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QUALITY CHARACTERISATION AND CONSUMER PERCEPTION OF A NOVEL FUNCTIONAL BEEF SNACK ENRICHED WITH MACA (*LEPIDIUM MEYENII*)

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Abstract

Maca is a plant-based superfood that enjoys great popularity for its bioactive effects. Although the benefits of its use are well documented in peer-reviewed articles, studies on its addition to meat are extremely limited, with almost no research on adding the superfood maca to meat products. Considering the popularity of snacks among the younger generation, we thought to create such a food that represents a quick and healthy alternative to classic snacks by enriching beef with maca. This innovative alternative increases the antioxidant capacity of beef, providing a nutritious and attractive food for today's consumers. In order to evaluate the impact of maca in beef snacks, we made 3 batches, one without maca addition and 2 batches with 1 and 3% maca addition. These were subjected to detailed physico-chemical and sensory analyses to characterize the product in terms of quality and consumer acceptability. The addition of maca (Lepidium meyenii) to beef snacks resulted in a clear improvement in antioxidant capacity, with DPPH and ABTS inhibition values increasing progressively with the level of plant addition concentration. The maca samples exhibited a higher antioxidant capacity than the control (BSM0), with DPPH inhibition reaching up to 37.07 ± 0.13% (vs. 17.75 ± 0.23%) and ABTS up to 39.13 ± 0.15% (vs. 19.41 ± 0.11%) in the 3% maca batch, together with a significantly higher content of polyphenols and flavonoids. From a sensory point of view, the 1% maca batch (BSM1) maintained a very good acceptability, comparable to the control, with only minor changes in the sensory profile. The data obtained were statistically analyzed in order to identify significant differences and to determine the influence of maca concentration on the finished products.

Key words*: antioxidants, food innovation, functional meat products, sensory analysis, superfood.*

INTRODUCTION

Over the centuries, we have evolved in the way we look at food. In the beginning, people saw food as a way to get the energy and nutrients the body needed. As the science of nutrition progressed, it was later recognized as a way to promote healthy growth and development. Nowadays, food is also considered to play a significant role in preventing certain diet-related diseases (Pogorzelska-Nowicka et al., 2018).

The development of functional meat products that exhibit health benefits and possess improved overall quality have received much attention in recent years (Zhang et al., 2010). By reformulating food preparations with bioactive components, the aim is to improve the physiological activity of natural nutrients and meet consumer demand for the development of value-added products (Ciobotaru et al., 2024a).

First used in Japan in the mid-1980s, the phrase "functional foods" describes processed foods that include nutrients together with additives (natural or synthetic) that support certain physiological processes (Anchidin et al., 2024b).

A common and straightforward definition of "functional foods", despite the lack of a universally accepted definition, is "processed foods that have disease prevention and/or health-promoting benefits in addition to their nutritional value" (Arihara & Ohata, 2011).

Functional compounds are added to foods to enhance their nutritional value and possible health benefits. Enriching the original products with health-promoting elements is the foundation of the concept of producing foods with a greater beneficial influence on health.

It appears that animal products and meat are an excellent matrix for creating new products with improved value (Pogorzelska-Nowicka et al., 2018). Also, modern food processing involves the use of various food improvement agents (Zugravu et al., 2017).

In the most recent Statistical Yearbook on Food and Agriculture, the FAO reported that 360.618 million tons of meat were produced in 2022 compared to 231.912 million tons in 2000, this highlights a 55.5% increase in meat production over the last two decades (FAO, 2024). This is largely due to population and income growth (Gucianu et al., 2024), but also to the fact that in contemporary society, meat and animal products provide a certain type of culinary satisfaction (Ciobanu et al., 2024). The meat industry is one of the most important in the world and, due to strong consumer demand and intense rivalry, there is a continuous demand for new product development (Boișteanu et al., 2025). In addition to this aspect, we can also add the consumers' increased demand on the food they buy and consume (Pogurschi et al., 2018) which leads to the need to respond to their demands through innovation.

Because they include proteins with high biological value, fat-soluble vitamins, minerals, trace elements and bioactive substances, meat and meat products are both nutrient-rich and diverse (Manoliu et al., 2024) and are recognized as essential foods for human consumption (Boișteanu et al., 2023; Ciobanu et al., 2023a; Anchidin et al., 2024a; Flocea et al., 2024). They perform various biological functions in the human body (Manoliu et al., 2023) that are of great interest nowadays due to the increasing concern of people about the health benefits they possess (Anchidin et al., 2023). The increase in meat production and consumption is due, in addition to the need to provide food for a growing population, to its high nutritional and biological value, especially as a good source of complete protein, with meat traditionally associated with health and prosperity (Ciobanu et al., 2025; Ciobotaru et al., 2024b).

Among other bioactive substances, meat products are excellent suppliers of iron, zinc, conjugated linoleic acid (found mainly in ruminants) and B vitamins. One of the most nutrient-rich and prized foods is beef. The importance of beef as a source of micronutrients (such as vitamins A, B6, B12, D, E, iron, zinc and selenium) and high biological value protein is widely recognized (Scollan et al., 2006). Despite all these beneficial characteristics, meat and meat products are perishable products that need additives to prevent them from spoiling quickly. One of the main reasons why meat and meat products lose their quality is lipid oxidation (Gucianu et al., 2023). As a result of these processes, meat products lose some of their nutritional content and sensory appeal. The changes caused by oxidation can affect product safety (hazardous chemicals) or even consumer acceptance (changes in color and texture, as well as rancid taste and smell). Antioxidants are added in this context to delay or prevent the occurrence of these negative effects (Pateiro et al., 2021).

The addition of plant-based, antioxidant ingredients that may be beneficial to health could further improve the nutritional profile of meat products and reduce the risk of quality impairment. These products fall into the category of functional foods, which are foods with higher nutritional profiles than conventional products (Decker & Park, 2010). And the addition of natural and organic additives to enhance their quality would align with new market trends (Grigore et al., 2023). The use of natural ingredients for meat preservation and enhancement, such as antioxidants, vitamins, minerals or fibers derived from plants and plant materials with a high content of bioactive components (such as phenolic compounds), has gained in popularity among consumers (Karakaya et al., 2011). One such type of ingredient with demonstrated antioxidant activity is Maca (*Lepidium meyenii*) (Merzah, 2022).

Maca (*Lepidium meyeni; Lepidium peruvianum* is a synonym), probably cultivated on the high plateaus of the central Andes of Peru between 4000 and 1200 BC (Wang & Zhu, 2019) is used as a dietary supplement and for its health benefits. Different varieties of maca are available in a range of 13 colors, from black to yellow. Experimental research shows that maca has a positive impact on mood, memory, fertility and nutrition (Gonzales et al., 2009).

The edible part of the plant, the tuber, is highly nutritionally interesting compared to other root crops such as turnips, potatoes and carrots. The additional nutritional components of dried and preserved maca tubers are similar to those of the seeds and legumes (rice, maize and corn) of other plants. Maca is composed of 59% carbohydrates, 2% lipids and 10% protein (Dini et al., 1994). Maca is rich in fiber and other minerals such as iron, copper, and vitamin C. In addition to these vital nutrients, this root has bioactive components that help those trying to find a balanced diet (Peres et al., 2020). The presence of bioactive substances including glucosinolates and flavonoids in maca (*Lepidium meyenni*) flour has positive health effects. Antioxidants derived from maca can also be used to regulate enzymatic browning of fresh produce and prevent rancidity in high-fat diets (Cerrón-Mercado et al., 2022). It is one of the most therapeutic plants, rich in antioxidants that protect cells from mutations and damage caused by free radicals. In addition, it contains large amounts of vitamins and is very rich in flavonoids that protect against many diseases (Merzah, 2022). Research by Sandoval et al. (2002) showed that maca has the ability to scavenge free radicals, reduce peroxynitrite-induced cell death, and protect cells from hydrogen peroxide by maintaining intracellular ATP production. All these results suggest that maca may scavenge free radicals and provide cytoprotection against oxidative stress.

Due to its numerous purported health benefits and its prominent and ubiquitous biological functions, maca continues to be of significant practical and scientific importance (*Lepidium meyenii*), becoming a popular functional plant food (Wang & Zhu, 2019; Valentová & Ulrichová, 2003). On top of that, it has been used for centuries in the Central Andes of Peru and no adverse effects have been documented if ingested after boiling. Data from previous reviews of in vivo and in vitro experiments with maca indicate that its use is safe (Valerio & Gonzales, 2005). In the last 5 years, various developed countries in North America, Europe and Asia and beyond have shown interest through an increasing demand for maca (Sandoval et al., 2002) due to its chemical composition, pharmacological effects and positive effects on different metabolisms, with a high demand worldwide in recent times (Korkmaz et al., 2018).

The aim of this research was to develop and characterize a functional beef snack fortified with maca (*Lepidium meyenii*). The study evaluated the influence of the addition of maca at concentrations of 1 and 3% in meat products on the physico-chemical parameters, antioxidant capacity and sensory acceptability of the product, in comparison with a control product (without maca addition).

MATERIALS AND METHODS

For this study, three batches of beef products were manufactured: a control batch, without the addition of maca, and two batches with the addition of 1 and, respectively, 3% yellow maca root powder (*Lepidium meyenii*). These were made in the microproduction workshop for meat and meat products processing of IULS. The raw material was represented by beef leg and beef shoulder, which were purchased from Selgros Cash & Carry SRL in Iași, as well as by semolina flour from Molisana, which was purchased from a local store in Iași. The bioactive yellow maca root powder was purchased from the company Niavis (SC Bio Niavis Trade SRL, Brașov, Romania). The seasoning ingredients were purchased from a local company in Iași county (SC Rocas FDS SRL, Iași, Romania).

The experimental batches and the ingredients used in them are presented in Table 1, in percentage form.

Table 1. Formulation of the experimental batches

Batch code	Raw materials and ingredients (%)											
	Beef round	Beef chuck	Semola flour	Maca root powder	Salt	Sweet paprika	Smoked paprika	Garlic powder	Ground pepper	Onion powder	Ground cumin	Chili flakes
B1M0	53.52	34.05	9.73	-	1.40	0.30	0.20	0.30	0.20	0.20	0.07	0.03
B2M1	52.97	33.70	9.63	1.00								
B3M3	51.87	33.00	9.43	3.00								

B1M0 – control beef snack batch (without maca); B2M1 – beef snack batch with 1% maca; B3M3 – beef snack batch with 3% maca.

The technological process consisted of blending the raw materials and ingredients, coarse grinding, through the intermeid of the meat, followed by its fine grinding in the cutter. During this stage, the spice mixture specific to each batch and the semolina flour were added, according to Table 1. The resulting composition was introduced into the dosing machine, and by means of a syringe with a diameter of 18mm and a length of ~20 cm, the meat sticks/snacks with/or without the addition of maca were formed, which were placed on the stainless steel grill of the trolleys with racks, in order to perform the heat treatment.

The heat treatment was identical for all three batches and consisted of four stages, as follows: I. drying I of the samples for 30 minutes at 60°C; II. smoking at 70°C for 35 minutes; III. boiling the samples until reaching a temperature of 72°C in the thermal center; IV. second drying for 90 minutes at 75°C. After completing all stages of thermal treatment, the samples were placed in cold storage until cooled, after which they were vacuum packed and stored at 2-4°C for laboratory analysis.

The laboratory analyses carried out in this study consisted of physicochemical evaluations (pH, color parameters, textural parameters, protein content, fat, moisture, dry matter, ash, collagen), analyses of the content of bioactive compounds (antioxidant capacity), as well as sensory analysis. The pH measurements of the experimental batches were performed with the HI98163 pH meter with FC2323 electrode (SC Hanna Instruments SRL). The colorimetric analyses were performed using the Konica Minolta CR-410 colorimeter (Konica Minolta, Inc.) and consisted of the analysis of color parameters in the three-dimensional CIELAB space. Based on the data obtained from these parameters, the colorimetric parameters Hue (H°) and Croma (C*) were also calculated, using formulas (1), (2) and (3), according to the model of Salueña et al. (2019). The textural analysis of the samples was performed using the TA1+1K Plus texturometer (Ametek, Inc., USA), using a cylindrical probe specific to the TPA (Texture Profile Analysis) test, to evaluate the mechanical properties of the double compression type.

$$H^\circ = \arctan \frac{b^*}{a^*} \tag{1}$$

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \tag{2}$$

$$E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \tag{3}$$

Using the Food Check meat analyzer (Bruins Instruments GmbH, KPM Analytics), a flexible near-infrared (NIR) spectroscopic determination method, crude chemical determinations were used to investigate the quantitative analysis of moisture content, protein content, collagen, fat content and salt content.

To perform the antioxidant capacity of the targeted samples, the first stage consisted of the extraction of bioactive compounds. In order to perform this extraction of bioactive compounds from maca root powder and meat samples, one gram of sample was weighed and combined with 10 mL of solvent (70% ethanol). The mixture thus obtained was subjected to ultrasound treatment for 40 minutes, at a controlled temperature of 36 ± 2°C, with a frequency of 40 kHz. The resulting extract was subjected to centrifugation for 10 minutes at 6000 rpm and 10°C. The supernatant obtained after this stage was collected and used in the analyses for phytochemicals (carotenoids, flavonoids and polyphenols) and for the analyses related to antioxidant activity (DPPH and ABTS).

The Folin-Ciocalteu method was used to determine the total polyphenol content, as explained by Trifunschi et al. (2017).

The free radical scavenging activity was determined using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay in accordance to Trifunschi et al. (2022).

The ABTS assay was used concurrently according to the protocol described by Dumitrașcu et al. (2022).

The absorbance of the meat samples was measured using a UV-Vis spectrophotometer (Specord Plus 210, Analytik Jena, Germany). After vortex mixing, sampling was performed to ensure reproducibility. Flavonoid content was expressed as mg/g DW, polyphenol content as mg GAE/g DW, DPPH and ABTS radical scavenging activity as % inhibition, total carotenoids as mg CT/g DW, and lycopene and β-carotene as mg/g DW. All reagents and standards used for the antioxidant assays were

purchased from Sigma-Aldrich (Steinheim, Darmstadt, Germany).
In addition to all the objective analyses described above, sensory analysis of the samples was also performed (this represents a subjective analysis). This was performed on a panel of 20 semi-trained tasters (13 women and 7 men). We decided to perform this analysis because in the late 1990s, consumer acceptance was cited as the main success factor for functional foods and as the main area of interest for further studies. Numerous studies have demonstrated that consumer acceptance of functional foods is far from unconditional, taste being one of the main requirements for acceptability, in addition to the veracity of health claims (Verbeke et al., 2006). Sensory evaluation of foods involves analyzing consumer reactions based on the senses (smell, appearance, taste, touch and hearing) and has a great influence on the overall quality of the product (Ciobanu et al., 2023b). The analysis was performed 48 hours after the experimental batches were made. The analysis was performed blindly, the samples being coded with three random digits. In this case, the external PrefMap analysis was used, which is an advanced sensory analysis that works with multivariate data, establishing correlations between quantitative data of sensory attributes and consumer preferences (Boișteanu et al., 2025).
Each physico-chemical and biochemical determination was carried out in five independent replicates and the sensory analysis was conducted in a single tasting session.
The following software packages were used for statistical analysis: SPSS (v. 26, IBM Corp., USA) was employed to evaluate the significance of differences between the studied samples based on physicochemical parameters, while XLSTAT (v. 2024.3, Addinsoft, France), used during the free trial period, was applied for sensory analysis using the External Preference Mapping (PrefMap) method.

RESULTS AND DISCUSSIONS

The chemical parameters studied and the pH of the maca-added meat snack samples are presented in Table 2 (mean ± SD) compared to the control lot, which does not have maca (*Lepidium meyenii*) added. The statistical differences between the 3 groups were analyzed by their total (The global p-value considering all samples), as well as by their pairwise comparison (BSM0 vs. BSM1, BSM0 vs. BSM3, BSM1 vs. BSM3).
The average results of the physico-chemical parameters studied showed highly significant differences ($p < 0.01$) for fat, moisture and dry matter content and very highly significant ($p < 0.001$) for the other parameters analyzed (protein, collagen, salt, pH) at their total (global) level (among all the batches evaluated).
The fat content of the samples decreased progressively as the percentage of *Lepidium meyenii* increased, from a maximum of 22.7 ± 0.46% in BSM0 to 21.7 ± 0.22% in BSM3, the lot with 3% added maca (the highest concentration in our study). Although the differences between the BSM0 (control) and BSM1 (1% maca-added) groups were not statistically significant, the BSM3 (3% maca-added) group showed highly significant differences ($p = 0.003$) from the BSM0 group and significant differences (0.015) from the BSM1 group. This reduction in lipid content can be considered as positive, as they are in line with current consumer demands for reduced fat content in meat products, as the growing awareness of the link between diet and health has changed consumer preferences, so that there is an increasing demand for low-fat meat products (Colmenero, 2000).
The moisture content of the samples also showed highly significant decreases ($p = 0.006$) among all samples analyzed, which correlates with the increase in mean dry matter values in the maca fortified batches compared to the control batch, the differences between all of them highly significant ($p < 0.001$). As in the case of fat content, no significant differences ($p > 0.05$) between BSM0 vs BSM1, very highly significant ($p < 0.001$) between BSM0 and BSM3 and only significant ($p < 0.01$) between BSM1 and BSM3 were observed for moisture and dry matter content.
The results obtained for the moisture parameter are at odds with those observed by Cerrón-Mercado et al. (2022) who introduced maca into some burger samples via a gelled emulsion. The addition of maca to these led to an increase in moisture in both raw and cooked samples. The authors do not mention maca as the main factor that led to this increase in moisture, but the water

intake used to create the gel emulsions. However, Alarcón-García et al. (2020) state that maca has a high capacity to retain water in the system in which it is added, being able to reduce moisture losses. However, this effect was not observed in our study, probably due to the fact that maca was incorporated as a dry powder without being dispersed in an aqueous medium.
Protein and collagen contents were decreased by maca additions, with the highest levels of protein and collagen being identified in the control group at 17.26 ± 0.11% and 15.30 ± 0.10%, respectively. The lowest values were observed in the BSM3 group, being 16.26 ± 0.05% and 14.28 ± 0.15%, respectively, which differed very highly significantly ($p < 0.001$) from those of the BSM0 group. This reduction in the protein and collagen content of the samples can be attributed to the addition of maca, which is a plant food, with a low protein content compared to meat, which led to a reduction in the overall value of these two parameters. Between the 1% maca-added group (BSM1) and the control group (BSM0) the differences were significant ($p < 0.05$) for protein content and insignificant ($p = 0.169$) for collagen content. Differences overall (among all 3 samples studied) were very highly significant ($p < 0.001$) for these two parameters (protein and collagen).
Very highly significant differences ($p < 0.001$) in the mean values of the salt parameter were observed between the control sample (BSM0) and the maca samples (BSM1 and BSM3), which showed significant decreases with the addition of maca. However, the interaction between the two maca-added groups (BSM1 and BSM3) was non-significant ($p = 0.131$), indicating that the amount of maca added does not necessarily influence maca content and its presence in a food system.
Maca had a rather significant influence on the acidity of the samples, with very highly significant differences ($p < 0.001$) between all analyzed samples. The decrease in pH (increase in acidity of the samples with maca may be motivated by the acidic character of this plant (its aqueous extracts are acidic), since the soil for its growth must be rich in organic matter and acidic (Gonzales et al., 2009). Also, the acidity of the samples increases significantly ($p < 0.05$) with increasing maca addition, as observed by analyzing the differences between BSM1 and BSM3 plots (Table 2).

Table 2. Physicochemical characteristics of maca-enriched beef snacks

Maca-enriched beef snacks	Studied parameters						
	Fat (%)	Moisture (%)	Dry Matter (%)	Protein (%)	Collagen (%)	Salt (%)	pH
BSM0	22.7 ± 0.46	58.38 ± 0.20	41.62 ± 0.20	17.26 ± 0.11	15.30 ± 0.10	1.54 ± 0.05	6.45 ± 0.10
BSM1	22.48 ± 0.38	58.2 ± 0.43	41.8 ± 0.43	17.02 ± 0.16	14.94 ± 0.48	1.28 ± 0.08	6.23 ± 0.41
BSM3	21.7 ± 0.22	57.64 ± 0.21	42.36 ± 0.21	16.26 ± 0.05	14.28 ± 0.15	1.18 ± 0.08	6.09 ± 0.03
	p-value						
BSM0 vs. BSM1	0.627 ^{ns}	0.621 ^{ns}	0.621 ^{ns}	0.020 *	0.169 ^{ns}	0.000 ***	0.001 ***
BSM0 vs. BSM3	0.003 **	0.006 **	0.006 **	0.000 ***	0.000 ***	0.000 ***	0.000 ***
BSM1 vs. BSM3	0.015 *	0.030 *	0.030 *	0.000 ***	0.011 *	0.131 ^{ns}	0.014 *
The global *p*-value considering all samples	0.003 **	0.006 **	0.006 **	0.000 ***	0.001***	0.000***	0.000***

Levels of significance: ns – $p > 0.05$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
BSM0 – control batch of beef snacks in the form of sticks, without the addition of maca; BSM1 – batch of beef snacks in the form of sticks with the addition of 1% maca; BSM3 – batch of beef snacks in the form of sticks with the addition of 3% maca.

The CIELab, Chroma, Hue and ΔE values of beef snacks with added maca are showed very highly significant differences ($p = 0.000$) between all product batches analyzed (The global p-value) (Table 3).
The brightness of the samples with added maca (BSM1 and BSM3) showed very highly significant decreases ($p < 0.001$) in mean values compared to the control lot (BSM0), where the maximum brightness value was obtained, being 46.80 ± 0.65 and decreasing to 44.13 ± 0.24 in the lot with 3% added maca (BSM3).
The intensity of the red color, identified by the parameter a*, showed significant decreases both according to the presence of the addition and the amount of it, between all the studied batches

(both as a whole and separately - two by two), very highly significant differences were observed ($p < 0.001$). The decrease in the CIEa* values from 18.03 ± 0.37 in batch BSM0 to 15.26 ± 0.27 in batch BSM3 reflects a reduction in the red color of the samples, most probably due to the presence of bioactive pigment compounds (e.g. polyphenols, flavonoids, carotenes), as we will see in Table 5.

The mean value of CIEb* (yellow-blue component) decreased very highly significant ($p = 0.000$) from 18.47 ± 0.48 in the BSM0 group to 17.42 ± 0.16 in the BSM1 group. However, the value of b* increased again in the BSM3 batch to 18.13 ± 0.14, the differences between this batch and the control batch (BSM0) being insignificant ($p = 0.211$), and the differences between the BSM3 and BSM1 batches were highly significant ($p = 0.008$). These results indicate that the addition of a low amount of maca, 1%, leads to a decrease in the yellow tones of the meat, followed by a concomitant increase with the increase in maca concentration in the meat samples.

The hue angle (hº) peaked in the control group (BSM0) at 44.31 ± 0.47, decreasing successively to 42.86 ± 0.28 in BSM1 and to 40.09 ± 0.44 in BSM3, the lowest value obtained by any of the three groups studied. Also, the differences between all the samples analyzed, both by groups of samples (BSM0 vs. BSM1, BSM0 vs. BSM3, BSM1 vs. BSM3) and in their totality (BSM0-BSM1-BSM3), were highly significant ($p = 0.000$).

The color saturation (C*) decreased very highly significant ($p = 0.000$) in the maca fortified samples (BSM1 and BSM3) compared to the control (BSM0), suggesting a decrease in the color intensity of the samples.

This decrease in color intensity may be due to the denaturation of meat-specific hemin pigments or to interactions between these and the specific pigments of *Lepidium meyenii* used in our study.

The results for ΔE (Total color difference) obtained mean values of 3.22 ± 0.62 for BSM0-BSM1 comparison and 3.89 ± 0.84 for BSM0-BSM1 comparison.

These values indicate that the differences are subjectively, not just objectively, visible and are sensory perceived by consumers (https://zschuessler.github.io).

Table 3. CIE L, a, b*, Chroma, Hue and ΔE colorimetric values of meat snacks with added maca (*Lepidium meyenii*)

Meat samples	Colour parameters					
	L*	a*	b*	Hue angle (hº)	Croma (C*)	ΔE
BSM0	46.80 ± 0.65	18.03 ± 0.37	18.47 ± 0.48	44.31 ± 0.47	25.81 ± 0.56	-
BSM1	44.42 ± 0.48	16.16 ± 0.10	17.42 ± 0.16	42.86 ± 0.28	23.76 ± 0.15	3.22 ± 0.62
BSM3	44.13 ± 0.24	15.26 ± 0.27	18.13 ± 0.14	40.09 ± 0.44	23.70 ± 0.24	3.89 ± 0.84
			p-value			
BSM0 vs BSM1	0.000***	0.000***	0.000***	0.000***	0.000***	-
BSM0 vs BSM3	0.000***	0.000***	0.211^{ns}	0.000***	0.000***	-
BSM1 vs BSM3	0.626^{ns}	0.001***	0.008**	0.000***	0.959^{ns}	0.235^{ns}
The global *p*-value considering all samples	0.000***	0.000***	0.000***	0.000***	0.000***	-

Levels of significance: ns – $p > 0.05$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
BSM0 – control batch of beef snacks in the form of sticks, without the addition of maca; BSM1 – batch of beef snacks in the form of sticks with the addition of 1% maca; BSM3 – batch of beef snacks in the form of sticks with the addition of 3% maca.

The textural profile of the studied samples is presented in Table 4. The three analyzed samples can be observed in Table 4, and the influence of maca addition on the textural characteristics is evident. The addition of maca powder produced highly statistically significant changes in the parameters hardness, adhesiveness, elasticity and gumminess ($p < 0.001$), depending on the concentration used. The addition of maca powder (*Lepidium meyenii*) caused very highly significant ($p < 0.001$) changes in most textural parameters evaluated for beef snacks. The mean value of the textural parameter Hardness increased highly significantly ($p < 0.001$) with increasing maca concentration, from 26.35 ± 0.57 N in the control (BSM0) to 33.16 ± 1.52 N in the 1% maca (BSM1) and 36.66 ± 0.85 N in the 3% maca (BSM3). This increase indicates a progressive hardening of the product structure, most probably due to the decrease in product moisture content (Table 2) which is directly proportional to the increase in the concentration of added maca powder. Most likely, this

increase in the hardness of the samples is due to the high fiber content of the maca powders, which is more than 23% on a dry matter basis, as shown in the research of Chen et al. (2017).
Similarly, the adhesiveness showed highly significant differences ($p < 0.001$) between the studied batches, with an increase in mean values with increasing concentration of added maca powder, as in the case of the Hardness parameter, which may suggest a stickier texture of the batches with the added vegetable.
In terms of elasticity, a highly significant decrease was observed with increasing maca concentration (from 0.54 ± 0.02 in control to 0.39 ± 0.04 in BSM3). This result indicates a loss in the ability of the product to recover its original shape after deformation, which can be explained by the stiffening of the product network (explained by the increase in the dry substance in the sample by the addition of maca powder, Table 2).
Most probably maca is responsible for this loss of elasticity, because between BSM1 and BSM3, both batches with added maca powder, no significant differences are identified ($p > 0.05$), but between them and the control batch (BSM0) the differences are highly significant ($p < 0.001$).
Cohesiveness did not undergo statistically significant changes between the analyzed samples ($p > 0.05$), the values being relatively constant and in the range of 0.44-0.49, which indicates that the integrity of the products is similar within the samples. In contrast, maca powder caused highly significant differences in the gumminess parameter, which showed a highly significant increase ($p < 0.001$) in the BSM1 and BSM3 batches. The concentration of added maca also had a considerable effect, with significant differences ($p < 0.05$) between the 2 batches containing maca powder, but not as evident as between these and the control batch.
In contrast, the chewiness parameter did not show significant differences ($p = 0.244$) between all batches of maca-added beef snacks, although an increasing trend was observed between the BSM0 (6.25 ± 0.41 J) and BSM1 (6.92 ± 0.51 J) and BSM3 (6.88 ± 0.96 J) batches, respectively, but not statistically significant ($p > 0.05$).

Table 4. Texture profile of beef snacks with added maca powder

Meat samples	Colour parameters					
	Hardness (N)	Adhesiveness (mJ)	Elaticity	Cohesiveness	Gumminess (N)	Chewiness (J)
BSM0	26.35 ± 0.57	3.49 ± 0.23	0.54 ± 0.02	0.44 ± 0.02	11.64 ± 0.66	6.25 ± 0.41
BSM1	33.16 ± 1.52	4.15 ± 0.14	0.44 ± 0.02	0.47 ± 0.03	15.63 ± 0.71	6.92 ± 0.51
BSM3	36.66 ± 0.85	4.41 ± 0.07	0.39 ± 0.04	0.49 ± 0.05	17.81 ± 1.58	6.88 ± 0.96
			p-value			
BSM0 vs BSM1	0.000***	0.000***	0.000***	0.451^{ns}	0.000***	0.288^{ns}
BSM0 vs BSM3	0.000***	0.000***	0.000***	0.193^{ns}	0.000***	0.327^{ns}
BSM1 vs BSM3	0.001***	0.068^{ns}	0.019*	0.816^{ns}	0.019*	0.995^{ns}
The global *p*-value considering all samples	0.000***	0.000***	0.000***	0.208^{ns}	0.000***	0.244^{ns}

Levels of significance: ns – $p > 0.05$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
BSM0 – control batch of beef snacks in the form of sticks, without the addition of maca; BSM1 – batch of beef snacks in the form of sticks with the addition of 1% maca; BSM3 – batch of beef snacks in the form of sticks with the addition of 3% maca.

The analysis of antioxidant compounds and antioxidant activity of beef snacks with maca powder (Table 5) highlights a strong influence of the addition of maca on the antioxidant profile of beef snacks. The analyses of antioxidant compounds and antioxidant activity were performed on both non-heat-treated and heat-treated samples, in order to evaluate possible changes (degradation or improvement) in antioxidant capacity induced by the heat treatment used. Maca, in the form used by us in the meat sticks (powder), showed a strong antioxidant activity, with inhibition values of 83.50% (DPPH) and 85.04% (ABTS), along with a flavonoid content of 0.98 mg CE/g DW and total polyphenols of 3.62 mg GAE/g DW.
The antioxidant activity values obtained by us recommend this product as having a high antioxidant potential, but the flavonoid and polyphenol content is not the highest, these results being specific for products obtained from roots, which are not exactly rich in these compounds, as shown in the study by Karimi et al. (2011), who conducted studies on several

types of *Labisa pumila* Benth, but also the research of Lee & Chang (2019), who, unlike us, performed methanol extractions of bioactive compounds from maca and obtained low results for polyphenols and flavonoids (0.17 ± 0.26 mg GAE/g DW and, respectively, 0.01 ± 0.17 mg CE/g DW), even lower than those obtained by us through ethanol extraction.

In meat samples without maca addition (BSM0N and BSM0T), the antioxidant activity was significantly lower (below 20% inhibition for both methods), and the content of phenolic compounds was also reduced (0.24-0.27 mg GAE/g DW). These values confirm that the beef base has a low native antioxidant activity.

The addition of maca powder led to increases in all analyzed parameters, but depending on the added concentration and the presence or absence of heat treatment. Samples with 3% non-heat-treated maca (BSM3N) recorded the highest values for antioxidant compounds: flavonoids (0.82 mg CE/g DW) and polyphenols (1.03 mg GAE/g DW), thus confirming the sensitivity of bioactive compounds to high temperatures. However, the antioxidant activity of this batch was lower than in the case of the sample with 3% addition of heat-treated maca (BSM3T), which presented inhibition values of 37.07 ± 0.13% (DPPH) and 39.13 ± 0.15% (ABTS), compared to the non-heat-treated sample with the same concentration of maca powder (BSM3N), whose oxidation inhibitory capacity was 33.70 ± 0.27% (DPPH) and 35.74 ± 0.43% (ABTS).

In contrast, heat treatment led to a slight decrease in the values for antioxidant compounds, observable in both flavonoid and polyphenol content for the BSM3T sample (0.76 mg CE/g DW and, respectively, 0.91 ± 0.02 mg GAE/g DW), but the effect was not drastic. This is supported by the literature, which indicates a certain stability of polyphenols to thermal processing of extraction of the compounds at 100ºC, since they do not have many hydroxyl substituents in their structure (Dai & Mumper, 2010). Our results show that they also resist after thermal processing of meat products at temperatures of 70-80ºC for 2-3h.

The content of β-carotene and total carotenoids was significantly higher ($p < 0.05$) in the non-heat-treated batches compared to the heat-treated batches. This difference suggests a possible partial degradation of these pigments following exposure to high temperatures. However, the content of lycopene increased significantly ($p < 0.05$) in the heat-treated samples compared to the non-heat-treated ones in all the batches studied, obtaining values of 0.07 ± 0.00 (BSM1T) and 0.12 ± 0.01 (BSM3T) in the heat-treated batches, compared to 0.06 ± 0.01 (BSM1N) and 0.11 ± 0.00 (BSM3N) in the non-heat-treated batches. Regarding the content of β-carotene, the non-heat-treated batch with 3% maca (BSM3N) recorded the highest concentration of it (0.34 mg/g d.w.), followed by BSM1N (0.23 mg/g d.w.). After applying the heat treatment, the average value decreased slightly in the BSM3T batch reaching 0.28 mg/g d.w., but increased to 0.25 mg/g d.w. in BSM1T. The decreasing trend in the BSM3T batch can be partially attributed to the thermal degradation and isomerization of β-carotene from its trans form (predominant in nature and stable) to the more unstable cis forms (Bernhardt & Schlich, 2006). The results between the batches with the addition of maca for total carotenoids, lycopene and β-carotene showed significant differences ($p < 0.05$). By comparing them with the values of these bioactive compounds in maca powder, the differences were very highly significant ($p < 0.001$).

Carotenoids are lipid-soluble compounds that are sensitive to light, oxygen, and temperature, and β-carotene and lycopene, in particular, are susceptible to isomerization and oxidation during heat treatments, leading to a decrease in stability and biological activity. Carotenoids are found in nature mainly in the more stable trans configuration, but small amounts of cis isomers are increasingly found. Because cis isomers have a different biological potency than their trans counterparts, these cis isomers have different biological activity compared to the trans form (e.g., they may be less or more effective as provitamin A) (Rodriguez-Amaya, 2001).

The antioxidant effect of maca powder was also observed by Półtorak et al. (2018), who evaluated a combination of plant ingredients (catuaba, galangal, roseroot, guarana and polyfloral honey), including maca root powder, added to the composition of some sausages, finding a significant increase in antioxidant activity (assessed by the DPPH method) during their storage.

Tabel 5. Antioxidant compounds content and antioxidant activity of beef snacks with added maca

Meat samples	Biochemical activity						
	Antioxidant Activity DPPH (% Inhibition)	Antioxidant Activity ABTS (% Inhibition)	Total flavonoids (mg CE/g DW)	Total polyphenols (mg GAE/g DW)	Total carotenoids (mg CT/g DW)	β-caroten (mg/g DW)	Lycopene (mg/g DW)
Maca	83.50 ± 0.31^{g}	85.04 ± 0.41^{g}	0.98 ± 0.00^{e}	3.62 ± 0.01^{e}	0.56 ± 0.00^{e}	0.48 ± 0.00^{e}	0.26 ± 0.00^{d}
BSM0N	16.77 ± 0.25^{a}	18.12 ± 0.21^{a}	0.29 ± 0.01^{a}	0.24 ± 0.02^{a}	-	-	-
BSM0T	17.75 ± 0.23^{b}	19.41 ± 0.11^{b}	0.29 ± 0.02^{a}	0.27 ± 0.02^{a}	-	-	-
BSM1N	29.51 ± 0.27^{c}	30.85 ± 0.48^{c}	0.58 ± 0.01^{b}	0.70 ± 0.04^{b}	0.32 ± 0.01^{b}	0.23 ± 0.01^{a}	0.06 ± 0.01^{a}
BSM1T	31.59 ± 0.28^{d}	33.80 ± 0.22^{d}	0.56 ± 0.01^{b}	0.67 ± 0.02^{b}	0.31 ± 0.01^{a}	0.25 ± 0.01^{b}	0.07 ± 0.00^{a}
BSM3N	33.70 ± 0.27^{e}	35.74 ± 0.43^{e}	0.82 ± 0.01^{d}	1.03 ± 0.02^{c}	0.46 ± 0.00^{d}	0.34 ± 0.01^{d}	0.11 ± 0.00^{b}
BSM3T	37.07 ± 0.13^{f}	39.13 ± 0.15^{f}	0.76 ± 0.02^{c}	0.91 ± 0.02^{d}	0.40 ± 0.01^{c}	0.28 ± 0.00^{c}	0.12 ± 0.01^{c}
	p-value						
The global *p*-value considering all samples	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***

Letters on the same column differ significantly.
Levels of significance: ns – p > 0.05, *p < 0.05, **p < 0.01, ***p < 0.001.
BSM0N – control batch of beef snacks in the form of sticks, without the addition of maca and not thermally treated; BSM0N – control batch of beef snacks in the form of sticks, without the addition of maca and thermally treated; BSM1N – batch of beef snacks in the form of sticks with the addition of 1% maca, not thermally treated; BSM1T – batch of beef snacks in the form of sticks with the addition of 1% maca, thermally treated; BSM3N – batch of beef snacks in the form of sticks with the addition of 3%, not thermally treated; BSM3T – batch of beef snacks in the form of sticks with the addition of 3%, thermally treated.

The sensory analysis of beef products with added maca is composed of 18 sensory characteristics and is presented in Table 6 and a graphical representation of consumer preferences is shown in Figure 1. Most of the sensory characteristics analyzed by the panelists in the panel analysis revealed that there were no significant differences (p > 0.05) among most of the sensory characteristics studied, these were as follows: Color uniformity; General aspect, Specific smell of meat, Plant odors, Unpleasant odor, Taste persistence, Taste balance, Tender, Juiciness, Desire to try the product again.

Very highly significant differences (p = 0.000) between samples were obtained for the sensory characteristics Foreign odors from meat products, Smoky taste and Foreign taste, and significant differences (p < 0.05) were identified within the characteristics Smoky odor, Specific meat product taste, Salty taste, Sweet taste and Firmness.

Smoky odor was diminished by the addition of maca in the samples, obtaining a score of 5.47 ± 0.74 in the BSM3 group and 6.00 ± 1.13 in the BSM1 group, both lower than the average score obtained by the control group (BSM0), 6.47 ± 0.99. Another sensory characteristic related to olfactory perception that was strongly influenced by the addition of maca is Foreign odors from meat products. As can be seen from the data in Table 6, the mean scores for the control batch (BSM0) and the batch with 1% maca powder addition (BSM1) are identical (1.00 ± 0.00), the major difference being observed only in the case of the batch with 3% added maca (BSM3), which obtained from the panelists the average score of 1.73 ± 0.70. From these results we can deduce that a low addition of maca powder does not influence the odor of the meat products studied, but higher concentrations (~3%) show a major influence on the olfactory perception of the odor of meat products, being perceived an uncharacteristic odor of the meat products. This result correlates with the characteristic Specific meat product taste which showed significant differences (p = 0.040) between the studied batches, its score decreasing concomitantly with the addition of maca, from 7.87 ± 1.19 in the BSM0 batch (no maca added) to 6.80 ± 1.01 in the BSM3 batch (batch with 3% maca added).

As well as smoky odor, smoky taste was also greatly affected by the addition of maca, decreasing its mean value in the control batch 5.33 ± 1.05 by about 2 points. This fact reveals that maca (*Lepidium meyenii*) has a pronounced characteristic flavor that covers the flavor characteristic of the meat and those imprinted by the technological process of production. This taste, as identified by the tasters, is a sweet taste, which is uncharacteristic for such products (foreign tastes), but which is not considered unpleasant by consumers, since the characteristic Desire to try the product again did not change significantly between batches ($p > 0.05$), indicating that the products with added maca powder are similar in terms of enjoyment to classic products without added plant-based ingredients. Also, the addition of maca, as observed in the chemical analysis of the analyzed products (Table 2), showed a decrease in the mean value concomitant with the addition of maca, the differences between batches being significant ($p < 0.05$), but without negatively affecting the overall taste of the products. From this we can deduce that consumers do not perceive the decrease in saltiness as having a negative effect on the taste of meat products, as long as it is balanced.

Table 6. Sensory attributes evaluated in beef snacks enriched with maca (*Lepidium meyenii*): mean ± SD and statistical significance

Sensory attributes	Beef sticks sampples			*p*-value
	BSM0	BSM1	BSM3	
Colour uniformity	7.53 ± 0.99	7.53 ± 1.13	7.40 ± 1.06	0.924 (ns)
General aspect	7.73 ± 0.70	7.60 ± 0.83	7.80 ± 0.86	0.786 (ns)
Specific smell of meat	4.47 ± 1.19	4.27 ± 1.22	4.13 ± 1.13	0.740 (ns)
Smoky odor	6.47± 0.99	6.00 ± 1.13	5.47 ± 0.74	0.026 (*)
Plant odors	1.07 ± 0.26	1.20 ± 0.56	1.33 ± 0.62	0.359 (ns)
Foreign odors from meat products	1.00 ± 0.00	1.00 ± 0.00	1.73 ± 0.70	0.000 (***)
Unpleasant odor	1.13 ± 0.35	1.07 ± 0.26	1.07 ± 0.26	0.773 (ns)
Specific meat product taste	7.87 ± 1.19	7.60 ± 1.24	6.80 ± 1.01	0.040 (*)
Salty taste	5.87 ± 0.92	5.47 ± 0.74	5.00 ± 0.76	0.020 (*)
Smoky taste	5.33 ± 1.05	4.67 ± 0.62	3.53 ± 0.83	0.000 (***)
Sweet taste	2.27 ± 0.96	2.93 ± 1.28	3.47 ± 1.19	0.024 (*)
Foreign taste	1.07 ± 0.26	1.27 ± 0.59	2.60 ± 0.83	0.000 (***)
Taste persistence	4.87 ± 1.06	4.67 ± 0.82	4.40 ± 0.83	0.378 (ns)
Taste balance	6.33 ± 1.59	6.60 ± 1.24	7.27 ± 1.03	0.145 (ns)
Tender	6.07 ± 0.96	5.60 ± 1.18	5.13 ± 0.92	0.056 (ns)
Juiciness	4.47 ± 1.30	4.33 ± 1.29	3.93 ± 1.28	0.506 (ns)
Firmness	3.67 ± 1.05	4.13 ± 0.64	4.47 ± 0.74	0.038 (*)
Desire to try the product again	6.47 ± 1.73	6.53 ± 1.81	7.13 ± 1.41	0.485 (ns)

Levels of significance: ns – $p > 0.05$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
BSM0 – control batch of beef snacks in the form of sticks, without the addition of maca; BSM1 – batch of beef snacks in the form of sticks with the addition of 1% maca; BSM3 – batch of beef snacks in the form of sticks with the addition of 3% maca.

The only texture-related sensory characteristic significantly affected ($p < 0.05$) by the addition of maca was Firmness, which recorded an increase in mean value directly proportional to the increase in maca powder content, reaching the maximum value in our study in the BSM3 lot 4.47 ± 0.74, which is 0.8 points higher than that of the control BSM0 lot, 3.67 ± 1.05. The External Preference Mapping (PrefMap) diagram presented in Figure 1 provides a two-dimensional graphical representation of consumer preferences for beef stick samples with the addition of yellow maca powder. This diagram is based on the mean scores of the experimental batches presented in Table 6.

In Figure 1, there are, as we can see, 6 areas of percentage preference, however, in the legend of the diagram, positioned on the right side of it, there are only 5 areas of percentage preference. As we can see on the diagram, there is an overlap of the red and yellow colors, which leads to an orange-brown color, the area on which all three batches of beef snacks enriched with maca (*Lepidium meyenii*) are positioned. This indicates that they fall within a preference range of 60-100%, which indicates that there are no major differences in their overall preference, at least not at a general level.

However, the placement of the samples in the same area and their proximity to the preference vectors of different consumer groups (clusters) indicate subtle variations in the preference of each of the segments.

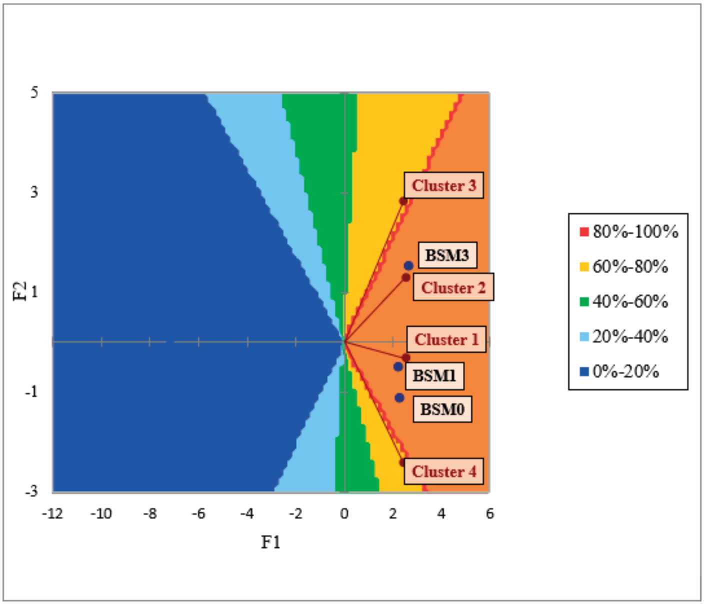

Figure 1. External Preferance Mappping (PrefMap)

(BSM0 – control batch of beef snacks in the form of sticks, without the addition of maca; BSM1 – batch of beef snacks in the form of sticks with the addition of 1% maca; BSM3 – batch of beef snacks in the form of sticks with the addition of 3% maca)

Results obtained from the sensory analysis show that the products are perceived similarly by consumers, without variations that affect the overall sensory perception. These results indicate that functional meat sticks with maca addition represent a viable option in the future of functional foods. The products were very well accepted by consumers, being appreciated not only for their balanced sensory profile, but also for their practical character, adapted to modern requirements for ready-to-eat foods, which do not require additional thermal preparation and can be consumed quickly, in various active life contexts.

CONCLUSIONS

The results obtained in this study highlight the potential of using maca powder (Lepidium meyenii) as a functional ingredient in the manufacture of meat products adapted to current and future consumer requirements.

The addition of maca in proportions of 1% and 3% contributed to the emergence of significant changes in the physicochemical, colorimetric, textural, antioxidant and sensory characteristics of the studied products, which in our case were represented by beef snacks (meat sticks).

The addition of maca powder to meat snacks significantly influenced the physicochemical parameters of the product, especially at a concentration of 3%. Very significant decreases in the content of fat, protein, collagen, moisture, salt and pH were observed, indicating an important compositional restructuring caused by the vegetable addition. These changes are explainable by the non-protein and acidic nature of maca powder.

Colorimetric analysis indicated a darker and less saturated appearance of maca products, changes that can be attributed to interactions between natural meat pigments and pigmentary (bioactive) compounds in maca.

Regarding texture, the addition of maca significantly influenced mechanical parameters, especially hardness, adhesiveness, elasticity and gumminess. These effects were dose-dependent, being more pronounced at 3%.

Antioxidant activity (DPPH, ABTS) and the content of bioactive compounds (flavonoids, polyphenols, carotenoids) increased proportionally with the level of added maca, but remained significantly lower compared to the values in the maca powder analyzed as such.

Sensory analysis highlighted that the addition of maca powder in proportions of 1% and 3%

influences certain sensory characteristics, especially those related to the taste and smell of the samples, firmness and the presence of foreign taste notes, without compromising the desire to consume this type of product again. The high scores for "Desire to try again" and the favorable positioning in the PrefMap analysis suggest a good acceptability of the maca-enriched products. Although the addition of maca attenuated the specific taste and smell of the meat products, it introduced a foreign sweet note that was not perceived as negative. The change in firmness (its increase) of the samples with the addition of maca was well tolerated and correlated with the maca concentration. In conclusion, maca powder can be successfully integrated into meat products, contributing to the improvement of the functional profile while maintaining, at the same time, the attractive sensory characteristics for consumers, and may represent a promising option for the development of functional meat products adapted to the requirements of the modern consumer.

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