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Special Graduation Project
**Evaluation of the nutritional components and physicochemical
properties of plant-based foods: beef patty analogues**

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Abstract

The rising demand for plant-based alternatives has driven the development of meat analogs intended to resemble animal-based products in nutritional composition and physicochemical properties. This study compared the nutritional and physicochemical characteristics of lentil-based and textured vegetable protein (TVP)-based patties with traditional beef patties. The formulations were optimized through preliminary trials and evaluated for water activity, moisture content, cooking loss, shrinkage, color, texture profile, fat, and protein content. Beef patties showed the highest protein levels, along with greater cooking loss, shrinkage, hardness, and springiness, attributed to protein denaturation during cooking. Lentil-based patties had the lowest protein values but reached fat levels comparable to beef due to the addition of canola oil. In contrast, TVP-based patties presented intermediate protein levels and lower fat values. They also had lower hardness, springiness, and compression rate values. Significant positive correlations were observed between protein content and moisture, cooking loss, and textural parameters, highlighting the role of protein concentration in overall patty performance. These results indicate that TVP-based formulations offer a promising alternative to animal-based products, while both lentil- and TVP-based patties demonstrated distinct physical and textural properties compared to beef, reinforcing their unique identities as plant-based products. However, further adjustments in formulation are recommended to improve textural quality and better replicate the physicochemical behavior of meat.

Keywords: ground beef, lentils, plant-based patties, sustainability, texture, textured vegetable protein

Resumen

La creciente demanda de alternativas de origen vegetal ha impulsado el desarrollo de análogos cárnicos destinados a asemejarse a los productos de origen animal en su composición nutricional y propiedades fisicoquímicas. Este estudio comparó las características nutricionales y fisicoquímicas de hamburguesas elaboradas a base de lentejas y de proteína vegetal texturizada (TVP) con hamburguesas tradicionales de res. Las formulaciones fueron optimizadas mediante pruebas preliminares y evaluadas en cuanto a actividad de agua, contenido de humedad, pérdida por cocción, encogimiento, color, perfil de textura, grasa y proteína. Las hamburguesas de res mostraron el mayor contenido de proteína, además de presentar mayor pérdida por cocción, encogimiento, dureza y elasticidad, atribuidos a la desnaturalización de proteínas durante la cocción. Las hamburguesas de lentejas tuvieron los valores más bajos de proteína, pero alcanzaron niveles de grasa comparables a la res debido a la adición de aceite de canola. En contraste, las hamburguesas de TVP presentaron niveles intermedios de proteína y menores valores de grasa. También mostraron menor dureza, elasticidad y tasa de compresión. Se observaron correlaciones positivas significativas entre el contenido de proteína y la humedad, la pérdida por cocción y los parámetros texturales, lo que resalta el papel de la concentración proteica en el desempeño general de las hamburguesas. Estos resultados indican que las formulaciones a base de soya ofrecen una alternativa prometedora a los productos de origen animal, mientras que tanto las hamburguesas de lentejas como las de TVP demostraron propiedades físicas y texturales distintas a las de res, reforzando su identidad como productos de origen vegetal. Sin embargo, se recomiendan ajustes adicionales en la formulación para mejorar la calidad textural y replicar con mayor precisión el comportamiento fisicoquímico de la carne.

Palabras clave: carne molida, hamburguesas vegetales, lentejas, proteína vegetal texturizada, sostenibilidad, textura

Introduction

The constant changes in consumer needs and preferences make the food industry transform continually, by adapting to new consumer trends and behaviors. In recent years, the demand for plant-based products has rapidly grown, driven by health, environment, sustainability, and animal welfare concerns. Plant-based alternatives are products that aim to imitate animal-based foods in terms of their appearance, flavor, functionality, and other characteristics (Bryant, 2022). These alternatives are typically formulated using plant-based ingredients, including legumes, grains, and other sources. The origin of plant-based meat analogues dates back several decades; however, a key development in their evolution was marked by the introduction of new-generation products from companies such as Beyond Meat (2009) and Impossible Foods (2011), which brought innovation by employing biotechnologies to improve the structural and flavor characteristics of these substitutes (Ali & Bharali, 2025).

People around the world are increasingly interested in adopting diets that reduce the consumption of certain animal-based foods such as meat and dairy. A global survey reported that in 2019, 40% of consumers were trying to reduce their consumption of animal proteins (Aschemann-Witzel et al., 2020). Currently, 39% of US consumers attempt to consume more plant-based foods (Ohr, 2020). According to the Plant Based Foods Association (2022), plant-based food sales grew 6.6% from 2021 to 2022 in the US. Other countries, such as the UK, have shown a significant increase in consumption of plant-based products (6.7% in 2008 to 13.1% in 2019) (Alae-Carew et al., 2022). Furthermore, reports indicate that regions such as Asia and the Pacific play a significant role in the plant-based alternatives markets, particularly in the plant-based meat and milk sectors (Wunsch, 2024), demonstrating the increasing popularity of this eating habit and its expanded market presence globally.

The growth in the consumption of plant-based foods is supported by several factors. Researchers have found that a plant-based diet can improve the health and well-being of consumers

through the effects of its bioactive compounds (Peña-Jorquera et al., 2023). Likewise, these products are known as good sources of dietary fiber and are lower in calories, cholesterol, and saturated fat than animal-based products (El Sadig & Wu, 2024). Furthermore, they are associated with the prevention of chronic diseases such as cardiovascular diseases, cancer, and others (Thompson et al., 2023). Additionally, the production and consumption of animal-based products are related to significant contributions to various environmental challenges that endanger sustainability, including greenhouse gas emissions, land use, and degradation, among others (Espinosa-Marrón et al., 2022). Studies have also shown that all food production systems have detrimental effects on bionetworks, with most of the harm affecting wildlife (Hampton et al., 2021). Consequently, animal-based diets have a greater environmental impact compared to plant-based alternatives (Nelson et al., 2016). This has led many individuals to reconsider their dietary choices in pursuit of environmental sustainability and improved animal welfare.

Among plant-based alternatives, burger patties have emerged as a particularly popular product due to their convenience and versatility. They aim to recreate the nutritional value and sensory attributes of animal-based burgers, including their distinct bites, chewiness, succulence, and firmness (Kyriakopoulou et al., 2021). Some common raw materials that are used for this purpose comprise soy protein, which has been recognized as an ideal option due to its good processing characteristics, balanced nutritional value, and relatively low price (Wang et al., 2023); and lentils, which are known as good sources of complex carbohydrates, protein, fiber, vitamins, and minerals (Durgapal, 2020).

However, even though these ingredients are growing in popularity due to their potential benefits, doubts persist regarding their capacity to provide nutritional content for human diets comparable to that of animal-based foods, since they are not similar in composition or structure (Nolden & Forde, 2023; van Vliet et al., 2020).

Moreover, beyond nutritional value, for plant-based alternatives, replicating the physicochemical properties of their animal-based counterparts remains a challenge, since these characteristics significantly impact consumer acceptance and overall quality. Among these, one of the most complex attributes to replicate is texture, due to the unique functional properties of animal proteins (Giacalone et al., 2022). Also, parameters such as moisture content, water activity, color, cooking loss, and shrinkage are crucial indicators of the product's performance during preparation and consumption, which not only affect sensory attributes but also affect their shelf life and consumer perception (McClements & Grossmann, 2022). Some studies have mentioned that plant-based alternatives often face challenges in mimicking properties such as juiciness and tenderness of traditional meat products. These difficulties are mainly attributed to the structural and functional differences of plant proteins, which lack the same binding and emulsifying capacity of animal proteins, leading to undesirable textures (Dekkers et al., 2018; Sha & Xiong, 2020).

Given the increasing demand for plant-based foods and ongoing concerns regarding their nutritional value and the ability to replicate physicochemical properties compared to animal-based products, even though they have been promoted as a sustainable option, it is essential to conduct studies that contribute to more information about these alternatives. For this reason, this research aimed to evaluate the nutritional components and physicochemical properties of plant-based foods compared to their animal-based counterparts. In addition, the following objectives were considered:

To formulate plant-based burger patties for comparative analysis with an animal-based equivalent.

To compare the nutritional content of plant-based and beef burger patties in terms of protein and fats.

To analyze the physicochemical properties of plant-based and beef burger patties.

Materials and Methods

Study Location

The processing of animal-based and plant-based burger patties, their physicochemical properties, texture, and proximal analysis were conducted at the University of Illinois Urbana-Champaign, Urbana, Illinois, in the United States of America.

Collection of Materials

The primary raw materials used for the preparation of plant-based burger patties included Great Value® (Bentonville, AR, USA) brand lentils and NOW Real Food® (Bloomington, IL, USA) brand organic textured vegetable protein, as well as Cargill Meat Solutions (Wichita, KS, USA) brand all natural ground beef chuck (80% lean, 20% fat), which was utilized to elaborate animal-based burger patties as the control group in the experiment. Ground beef was stored at $-18\text{ }^{\circ}\text{C}$ before use. Additionally, Meijer® (Grand Rapids, MI, USA) brand salt, Great Value (Bentonville, AR, USA) brand canola oil, and Great Value (Bentonville, AR, USA) brand all-purpose flour were used not only to improve the structural integrity and cohesiveness of the patties. These ingredients were selected based on their availability, as well as their reliability and results from preliminary trials. All the ingredients were purchased from local markets in Urbana-Champaign, IL, USA.

Preliminary Trials

Preliminary focus groups were conducted in the sensory facilities of the University of Illinois to evaluate and adjust sensory attributes such as texture and taste. Panelists participated in tasting different formulations of plant-based patties and provided feedback on flavor and textural characteristics. The methodology followed an open discussion format, and the main responses from consumers were recorded to guide the refinement of the formulations. The feedback obtained from these sessions supported the optimization of the final recipes used in the study.

For the formulation of the plant-based burger patties, the recipe proposed by Samard et al. (2021) was used as a reference, excluding all additives mentioned in the original formulation except

for salt. Based on this, the recipe was adapted to contain around 85% plant-based raw materials and 15% oil. However, during preliminary trials, some inconsistencies were observed in terms of texture, as the burgers made from both plant matrices lacked cohesiveness. Furthermore, the initial amount of salt used was insufficient to provide a comparable taste to beef (based on preliminary focus group panels). As part of the optimization process, several adjustments were made to the formulation, including increasing the salt content to enhance flavor and increasing the oil content to improve texture. However, even with the increased oil concentration, the desired improvement was not achieved compared to that of beef patties (based on preliminary focus panels), so a binding agent (flour) was incorporated, which enhanced the cohesiveness and resulted in a firmer burger structure.

Preparation of Burger Patties

The methods used to prepare the burger patties and their formulations were selected based on preliminary tests. Two types of plant-based burger patties were prepared using lentils and textured vegetable protein (TVP, derived from soy). These ingredients were selected due to their high protein content and their ability to provide a texture that resembles that of conventional meat patties (Chelladurai & Erkinbaev, 2020; Riaz, 2001). For lentil patties, lentils were boiled in water for 25 minutes to obtain soft grains. A water-to-lentil ratio of approximately 2.5:1 was applied based on preliminary trials to ensure adequate hydration without excessive residual moisture. After boiling, lentils were passed through a sieve and left to rest for 20 minutes, then they were blended using a Proctor Silex® brand immersion blender and mixed with salt, all-purpose flour, and canola oil (Table 1) until the mixture was well-combined but still had a granular texture.

In the case of TVP burger patties, textured vegetable protein was used as the main ingredient. TVP was hydrated with boiling water in a bowl for 25 minutes; after hydration, it was passed through a sieve and squeezed until the excess water was removed. Subsequently, TVP was mixed with salt, all-purpose flour, and canola oil (Table 1) until all the ingredients were integrated. For the preparation of

animal-based burger patties (control group), ground beef was mixed with salt until a homogeneous mixture was obtained. The composition of individual 110 g patties is presented in Table 1.

Table 1

Composition of individual 110 g burger patties.

Ingredients (%)	Treatments		
	Ground beef burger patty (%)	Lentil burger patty (%)	TVP burger patty (%)
Ground beef	99.73	-	-
Lentils**	-	72.45	-
TVP*	-	-	72.45
Canola oil	-	18.18	18.18
Flour	-	9.09	9.09
Salt	0.27	0.27	0.27
TOTAL	100	100	100

Note. TVP= Textured Vegetable Protein; *TVP was already hydrated before incorporation; **Lentils were already cooked before

incorporation

All the mixtures were subjected to a molding process. They were placed into a non-stick HOULIME brand burger press and molded to achieve a uniform and desirable shape. Finally, burger patties were frozen at -18 °C for at least one day before being cooked in order to retain their quality (Rajaretnam & Malik, 2023).

Cooking Method

Burger patties were cooked in a PRESTO® brand electric griddle to control the temperature throughout the process. An internal temperature of 71 °C (160 °F) was used to ensure that they were properly cooked and to prevent microbial contamination (United States Department of Agriculture, 2020). For this purpose, a cooking time of 12 minutes (6 minutes per side) at 177 °C (350 °F) was used to reach the internal temperature of 71 °C for all patties.

Physicochemical Analysis

Physicochemical analyses were conducted on both the plant-based burger patties and the animal-based patties (control). Water activity (A_w), moisture content, color, and texture profile analysis (TPA) were measured after cooking. Shrinkage and cooking loss were evaluated by comparing the samples before and after cooking.

Water Activity Analysis

Water activity was determined using an HD-4B Smart Water Activity Meter (Measuring Instrument) with a WSC-4 water activity sensor. All the samples were ground in advance to be placed in the equipment's measuring sensor.

Moisture Content

A U.S. Solid moisture analyzer (5SS-HMA01) was used to assess the moisture content of the burger patties. All the samples were ground, and 1 gram of each was placed into the equipment.

Cooking Loss

The cooking loss (Eq. 1) was determined as the percentage of weight loss that occurred after cooking. This value was obtained by weighing the samples before and after cooking. To calculate this, the following equation was used:

$$\text{Cooking Loss (\%)} = \frac{\text{Initial Weight} - \text{Weight after cooking}}{\text{Initial Weight}} \times 100 \quad [1]$$

Where:

Initial Weight is the raw weight of the sample before cooking (g).

Weight after cooking is the final weight of the sample after the cooking process (g).

Shrinkage

The shrinkage (Eq. 2) of the patties was estimated by measuring the changes in their volume after cooking. Both diameter and height were measured using a 200 mm Digital Vernier Caliper Micrometer Gauge at three different and random points of each patty. The volume of the samples was calculated based on the following equation, assuming a cylindrical geometry:

$$\text{Volume} = \pi \times \frac{\text{Diameter}^2}{4} \times \text{Height} \quad [2]$$

Where:

π (pi) is a mathematical constant approximately equal to 3.1416.

Diameter is the straight-line distance across the circular base of the patty (cm).

Height is the thickness of the patty measured vertically (cm).

Finally, the percentage of shrinkage was calculated using the following equation (Eq. 3):

$$\text{Shrinkage (\%)} = \frac{\text{Initial Volume} - \text{Final Volume}}{\text{Initial Volume}} \times 100 \quad [3]$$

Where:

Initial Volume is the volume of the patty before cooking (cm³).

Final Volume is the volume of the patty after cooking (cm³).

Color Analysis

Color analysis was performed using a precise color reader (WR-10). For this test, L*, a*, and b* values were measured. The L* value (lightness) operates on a scale from 0 to 100, with 0 representing black and 100 representing white. Likewise, the a* and b* values represent chromaticity, where positive and negative a* values correspond to red and green, respectively, and positive b* values are toward the yellow, and negative b* values correspond to blue color.

Texture Profile Analysis

Texture analysis was evaluated using a double compression test performed with a TA.HDplus Texture Analyzer (Stable Micro Systems brand) equipped with a 50 mm diameter probe. The measurements were conducted according to the methodology described by Vu et al. (2022). Samples were prepared by cutting them into 1 cm × 1 cm × 1 cm cubes to get uniform geometries. Subsequently, they were placed in the measurement cell of the instrument and subjected to two cycles of compression/decompression at a fixed speed of 2.00 mm/s. The test parameters included a final strain of 50%, a trigger force of 15.0 g, and an interval of 5 seconds between compressions.

Proximal Analysis

Proximal analyses were carried out on both the plant-based burger patties and the animal-based patties (control) after cooking.

Protein Content

Protein content was determined using the AOCS Method PROTEIN-COMBUSTION (NX6.25), where total nitrogen was measured and multiplied by a conversion factor of 6.25 to estimate the

protein content. The analysis followed the AOCS Ba4e-93 procedure, using a LECO FP828 unit that measures nitrogen by combustion. The furnace operated at 950 °C to ensure complete sample combustion (AOCS, 1998).

Total Fat

Fat content was determined using the AOCS Method OIL/FAT-ETHER EXTRACT, where fats and oils were extracted from the sample using an ether solvent, and the remaining fat was weighed to calculate its percentage. For this analysis, the AOCS Method Am 5-04 was followed, using an Ankom XT15 extractor set to operate at 90 °C for 100 minutes, with petroleum ether as the extraction solvent (AOCS, 1998).

Experimental Design & Statistical Analysis

Physicochemical analysis were performed in all treatments. For each treatment, three repetitions were taken. The analyses included the following parameters: fat, protein, water activity (aw), moisture, color, shrinkage, cooking loss, hardness, springiness, and compression rate. A Randomized Complete Block Design (RCBD) was employed to assess differences in physicochemical parameters and nutritional content among treatments, with a significance level of $P < 0.05$. A Shapiro-Wilk normality test was conducted to test the normal distribution of the data. For those results that exhibited a normal distribution, an ANOVA was applied, while for those that were not normal, the Kruskal-Wallis test was used. Additionally, a post-hoc Tukey test for multiple means comparison was conducted to identify individual differences. Finally, Pearson correlation analysis was conducted to explore the potential linear relationships between the main parameters evaluated in this study.

Results and Discussion

Physicochemical Analysis

Water Activity Analysis (Aw)

Water activity is a parameter that describes the amount of free water available for chemical reactions and microbial growth in food matrices and is, therefore, a key factor in the determination of the shelf life of food (Syamaladevi et al., 2016). Moreover, water activity is considered a critical boundary for evaluating the microbiological and physicochemical properties of food products (Barbosa-Cánovas et al., 2020). According to the results presented in Table 2, all the treatments exhibited Aw values above 0.95, which indicates a high availability of free water and susceptibility to microbial growth (U.S Food & Drug Administration, 2014).

Statistical analysis revealed significant differences between ground beef and lentil patties; however, differences between ground beef and TVP patties, and between TVP and lentil patties, were not statistically significant. These results are consistent compared to other studies that have shown that values for water activity of plant-based burger patties ranged from 0.978 to 0.982 (Ardila et al., 2023), and for ground beef patties were around 0.992 (Li et al., 2017). On the other hand, the ANOVA results indicate that the type of burger patty (treatments with different formulations) had a statistically significant effect on Aw ($F = 5.43$; $p = 0.02$), which confirms that the differences in these parameter values are driven by the raw materials.

Table 2

Water activity analysis results of plant-based and animal-based patties.

Treatment	Water Activity
Ground beef burger patty	0.982±0.004 ^a
Lentil burger patty	0.972±0.006 ^b
TVP burger patty	0.979±0.005 ^{ab}
CV (%)	0.62

Note. TVP= Texture Vegetable Protein; a-b= means with different letters are statistically different ($P \leq 0.05$); C.V(%) = Coefficient of variation

Moisture Content

Moisture content is a key factor in food materials, as it influences shrinkage or expansion during the drying process. It refers to the total amount of water in a sample, expressed on a wet or dry weight basis (Joardder et al., 2019). This parameter directly influences the physical structure, sensory properties, and stability of food products. In Table 3, the results for moisture content are shown. According to statistical analysis, significant differences ($p < 0.05$) were found among all treatments; ground beef patties exhibited the highest moisture content, followed by TVP patties, while lentil patties had the lowest value.

These variations can be attributed primarily to the composition and structure of the raw ingredients. Beef naturally contains a high proportion of muscle fibers, fat, and structural proteins such as actin and myosin. These proteins form a complex matrix that retains water through both capillary action and polar interactions, allowing for greater water retention (Zielbauer et al., 2016). Although some moisture is lost during cooking due to protein denaturation and structural shrinkage, the inherent capacity of muscle tissue to bind water enables ground beef patties to maintain higher moisture levels than plant-based alternatives. In the case of Textured vegetable protein (TVP), derived from soy, it can form fibrous, meat-like textures through extrusion (Baune et al., 2022). During this process, proteins denature and align into porous structures that enhance water absorption during rehydration. However, because soy lacks the organized fiber network found in meat, the absorbed water is not as tightly bound. As a result, despite its good hydration capacity, soy-based TVP tends to show moderate moisture retention after cooking (Hong et al., 2022).

Finally, lentil burger patties exhibited the lowest moisture content, likely due to their low fat and protein content and high levels of starch and dietary fiber compared to ground beef and soy-based TVP (Jarpa-Parra, 2018). These compositional differences limit the water-binding capacity of lentils, as their proteins are less functional in hydration.

The ANOVA also indicated that the type of formulation had a significant effect on moisture ($F = 173.88$, $p < 0.01$), suggesting that the observed variations are primarily attributable to the intrinsic properties of the raw materials.

Table 3

Moisture content results of plant-based and animal-based patties.

Treatment	Moisture (%)
Ground beef burger patty	47.78±2.44 ^a
Lentil burger patty	37.83±1.41 ^c
TVP burger patty	43.38±1.16 ^b
CV (%)	2.63

Note. TVP= Texture Vegetable Protein; a-c= means with different letters are statistically different ($P \leq 0.05$); C.V(%) = Coefficient of variation

Cooking Loss

Cooking loss is an essential attribute of meat quality and is used to evaluate its water-holding capacity; this parameter is expressed as the percentage of weight lost in meat while cooking (Pang et al., 2020). To obtain this value, samples were weighed before and after cooking. According to statistical analysis, this attribute was significantly affected by the type of burger patty ($F=159.30$, $p < 0.01$). As indicated in Table 4, there were no significant differences between the two types of plant-based burger patties. However, both were different from the control (animal-based), which was the treatment that obtained the highest percentage of cooking loss, with 28.48% (mainly moisture and fat). This result is consistent with other studies, which have shown that the percentage of weight loss for beef patties cooked at 70 °C ranged from 29 to 32% (Vaskoska et al., 2020).

In meat, thermal processes induce protein denaturation, which alters the interactions between proteins and water, along with structural changes. Those changes affect the spacing between muscle fibers and create pressure gradients, impacting their water-holding capacity, leading to water loss (Zielbauer et al., 2016). Moreover, although the main objective of adding salt was to enhance sensory properties, its functional role may also be linked to this behavior. As explained by Rysová & Šmídová (2021), sodium chloride increases the solubility of myofibrillar proteins such as actin and

myosin, which, upon heating, form strong gels but also promote the expulsion of water from the muscle fibers. This mechanism may explain why beef patties, which contain a high proportion of these proteins, exhibited greater cooking loss compared to the plant-based patties. In contrast, lentils and soy contain starch with the ability to absorb and retain water, a property that contributes to the lower cooking loss observed in plant-based patties (Jarpa-Parra, 2018).

In addition, for textured vegetable protein (TVP), the extrusion cooking process thermally denatures the protein with a series of unfolding and aggregation, which leads to a significant reduction in its solubility; thereby, TVP presents lower solubility than its native form (Hong et al., 2022). In general, for plant-based burgers, their protein structure does not collapse during heating since the proteins have already been denatured by previous procedures. This affirmation is supported by Vu et al. (2022) who obtained similar results.

Table 4

Cooking loss results of plant-based and animal-based patties.

Treatment	Cooking Loss (%)
Ground beef burger patty	28.48±2.10 ^a
Lentil burger patty	6.66±1.05 ^b
TVP burger patty	8.48±1.05 ^b
CV (%)	11.42

Note. TVP= Texture Vegetable Protein; a-b= means with different letters are statistically different ($P \leq 0.05$); C.V(%) = Coefficient of variation

Shrinkage

Dimensional shrinkage during cooking is a critical parameter in both animal-based and plant-based patties, as it reflects their ability to retain their shape and structure during cooking. The shrinkage of a food product is expressed as the change in volume of food material due to water loss during dehydration (Parthasarathi & Anandharamakrishnan, 2014). In this sense, these structural changes might influence consumer perception, particularly regarding size, texture, and juiciness.

The dimensional measurements before and after cooking are shown in Table 5, while the corresponding percentage shrinkage values for height, area, and volume are presented in Table 6.

In this study, ground beef burger patties exhibit the greatest reduction in area and volume with 47.10% and 19.79%, respectively, indicating a significant contraction during cooking. These reductions were statistically different from the two types of plant-based patties ($P < 0.01$). This high contraction could be attributed to protein denaturation, structural changes, moisture loss, and fat drainage during cooking (Hong et al., 2022). These results are aligned with findings by Zielbauer et al. (2016), who reported that thermal processing causes protein denaturation in meat, reducing water-holding capacity and leading to muscle fiber contraction.

In the case of plant-based burger patties, both presented lower dimensional reduction compared to the control treatment, maintaining more stable structures after cooking. Notably, lentil patties slightly decreased their surface area and volume by 1.23% and 4.06%, respectively, which is consistent with their low cooking loss. Similarly, TVP burger patties also showed moderate decreases in shrinkage parameters with reductions of 5.86% in surface area and 23.55% in volume. These reductions, despite a loss of only 8.88% of fluids, can be attributed to the lower apparent density of TVP. A greater initial mass to reach the target weight of 110 g was needed for this ingredient; as noted, an increase in expansion generally results in a decrease in apparent density (Lyu et al., 2023). This initial expansion during hydration and the compression of the internal matrix during cooking contribute to this significant decrease in observed volume.

In addition, the ANOVA indicated that the type of burger patty (treatments with different formulation) had a significant effect on all shrinkage parameters, which confirms that the differences in these values are driven by the raw materials.

Table 5

Shrinkage results of plant-based and animal-based patties.

Treatment	Shrinkage					
	Before Cooking			After Cooking		
	Height (cm)	Area (cm ²)	Volume (cm ³)	Height (cm)	Area (cm ²)	Volume (cm ³)
Ground beef burger patty	1.31±0.11 ^b	86.88±2.53 ^a	114.40±10.87 ^b	1.98±0.08 ^a	45.92±1.54 ^c	91.01±4.54 ^b
Lentil burger patty	1.24±0.06 ^b	87.34±1.03 ^a	108.88±5.82 ^b	1.20±0.04 ^b	86.25±1.04 ^a	104.22±4.16 ^a
TVP burger patty	1.55±0.11 ^a	89.13±2.82 ^a	138.97±12.89 ^a	1.26±0.05 ^b	83.83±2.36 ^b	105.80±5.67 ^a
CV (%)	8.27	2.50	9.51	4.60	2.62	5.39

Note. TVP= Texture Vegetable Protein; a-c= means in same column with different letters are statistically different ($P \leq 0.05$); C.V(%) = Coefficient of variation

Table 6

Percentage shrinkage (height, area, and volume reduction) of plant-based and animal-based patties.

Treatment	Height reduction (%)	Area reduction (%)	Volume reduction (%)
Ground beef burger patty	-51.53±13.91 ^a	47.10±2.41 ^a	19.79±8.48 ^a
Lentil burger patty	2.92±4.35 ^c	1.23±2.05 ^c	4.06±5.89 ^b
TVP burger patty	18.73±4.74 ^b	5.86±2.05 ^b	23.55±4.55 ^a
P Value	<.0001	<.0001	0.0002

Note. TVP= Texture Vegetable Protein; a-c= means with different letters are statistically different ($P \leq 0.05$)

Color Analysis

As stated by (Wrolstad & Smith, 2017), among the main attributes that determine food acceptance, color often presents a stronger influence in consumer perception than expected. Color is defined as the sensation produced when radiant energy within the visible spectrum (370-770 nm) reaches the retina of the eye (Berns, 2019); and it is frequently used as an indicator of food overall quality, including factors such as flavor, safety, and nutritional value (Imchen & Singh, 2023).

According to the ANOVA results, the L* values, which means “lightness”, were significantly affected by the type of burger patties (treatments with different formulations) that were used ($F=1804.70$, $p<0.01$). As shown in Table 7, there were significant differences among all the treatments; however, all of them presented low luminosity, indicating darker colors. On the other hand, TVP

burger patties had the highest L* value, indicating that they have a lighter color when compared to the other treatments.

Similarly, the a* values, where positive and negative values correspond to red and green, respectively, were significantly affected by the type of burger patty (F=13.51, p=0.001). Among treatments, all of them presented positive values, ranging from 6.47 to 8.59, meaning a tendency towards redness. Also, for the a* values, there were no significant differences between the two types of plant-based burger patties. Nevertheless, both were different from the control, which had the lowest value.

Finally, for the b* values, where positive values are towards the yellow color and negative values correspond to blue color, there were significant differences among treatments; however, all of them exhibited positive values, ranging from 7.97 to 27.81, indicating a tendency towards yellowness. TVP burger patty presented the highest b* value with 27.81. Additionally, the b* values were significantly affected by the type of burger patty (F=3245.96, p<0.01).

Table 7

Color analysis results of plant-based and animal-based patties.

Treatment	L*	a*	b*
Ground beef burger patty	18.83±0.57 ^c	6.46±0.94 ^b	7.97±0.74 ^c
Lentil burger patty	34.11±1.11 ^b	8.15±0.93 ^a	25.51±0.83 ^b
TVP burger patty	43.83±0.87 ^a	8.59±0.77 ^a	27.81±0.89 ^a
CV (%)	2.75	11.83	2.79

Note. TVP= Texture Vegetable Protein; a-c= means in the same column with different letters are statistically different (P ≤ 0.05); C.V(%) =

Coefficient of variation

Texture Profile Analysis

Texture is one of the attributes used by consumers to evaluate food quality, playing an important role in the liking of a product (Day & Golding, 2016). In this context, TPA helps in the characterization of foods and their influence in individuals with compromised oral function (Peleg, 2019). For this analysis, three rheological properties were assessed, including hardness, springiness, and compression rate.

Hardness

Hardness was measured by the first force peak achieved by the sample. As revealed in Table 8, there were no significant differences between the two types of plant-based burger patties, which presented the lowest values. Conversely, both were different from the control. As mentioned, the structure of plant-based protein sources did not collapse during heating, as the proteins were already denatured prior to cooking; thus, the cooking process had less impact on this parameter. Furthermore, the low loss of fluids during the thermal process led to fewer changes in the texture attributes.

In contrast, the ground beef burger patty showed a high peak force of 23.3 N; this result might be attributed to the denaturation of proteins, especially of actin and myosin, that occurred during the heating process, leading to the expulsion of fluids and shrinkage of the product's structure. This structural contraction increases the density of the protein matrix, reduces water-holding capacity, and results in a firmer, more compact texture, thereby contributing to the observed increase in hardness (Vu et al., 2022; Yu et al., 2017). Furthermore, although salt was primarily added for taste, it may have contributed to firmness by enhancing protein solubilization and gel formation upon heating, which reinforces the internal structure (Rysová & Šmídová, 2021).

Also, non-parametric statistical analysis (Kruskal-Wallis test) reflected that the type of burger patty had a statistically significant effect on this parameter ($\chi^2 = 17.36$, $p = 0.0002$).

Table 8

Hardness results of plant-based and animal-based patties.

Treatment	Hardness (N)
Ground beef burger patty	23.30±3.14 ^a
Lentil burger patty	5.24±0.86 ^b
TVP burger patty	5.25±0.92 ^b
P Value	0.0002

Note. TVP= Texture Vegetable Protein; a-c= means with different letters are statistically different ($P \leq 0.05$)

Springiness

As established by (Szczesniak, 2002), “Springiness is the rate at which a deformed material goes back to its undeformed condition after the deforming force is removed”. In this context, this parameter is essential for assessing the texture of different food products. In Table 9, the results for springiness values on a scale of 0 to 1 are shown. According to the ANOVA results, there were significant differences among all the treatments. In this case, the animal-based burger patty presented the highest springiness value with 0.93, indicating that it had the greatest ability to recover its original shape after deformation, which is related to having a firmer and more elastic texture. This result can be explained by the denaturation of proteins, especially of actin and myosin, during the cooking process, known for forming elastic gels, contributing, in this way, to its firm and springy texture (Tornberg, 2005).

On the other hand, the lentil patty had the lowest springiness value, which is associated with its softer texture. Similarly, for the TVP burger patty, an intermediate value was obtained; however, even though its extruded structure offers better texture attributes over lentils, it lacks certain characteristics of meat proteins, such as their thermic responses. In addition, both plant-based patty structures were already denatured before cooking, causing minimal changes and limiting their elasticity (Vu et al., 2022).

Furthermore, the statistical analysis indicated that the type of burger patty had a significant effect on this parameter ($F=86.22$, $p<0.01$).

Table 9

Springiness results of plant-based and animal-based patties.

Treatment	Springiness (%)
Ground beef burger patty	0.93±0.01 ^a
Lentil burger patty	0.81±0.03 ^c
TVP burger patty	0.84±0.02 ^b
CV (%)	2.78

Note. TVP= Texture Vegetable Protein; a-c= means with different letters are statistically different ($P \leq 0.05$); C.V(%) = Coefficient of

variation; Springiness values range from 0 to 1

Compression Rate

Compression rate is represented by the percentage reduction in a food sample's height when it is compressed under a specific force and is considered a key parameter in food texture analysis. In this study, the differences in compression rates among animal and plant-based burger patties were statistically significant ($P < 0.05$), indicating that the type of burger patty, which had different protein sources, significantly affected this boundary ($F=22.67$, $p<0.01$).

In table 10, the results showed that ground beef patties exhibited the highest value with 83.97%, meaning a greater firmness than that of plant-based alternatives. As discussed earlier, the denaturation and aggregation of muscle proteins during the thermal process led to a tighter and more cohesive structure that resists deformation (Zielbauer et al., 2016). In contrast, lentil and TVP patties, with 70.31% and 69.63% respectively, exhibited statistically similar values to each other, but both were lower than their animal counterpart. It can be attributed to the previous denaturation of the protein sources, causing them to unfold and aggregate correctly into new configurations. Consequently, the final products (burger patties) tended to present a less cohesive structure and become more susceptible to deformation under compressive forces (Hong et al., 2022; Vu et al., 2022).

Table 10

Compression rate results of plant-based and animal-based patties.

Treatment	Compression Rate (%)
Ground beef burger patty	82.97±4.79 ^a
Lentil burger patty	70.31±5.73 ^b
TVP burger patty	69.63±4.10 ^b
CV (%)	6.37

Note. TVP= Texture Vegetable Protein; a-b= means with different letters are statistically different ($P \leq 0.05$); C.V(%) = Coefficient of variation

Proximal Analysis

Proximate analysis is a fundamental tool in food science used to determine the macronutrient composition of food products. These parameters are essential for evaluating the nutritional value and

overall quality of foods; in this way, monitoring these components allows for the comparison of formulations and assessment of how closely plant-based products resemble traditional animal-based foods in nutritional terms. For this analysis, two macronutrients were assessed: total protein and total fat.

Total Fat

Fat is a crucial macronutrient that serves as a dense energy source (9 kcal/g), supplies essential fatty acids like omega-3 and omega-6, and supports the absorption of fat-soluble vitamins A, D, E, and K (Espinosa-Salas & Gonzalez-Arias, 2023). Furthermore, it enhances texture, flavor, and juiciness, influencing consumer acceptance. In Table 11, statistically significant differences were found in fat content among the burger formulations ($F = 17.12$; $p = 0.0109$). Tukey's HSD test showed that the TVP burger had significantly lower fat content compared to the lentil and beef patties, which did not differ from each other. These outcomes suggest that the variation in fat content is primarily associated with the type of formulation used.

Although beef naturally contains fat due to intramuscular adipose tissue, canola oil was incorporated into the plant-based formulations as a strategy to mimic the fat levels of beef. In the case of the TVP burger, its lower fat value may be linked to its lower oil absorption capacity, which limits the amount of fat retained during formulation. This behavior has been previously reported by (Samard & Ryu, 2019) in various textured vegetable protein systems.

Table 11

Fat content results of plant-based and animal-based patties.

Treatment	Fat (g/100 g)
Ground beef burger patty	17.51±0.35 ^a
Lentil burger patty	18.07±1.01 ^a
TVP burger patty	15.69±0.02 ^b
CV (%)	3.04

Note. TVP= Texture Vegetable Protein; g/100 g in wet-based; a-b= means with different letters are statistically different ($P \leq 0.05$); C.V(%)

= Coefficient of variation

Total Protein

Protein is an essential macronutrient for human health, and it is required for numerous physiological functions, including muscle development, enzymatic functions, and overall metabolic regulation (Wu, 2016). According to the data shown in Table 12, the ground beef burger patty exhibited the highest protein content, which is consistent with its origin, as meat is known for its high-quality protein with complete amino acid profiles and excellent digestibility (Geiker et al., 2021).

In contrast, the protein levels in the plant-based formulations were significantly lower than in the animal-based patties, which can be attributed to differences in the composition of the raw materials. Regarding TVP burger patties, they exhibited intermediate protein levels. This result is consistent with the nutritional profile of soy, which contains all essential amino acids, making it one of the few plant-based proteins considered complete (Thrane et al., 2017); although its digestibility is slightly lower than that of animal proteins, soy still offers a high protein density and favorable amino acid profile, especially when processed into TVP. These findings align with (Biazotto et al., 2025), who reported that soy-based burgers presented protein contents ranging from 12 to 13 g/100 g, confirming their role as a valuable protein source in plant-based meat analogs. Similarly, lentil patties had the lowest protein content among treatments. While lentils are recognized as a valuable source of plant-based protein, their overall protein concentration is lower compared to soy.

Table 12

Protein content results of plant-based and animal-based patties.

Treatment	Protein (g/100 g)
Ground beef burger patty	17.70±0.45 ^a
Lentil burger patty	10.58±0.62 ^c
TVP burger patty	12.93±0.40 ^b
CV (%)	0.94

Note. TVP= Texture Vegetable Protein; g/100 g in wet-based; a-c= means with different letters are statistically different ($P \leq 0.05$); C.V(%) =

Coefficient of variation

Correlation Analysis

Pearson correlation analysis was conducted to explore the linear relationships among the various physicochemical, proximal, and textural parameters of the burger patties. Statistically significant correlations were observed across several key parameters, underscoring the interplay between ingredient composition and the final product characteristics (Table 13). A strong positive correlation was found between protein content and moisture, suggesting that patties with higher protein concentrations retained more moisture. This result supports the idea that proteins, especially structural ones such as actin and myosin in meat or soy proteins in TVP, can effectively bind and retain water (Hong et al., 2022; Zielbauer et al., 2016). Furthermore, protein content was positively correlated with cooking loss, indicating that high-protein samples experienced greater fluid loss during cooking. This relationship is explained by the contraction of the protein network under heat, which expels moisture and fat (Zielbauer et al., 2016). In addition, protein content showed a strong positive correlation with hardness, meaning that higher protein density contributes to firmer textures.

In terms of moisture, it was positively correlated with several other parameters, including cooking loss, shrinkage, and compression rate. These results suggest that higher moisture content leads to greater fluid loss and volume reduction during cooking, as well as an increased tendency for the patties to deform under compression. Regarding texture attributes, springiness and hardness exhibited a strong positive correlation, highlighting the cohesive nature of firmer matrices. Compression rate, another indicator of textural resistance, also showed a high correlation with hardness and cooking loss, suggesting that patties losing more fluids during cooking tend to develop firmer structures that are more resistant to deformation.

Additionally, water activity (A_w), typically discussed in terms of microbial safety, showed significant positive correlations with protein, moisture, and shrinkage. These findings suggest that A_w is not only a microbiological parameter but also reflects the functional availability of water for structural transformations. Higher A_w may increase the susceptibility of patties to moisture loss and

dimensional reduction during thermal processing, especially when the protein matrix is less capable of binding water (Barbosa-Cánovas et al., 2020; Syamaladevi et al., 2016). Furthermore, the compression rate emerged as an integrative texture parameter, strongly correlated with protein, moisture, cooking loss, hardness, and springiness. These associations indicate that patties with higher moisture and protein content, particularly animal-based, tend to experience more severe contraction during cooking, resulting in denser matrices that resist compression.

Finally, these interrelations reflect a functional chain in which protein content appears to influence A_w and cooking loss, which in turn affect key texture attributes like hardness, elasticity, and compressibility. This is particularly evident in the ground beef patties, which showed the highest values in these parameters. The observed correlations align with known mechanisms of protein denaturation and matrix contraction under heat, supporting the idea that the structural changes occurring in formulations with higher protein concentrations during cooking directly influence the final physicochemical and textural profile of the patties (Vu et al., 2022; Zielbauer et al., 2016).

Table 13

Pearson correlation analysis of physicochemical, proximal, and textural parameters of plant-based and animal-based patties.

	Parameters	Pearson's r	p-value
Protein	Moisture	0.938	0.0002
Protein	A_w	0.768	0.0156
Protein	Cooking loss	0.953	<0.0001
Protein	Springiness	0.753	0.0191
Protein	Hardness	0.937	0.0002
Protein	Compression rate	0.838	0.0047
Moisture	A_w	0.703	0.0344
Moisture	Cooking loss	0.859	0.0030
Moisture	Shrinkage	0.671	0.0477
Moisture	Hardness	0.813	0.0077
Moisture	Compression rate	0.704	0.0340
A_w	Shrinkage	0.685	0.0414
Cooking loss	Springiness	0.877	0.0019
Cooking loss	Hardness	0.987	<0.0001
Cooking loss	Compression rate	0.875	0.0020

	Parameters	Pearson's r	p-value
Springiness	Hardness	0.907	0.0007
Springiness	Compression rate	0.673	0.0467
Hardness	Compression rate	0.868	0.0024

Note. Pearson's correlation coefficients (r) between physicochemical and textural parameters. Statistically significant correlations

($p < 0.05$). Positive values indicate direct relationships.

Conclusions

Plant-based patties made from lentils and textured vegetable protein (TVP) were successfully formulated using simple, accessible ingredients. Preliminary trials allowed improvements in texture and structure, particularly through the incorporation of flour and adjustments in oil and salt content. These modifications resulted in patties with acceptable consistency and cohesion for cooking and analysis. In terms of nutritional composition, ground beef patties exhibited the highest protein content, while TVP patties presented intermediate levels and lentil patties the lowest. Although both plant-based alternatives had lower protein values compared to meat, lentil patties reached fat content comparable to beef, mainly due to the addition of canola oil. TVP patties, on the other hand, contained slightly more protein than lentils but had lower fat values, resulting in a different nutritional profile.

Physicochemical and textural analyses revealed that beef patties retained more moisture before cooking but experienced greater fluid loss, shrinkage, and firmness after cooking due to protein denaturation. Plant-based patties, especially those made with lentils, maintained more stable structures and showed lower cooking loss, but were also softer and less elastic. Correlation analysis confirmed strong associations between protein content, moisture, texture, and cooking loss, indicating that protein concentration plays a central role in shaping the structural behavior of burger patties. Overall, beef patties maintained superior structural and textural properties, but, the plant-based formulations exhibited promising characteristics, especially those incorporating soy-derived ingredients. Their performance demonstrates the feasibility of developing plant-based meat analogs with acceptable nutritional value and functional quality, provided that appropriate formulation strategies are applied.

Recommendations

A microbiological analysis with repeated measures over time is recommended before conducting sensory evaluations, both for beef patties and plant-based patties, in order to ensure food safety during storage and testing.

A sensory analysis is recommended for future research to assess the acceptability of plant-based patties in comparison to their animal-based counterparts. By evaluating attributes such as taste, texture, and overall satisfaction, among others, a clearer understanding of consumer perception can be obtained. Additionally, the implementation of satiety tests is encouraged to determine whether differences in composition influence the feeling of fullness after consumption. This would allow the nutritional and functional impact of these formulations to be more comprehensively evaluated. Further research should be directed toward the inclusion of alternative plant-based protein sources such as chickpeas, peas, or quinoa. These ingredients may contribute to more diverse and nutritionally balanced formulations. Moreover, the incorporation of natural binders or structuring agents should be investigated to improve texture, water retention, and overall product stability, with the aim of enhancing the physicochemical performance of plant-based patties to more closely resemble that of animal-based counterparts.

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Appendices

Appendices A

Correlation analysis

Coeficientes de correlación Pearson, N = 9 Prob > r suponiendo H0: Rho=0									
	PROTEIN	FAT	MOISTURE	AW	COOKINGLOSS	SHRINKAGE	SPRINGINESS	HARDNESS	COMPRESSIONRATE
PROTEIN	1.00000 0.02432 0.9505	0.02432 0.9505	0.93857 0.0002	0.76829 0.0156	0.95302 <.0001	0.56471 0.1132	0.75324 0.0191	0.93774 0.0002	0.83869 0.0047
FAT	0.02432 0.9505	1.00000	-0.21049 0.5867	-0.11728 0.7638	0.19237 0.6200	-0.70974 0.0322	0.55779 0.1186	0.28079 0.4642	0.08968 0.8185
MOISTURE	0.93857 0.0002	-0.21049 0.5867	1.00000	0.70369 0.0344	0.85905 0.0030	0.67134 0.0477	0.57302 0.1068	0.81312 0.0077	0.70469 0.0340
AW	0.76829 0.0156	-0.11728 0.7638	0.70369 0.0344	1.00000	0.58769 0.0961	0.68584 0.0414	0.41318 0.2690	0.56245 0.1149	0.47556 0.1957
COOKINGLOSS	0.95302 <.0001	0.19237 0.6200	0.85905 0.0030	0.58769 0.0961	1.00000	0.35271 0.3518	0.87747 0.0019	0.98730 <.0001	0.87527 0.0020
SHRINKAGE	0.56471 0.1132	-0.70974 0.0322	0.67134 0.0477	0.68584 0.0414	0.35271 0.3518	1.00000	0.04158 0.9154	0.31090 0.4155	0.30778 0.4204
SPRINGINESS	0.75324 0.0191	0.55779 0.1186	0.57302 0.1068	0.41318 0.2690	0.87747 0.0019	0.04158 0.9154	1.00000	0.90789 0.0007	0.67351 0.0467
HARDNESS	0.93774 0.0002	0.28079 0.4642	0.81312 0.0077	0.56245 0.1149	0.98730 <.0001	0.31090 0.4155	0.90789 0.0007	1.00000	0.86883 0.0024
COMPRESSIONRATE	0.83869 0.0047	0.08968 0.8185	0.70469 0.0340	0.47556 0.1957	0.87527 0.0020	0.30778 0.4204	0.67351 0.0467	0.86883 0.0024	1.00000