is gaining importance, not just in snack foods, it further highlights the growing recognition of alternative protein sources and their sustainability potential (Grasso and Goksen, 2023). Beyond their nutritional benefits, insects are also being explored for their techno-functional and physicochemical properties in various meat products. However, insect-based food consumption in Turkey is quite limited, and a large portion of society does not consider these products edible. Religious perceptions, cultural habits, and neophobia towards insect consumption are the main factors negatively affecting consumption (Hajhamidi et al., 2025). However, in recent years, insect-based foods have begun to be researched in our country in terms of sustainability, nutrition, and consumer attitudes; studies show that awareness on this subject is increasing, albeit slowly. Although it has been found that individuals who are conscious about sustainability and animal welfare have a more positive attitude towards these products, this positive attitude often does not translate into actual consumption. This situation stems from a lack of information, psychological barriers, and social norms. Therefore, strategies that aim to raise awareness, are compatible with cultural values, and gradually involve consumers in the process are needed to increase the acceptance of insect-based foods in Turkey.

Borges et al, (2022) investigated the incorporation of *Bombyx mori* (silkworm pupae) into meat batters at levels of 5%, 10%, and 15%, along with transglutaminase (TG). The addition of silkworm pupae powder enhanced the nutritional value of the meat batter by increasing protein, fat, and ash content while reducing cooking loss. However, higher levels of silkworm pupae resulted in increased hardness, gumminess, and chewiness of the meat batters. Cho and Ryu (2021) examined the effects of incorporating *Tenebrio molitor* (mealworm) larva powder into extruded meat analogs at inclusion levels of 0%, 15%, and 30%. Their findings indicated that as the mealworm content increased, water-holding

capacity, protein digestibility, and DPPH radical scavenging activity improved. However, higher mealworm concentrations resulted in a decline in textural properties and the integrity index. Scholliers et al. (2020) investigated the partial replacement of meat with *Zophobas morio* (superworm) powder in sausages at inclusion levels of 5% and 10%. Their findings showed that insect powder incorporation led to reduced cooking loss and maintained adequate emulsion stability. However, the texture properties of the insect-based sausages were inferior compared to traditional meat sausages. Kim et al. (2016) observed that sausages incorporating 10% mealworm and silkworm protein had higher cooking yields and increased hardness. The study highlights insect proteins as a sustainable option for improving processed meat quality. Similarly, a study found that adding 5%, 10%, and 15% silkworm larva powder to pork reduced cooking loss most effectively at the highest concentration (15%) (Choi et al., 2017). Studies have highlighted the potential of incorporating insects into food products to improve physicochemical properties such as protein content, water-holding capacity, and cooking yield, while also suggesting that textural properties may need further development at higher inclusion levels.

This study assesses the potential of locust powder as a sustainable alternative protein source in meat products. Chicken meatballs were formulated with *Locusta migratoria* powder at inclusion levels of 10%, 15%, and 20%, alongside a control group without insect powder. The formulated products were analyzed for color properties, water-holding capacity, emulsion stability, cooking loss, and shrinkage to determine the effects of locust powder incorporation on the physicochemical characteristics of the meatballs.

Material and Methods

Insect Source and Preparation

Locusta migratoria used in this study were provided frozen by Mira Canlı Hayvan Böcek Turizm İnşaat Tarım Sanayi Şti. (Antalya, Turkey).

Ingredients for emulsified chicken meatballs

All raw materials used for the preparation of emulsified chicken meatballs were procured from local retail outlets in Aydın, Turkey. Chicken breast (*Muscularis pectoralis*) was acquired from Gedik Piliç, starch was obtained from Başak Gıda, spice mix were sourced from Selay, and salt was provided by Salina.

Preliminary processes applied to Locusts

Locusts brought to the laboratory were dried in an airflow tray dryer at 45 ± 2 °C (1.4 m s^{-1} air flow rate; <10% relative humidity) for 6 hours after their first legs and wings were separated. After the drying process, it was ground with the help of a blade grinder (Homend, Türkiye). The ground samples were stored in the refrigerator (4 °C) in aluminum-layered polyethylene (ALPE) packages until further processing.

Fat Extraction from Locust Powder

Fat extraction from locusts was performed using n-hexane ($1:5 \text{ m v}^{-1}$) according to the procedure described by (Kim et al., 2020). Locust

powder was treated with n-hexane at ambient temperature for 1 hour, after which the solvent was filtered and separated. This procedure was repeated five times until a clear solvent was obtained. The residual solvent was evaporated in a rotary evaporator at ambient temperature (20 °C) for 12 hours. The fat-extracted locusts were subsequently used for further analyses.

Emulsified chicken meatball production

The production of emulsified chicken meatball was carried out following the method described by Öztürk and Serdarođlu, (2018), with formulations presented in Table 1.

For cooking loss analysis, the samples were cooked in a non-fat frying pan for 5 minutes on each side until their internal temperatures reached 72 °C. During cooking, thermocouples were inserted into the center points of the meatballs to measure the internal temperature, and the temperature changes occurring in the meatballs throughout the cooking process were recorded using a data logger.

Table 1. Emulsified chicken meatball formulations

%	Control	10% LP	15% LP	20% LP
Chicken breast meat	57.00	51.30	48.45	45.60
Fat	9.00	9.00	9.00	9.00
Water	25.50	25.50	25.50	25.50
Potato Starch	6.00	6.00	6.00	6.00
Salt	1.00	1.00	1.00	1.00
Sodium tripolyphosphate	0.50	0.50	0.50	0.50
Spice mix	1.00	1.00	1.00	1.00
Locust powder	0.00	5.70	8.55	11.40

LP: *Locusta migratoria* powder

Chemical Composition

In order to ascertain the chemical composition of the emulsified chicken meatball samples, the following analyses were performed: moisture determination (950.46) (AOAC, 1990), total fat determination (Flynn and Bramblett, 1975), protein determination (955.04) (AOAC, 1990), and ash determination (920.153) (AOAC, 1990).

Color

Color measurement (L^* , a^* , b^*) was performed at room temperature using a portable colorimeter (PCE - CSE 4, PCE Instruments,

Germany) on at least three different samples, with readings taken from four different points on each sample (Serdarođlu et al., 2024). Measurements were conducted on both the outer and inner surfaces of the emulsified chicken meatballs. The color evaluations were carried out using the D65 illuminant, 10° standard observer, and an 8-mm measurement aperture. The results were expressed in terms of Hunter L^* (lightness), a^* (redness), and b^* (yellowness) values.

Water holding capacity

The determination of water holding capacity

in the chicken meatball emulsion dough was carried out according to Hughes et al. (1997),

and the percentage of water holding capacity was calculated using the following Equation 1:

$$WHC (\%) = 1 - \left(\frac{T}{M}\right) * 100 = 1 - \frac{B-A}{M} * 100 \quad (\text{Eq. 1})$$

T: Total water loss after heating and centrifugation

A: Sample weight after heating and centrifugation

B: Sample weight before heating

M: Total water in the sample

Emulsion stability

The emulsion stability (ES) analysis of chicken meatball emulsions was performed according to Hughes et al. (1997). The percentages of total released water (TRW) and total released fat (TRF) were calculated using the following Equation 2 and Equation 3.

$$\%TRW = \frac{(\text{Weight of sample}) - (\text{Weight of pellet})}{\text{Weight of sample}} \times 100 \quad (\text{Eq. 2})$$

$$\%TRF = \frac{(\text{Weight of crucible} + \text{Weight of dried supernatant}) - (\text{Weight of empty crucible})}{TRW} \times 100 \quad (\text{Eq. 3})$$

Cooking loss

The cooking loss in products was calculated by recording the weights before and after cooking,

according to the following formulation (Eq.4) (Serdarođlu et al., 2024).

$$\text{Cooking loss } (\%) = \left[\frac{\text{Raw weight} - \text{Cooked weight}}{\text{Raw weight}} \right] * 100 \quad (\text{Eq. 4})$$

Shrinkage

The determination of shrinkage in samples was carried out by measuring the diameters of the

samples before and after cooking (Modi et al., 2004). The results were calculated using the following Equation 5.

$$\text{Shrinkage } (\%) = \left[\frac{\text{Raw diameter} - \text{Cooked diameter}}{\text{Raw diameter}} \right] * 100 \quad (\text{Eq. 5})$$

Statistical analysis

Statistical analysis of the data was conducted using SPSS software (IBM SPSS 302 v15.0, USA). The effect of use of locust protein powder on the measured properties was evaluated using one-way analysis of variance (ANOVA). The statistical significance of the differences between the means of each group was determined. This was followed by a more detailed analysis using Duncan's multiple range test.

Results and Discussion

Chemical Composition

The incorporation of *Locusta migratoria* powder significantly affected the chemical composition of emulsified chicken meatballs ($p < 0.05$). As shown in Table 2, the moisture content progressively decreased with increasing MLPP levels. The control group exhibited the highest moisture value ($65.86 \pm 3.16\%$), whereas the lowest moisture content was observed in the 20% LP sample ($63.48 \pm 2.50\%$), likely due to the higher dry matter contribution of insect protein powder.

Table 2. Chemical compositions of raw emulsified chicken meatball samples

Groups	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
Control	65.86±3.16 ^a	19.27±0.87 ^d	11.02±1.20 ^d	2.10±0.01 ^d
10% LP	65.01±1.98 ^b	19.57±0.45 ^c	11.24±0.65 ^c	2.87±0.01 ^c
15% LP	63.99±2.34 ^c	19.84±0.89 ^b	11.49±0.43 ^b	3.01±0.02 ^b
20% LP	63.48±2.50 ^d	20.05±1.01 ^a	11.95±0.37 ^a	3.27±0.02 ^a

*Data are represented mean ± standard error. Different lowercase letters (a, b, c, d) in each column in the analysis indicate statistically significant ($p < 0.05$) differences between treatments. LP: *Locusta migratoria* powder

Protein content significantly increased with MLPP addition. While the control sample had the lowest protein content (19.27±0.87%), the 20% LP group exhibited the highest (20.05±1.01%), confirming that MLPP fortification enhanced the overall protein richness of the formulations. A similar increase was observed in fat and ash content. The fat content ranged from 11.02±1.20% in the control to 11.95±0.37% in the 20% LP sample, whereas ash content increased from 2.10±0.01% to 3.27±0.02% with higher LP levels. These increases can be attributed to the intrinsic lipid and mineral composition of locust powder.

Overall, the results indicate that LP enrichment enhances the nutritional profile of emulsified chicken meatballs by increasing protein, fat, and

mineral content, while reducing moisture due to increased solid content in the formulation.

Color

Color of meat serves as a critical sensory characteristic for both manufacturers and consumers in evaluating product quality, as visual appearance often acts as the primary determinant available to buyers during selection. Variations in meat color may arise from multiple factors, including pH levels, muscle tissue structure, animal nutrition practices, and post-processing preservation parameters (Altmann et al., 2022; Rodríguez-Rodríguez et al., 2022; Tomasevic et al., 2021).

The color values of raw and cooked emulsified chicken meatballs are presented in Table 3 and Table 4, respectively.

Table 3. Color values of raw emulsified chicken meatball samples

Groups	L^*	a^*	b^*	C^*	h°
Control	67.47±0.37 ^a	9.96±0.18 ^a	23.31±0.37 ^a	25.32±0.34 ^a	66.86±0.71 ^a
10% LP	32.77±0.22 ^b	6.97±0.17 ^b	14.62±0.20 ^b	16.25±0.18 ^b	64.45±0.68 ^b
15% LP	29.27±0.37 ^c	7.11±0.15 ^b	13.48±0.19 ^b	15.24±0.16 ^b	62.11±0.67 ^c
20% LP	29.07±0.35 ^c	6.51±0.11 ^b	11.37±0.20 ^c	13.12±0.15 ^c	59.92±0.66 ^d

*Data are represented mean ± standard error. Different lowercase letters (a, b, c, d) in each column in the analysis indicate statistically significant ($p < 0.05$) differences between treatments. LP: *Locusta migratoria* powder

Table 4. Color values of cooked emulsified chicken meatball samples

Product	L*	a*	b*	c	H
Control	73.42±0.89 ^a	7.29±0.05 ^b	23.13±0.33 ^a	24.25±0.31 ^a	72.51±0.70 ^a
10% LP	37.53±0.56 ^b	9.47±0.16 ^a	17.78±0.20 ^b	20.14±0.34 ^b	61.97±0.52 ^b
15% LP	34.46±0.40 ^b	9.11±0.15 ^a	16.48±0.17 ^b	18.60±0.24 ^c	61.05±0.66 ^b
20% LP	27.40±0.40 ^c	9.29±0.09 ^a	13.41±0.20 ^c	16.32±0.22 ^d	55.19±0.37 ^c

*Data are represented mean ± standard error. Different lowercase letters (a, b, c, d) in each column in the analysis indicate statistically significant ($p < 0.05$) differences between treatments. LP: *Locusta migratoria* powder

Water holding capacity

The water-holding capacity in meat product is a parameter that determines the extent to which meat can retain its water content during cooking and processing, and this property is a crucial factor influencing the textural characteristics of the meat and the water loss occurring during cooking (Szymańko et al., 2021; Warner, 2014). Water-holding capacity plays a vital role in evaluating the quality of meat during its processing stages. It is assessed both at the initial

stage of raw material inspection and throughout the processing phase. This property is closely associated with the release of water from the myofibrillar structure (Huff-Lonergan and Lonergan, 2005; Pearce et al., 2011). In addition to its direct impact on the economic efficiency of the meat processing industry, WHC significantly influences the sensory attributes of meat, both in its fresh form and as part of processed meat products (Bertram et al., 2004).

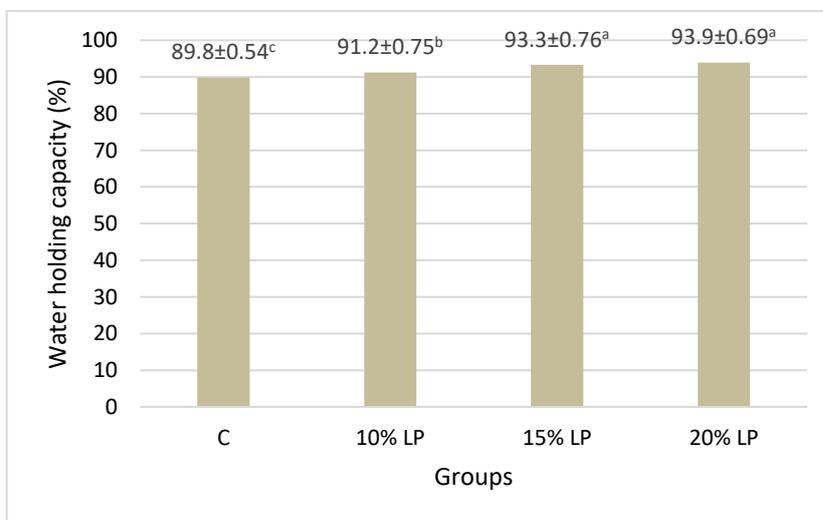


Figure 1. Water holding capacity of emulsified chicken meatballs

*Data are represented mean ± standard error. Different lowercase letters (a, b, c, d) in each column in the analysis indicate statistically significant ($p < 0.05$) differences between treatments. LP: *Locusta migratoria* powder

In the control group, the water holding capacity (WHC) was measured at 89.8%. With the addition of 10% locust powder, WHC increased to 91.2%, while the sample containing 15% locust powder reached 93.3%, and the highest value of 93.9% was observed in the 20% locust powder formulation. These results indicate that the water holding capacity increases as the proportion of

locust powder increases.

In a study by Cho and Ryu, (2021), it was found that the incorporation of *Tenebrio molitor* (mealworm) larvae at 15% and 30% by mass into extruded plant-based meat analogs significantly increased the water-holding capacity (WHC) of the products compared to the control group, with statistically significant differences observed. In

another study by Choi et al. (2024) , it concluded that the incorporation of *Tenebrio molitor*, *Protaetia brevitarsis seulensis*, *Gryllus bimaculatus* and *Allomyrina dichotoma* at %20 by mass into the patty samples increased water holding capacity by 18%, 13%, 19% and 29% respectively, compared to the control group.

Emulsion stability

Emulsion stability refers to the ability of meat products (e.g., sausages, salami, pâté) to maintain their structural integrity and texture by ensuring a homogeneous distribution of fat and water phases. This stability is critically important to prevent fat separation (syneresis) or water leakage during production and storage stages (Barbut, 1992; Jiménez Colmenero, 2004).

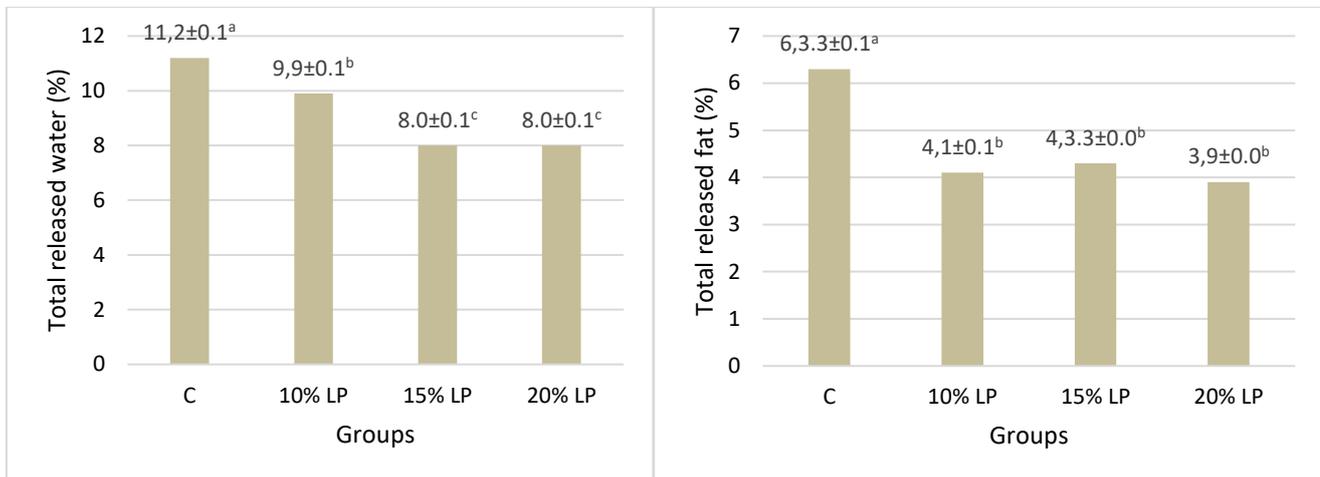


Figure 2. Total released water (%) and total released fat (%) values of emulsified chicken meatballs

*Data are represented mean ± standard error. Different lowercase letters (a, b, c, d) in each column in the analysis indicate statistically significant ($p < 0.05$) differences between treatments. LP: *Locusta migratoria* powder

Emulsion stability is assessed separately in terms of total released water and total released fat. The 15% and 20% locust groups exhibited comparable values, with no statistically significant difference between them. The control group exhibited the highest levels of fat and water release. These findings suggest that the addition of locust to the formulation enhances emulsion stability by reducing fat and water release.

The study conducted by Choi et al. (2017)) revealed that the incorporation of 5%, 10%, and 15% *Tenebrio molitor* into frankfurter products led to a reduction in the total amount of separated water. In another study, it was observed that the groups with 5%, 10%, and 15%

addition of microwave-dried *Tenebrio molitor* larvae in frankfurter products exhibited higher fat separation in terms of emulsion stability compared to the control group (Zhang et al., 2022).

Cooking loss

Cooking loss is a key indicator of the intrinsic characteristics of raw muscle proteins, influencing not only the functional properties of the meat but also the efficiency of the processing stages. It directly affects both the final yield and the overall quality of meat products in subsequent processing, making it a crucial factor for optimizing production outcomes (Li et al., 2013).

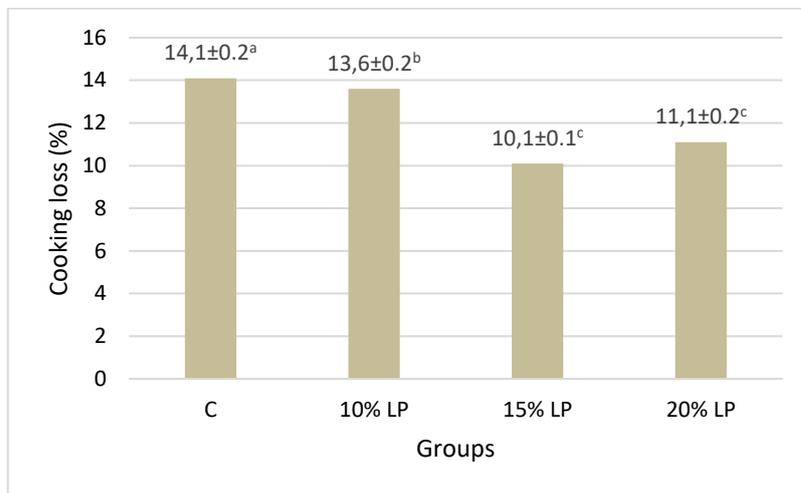


Figure 3. Cooking loss (%) values of emulsified chicken meatballs

*Data are represented mean \pm standard error. Different lowercase letters (a, b, c, d) in each column in the analysis indicate statistically significant ($p < 0.05$) differences between treatments. LP: *Locusta migratoria* powder

During cooking, most of the water loss is attributable to the denaturation or structural changes in meat proteins induced by temperature (Pang et al., 2021). The addition of locusts to the formulation showed potential in minimizing cooking loss. The incorporation of locust powder into the formulation resulted in a reduction in cooking loss. The lowest cooking loss was observed in samples with a 15% locust powder addition. The addition of locust increases the protein content, which accounts for this effect. Proteins are known for their functional properties—such as hydration, fat-binding capacity, foaming, emulsifying, and gel-forming abilities—along with contributing to stability, viscosity, elasticity, and texture (Kolpakova et al., 2018). Moreover, when proteins interact with water molecules, they help retain water in the sample, thereby reducing water loss during cooking. This water retention is mainly achieved through hydrogen bonds formed between water and the polar groups on the amino acid side chains, which stabilize the protein structure and prevent denaturation at high cooking temperatures (Raschke, 2006). Puechkamutr and Arsa, (2024) observed that pork meatball samples formulated with tapioca flour, carrageenan and 10%, 15%, and 20% of the additions of a *Patanga succincta* species exhibited significantly reduced cooking loss compared to the control group. Choi

et al. (2017) observed that the addition of 5% and 10% *Tenebrio molitor* had lower cooking loss than the control group in frankfurter sausages. However, cooking loss increased as the concentration above the %15 of *Tenebrio molitor*. This phenomenon is explained by the denaturation of myofibrillar proteins during cooking, which results in the loss of their ability to enhance binding capacity, thereby leading to a reduction in binding within meat products.

Shrinkage

Shrinkage in meat refers to the reduction in its volume and size that occurs during cooking, primarily due to the loss of water and fat as the muscle fibers contract (Barbera and Tassone, 2006). Shrinkage of meat during cooking is frequently perceived as indicative of poor quality or the potential use of hormones. Consumers typically expect meat to maintain a specific size and appearance, and any reduction in size during cooking is often viewed unfavorably. Although shrinkage, cooking loss, and tenderness are interrelated phenomena, they are perceived as distinct events by consumers due to their observation at different stages of the process. Furthermore, as purchasing, cooking, and consumption are often carried out by separate individuals, these aspects are evaluated through different perspectives (Denoyelle and Lebihan, 2004; Palka and Daun, 1999).

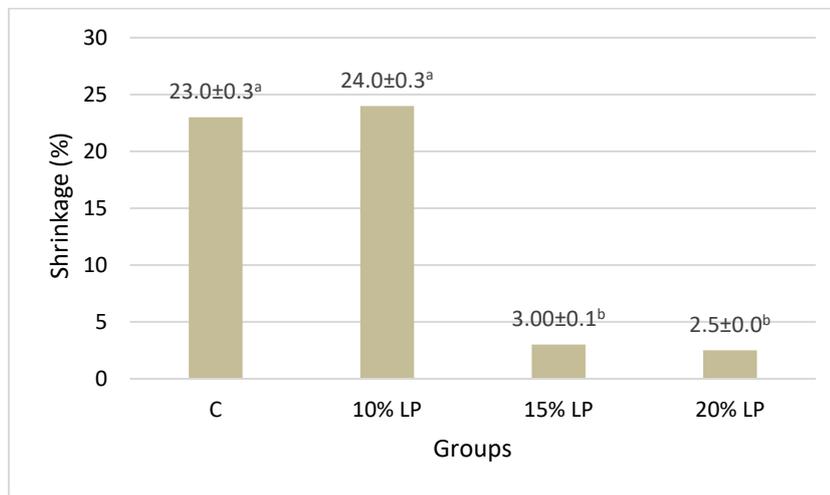


Figure 4. Shrinkage (%) values of emulsified chicken meatballs

*Data are represented mean \pm standard error. Different lowercase letters (a, b, c, d) in each column in the analysis indicate statistically significant ($p < 0.05$) differences between treatments. LP: *Locusta migratoria* powder

It is important to note that a significant decrease in shrinkage was observed with the addition of 15% and 20% locust to the formulation. The reduction in shrinkage in meat products is generally considered a positive attribute, as it indicates better structural integrity and a higher water holding capacity of the product. A decrease in shrinkage also suggests that meat products undergo less water loss during the cooking process, which allows the product to remain juicier, more flavorful, and fresher (Denoyelle and Lebihan, 2004; Fowler and Bejan, 1991). The significant reduction in shrinkage observed with the addition of 15% and 20% locust indicates increased stability of these emulsions and improved quality of the meat products. This phenomenon contributes to higher water holding during cooking, thereby helping to preserve sensory properties of the products more effectively. In the study conducted by Gomes Martins et al. (2024), it was determined that the shrinkage rate in samples with 10%, 15%, and 20% *Gryllus assimilis* added to the meatball formulation was lower compared to the control group.

Conclusion

This study investigated the potential of locust powder as a sustainable alternative protein source in meat products. These findings suggest

that *Locusta migratoria* powder can be effectively utilized to produce nutritionally enriched emulsified meat products, indicating promising applications in the development of sustainable, high-protein food systems. It was observed that the addition of *Locusta migratoria* at levels of 10%, 15%, and 20% had a positive effect on various quality parameters of chicken meatballs, including color, water-holding capacity, emulsion stability, cooking loss, and shrinkage. The observed improvements in key quality parameters, such as water-holding capacity, emulsion stability, and reduced cooking loss, suggest that *Locusta migratoria* could be a promising alternative protein source in meat products.

Conflict of Interest

The authors declared no potential conflicts of interest regarding the publication of this article.

Author's Contributions

Can DİNÇER and Aslı ZUNGUR BASTIOĞLU were responsible for selection of the research topic, conducting experiments, data collections and analysis, writing and reviewing the manuscript.

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