Influence of Maca (*Lepidium meyenii*) on Selected Chemical and Technological Parameters of Rabbit Meat

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Keywords: *rabbit meat, maca (Lepidium meyenii), protein content, fatty acids, meat quality.*

Abstract. *The aim of this study was to evaluate the effect of dietary supplementation with maca (Lepidium meyenii) root powder on selected chemical, nutritional, and technological parameters of rabbit meat, focusing on Musculus vastus lateralis (MVL) and Musculus longissimus dorsi (MLD). Fifty-four adult male rabbits of the Nitra breed were divided into three groups: a control group without supplementation and two experimental groups receiving 0.3% (E1) and 0.6% (E2) maca root powder in the feed ration for 13 weeks. In the MLD muscle, protein content was significantly higher in group E2 compared with both the control and E1 groups. The content of omega-6 fatty acids was also significantly increased in group E2, while no differences were observed in saturated, monounsaturated, and omega-3 fatty acids. In both muscles, the pH values of meat during storage were significantly lower in E2 compared with the control. Meat colour was also affected, with higher yellowness (b*) values observed in experimental groups after storage. No significant differences were detected in lipid oxidation parameters among groups. Overall, maca supplementation, particularly at 0.6%, enhanced the nutritional quality of rabbit meat by increasing protein and omega-6 fatty acid content, without compromising oxidative stability.*

Introduction

Rabbit meat is a traditional dietary component in European countries, which together account for the second-highest global production of meat rabbits. The majority (83%) of production takes place in Spain (48.5 million rabbits slaughtered), followed by France (29 million) and Italy (24.5 million) (EFSA, 2020). Globally, rabbit meat consumption remains low compared with other types of meat (0.19 kg per capita per year). However, in the European Union (EU), average consumption is around 0.51 kg per capita per year (Spain 1.09 kg, Italy 0.91 kg, and France 0.75 kg) (Szendrő et al., 2020). To respond to the needs of the agri-food system and consumers, the scientific community is increasingly focused on developing sustainable feed additives to improve rabbit welfare and meat quality.

Meat quality is influenced by the animal's health before slaughter, the composition of the feed ration, and both microbial and chemical contamination. Chemical composition significantly affects technological parameters such as colour, texture, water-holding capacity (WHC), and pH (Mínguez et al., 2017; Dalle Zotte, 2002). Age, genetics, diet composition, and processing technology are also fundamental factors influencing meat quality. Rabbit meat is a low-calorie, highly digestible food with low fat and cholesterol content, but rich in unsaturated fatty acids (UFA) (Pavelková et al., 2017). Due to the low content of saturated and high content of UFA compared with other meats, rabbit meat has a favourable nutritional profile (Mínguez et al., 2017). It is considered healthier than other commonly consumed meats due to its high protein and low-fat content (Nistor, 2013). Protein levels in rabbit, chicken, and turkey meat are relatively high (20–21.9%), and the amino acids present are of a high biological value, with a relatively low energy content (427–849 kJ/100 g of fresh meat) compared with other meats (Gašperlin et al., 2010). The fat content of rabbit meat depends largely on feed composition, age, and genetic predisposition to fat storage, typically ranging within 1–12 g/100 g. This is comparable to

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veal (1–7 g/100 g) and chicken (0.9–12 g/100 g) (Combes, 2004). The fatty acid (FA) composition of rabbit meat is influenced by dietary fat sources and, in turn, affects the main physical, chemical, and sensory properties of the meat (Peiretti and Meineri, 2008).

Given these aspects of meat quality, plants and phyto-derivatives have received considerable attention as safe feed additives in animal nutrition. Maca (*Lepidium meyenii*), known as "Peruvian Maca", originates from South America and has been used as a traditional dietary supplement since the Incan era. Belonging to the *Brassicaceae* family, it was originally cultivated in the central highlands of the Peruvian Andes. Maca is classified into black, purple, and yellow varieties according to hypocotyl colour (Tang et al., 2017). In 1992, the Food and Agriculture Organization (FAO) recommended maca as a safe food. After two decades of development, it has become one of the main products on the global healthcare market (Meissner et al., 2019). Maca roots can reach a circumference of about 20 cm, while plants grow to a height of 10–20 cm. Considerable genetic diversity exists in root morphology, with variations in weight (1–5 kg), shape, and skin and flesh colour (white, cream, yellow, orange, red, and magenta) (Jin et al., 2018). Dried maca hypocotyls are rich in nutrients such as carbohydrates, proteins, lipids, essential amino acids, and free fatty acids, and contain numerous secondary metabolites with strong antioxidant properties (Tafuri et al., 2019). Antioxidant levels vary depending on soil composition, harvest time, drying process, and extraction method. Nevertheless, maca consistently contains key antioxidant compounds, including phenols, glucosinolates, alkamides, and polysaccharides, which perform various metabolic and antioxidant functions (Korkmaz, 2018).

In animal production research, the effects of natural dietary compounds are often assessed by measuring primary and secondary oxidation products, which serve as indicators of oxidative status. These include conjugated dienes, hydroperoxides, and malondialdehyde (Niki et al., 2005; Ross and Smith, 2006). Meat colour, the first quality parameter consumers notice, is influenced by myoglobin (Kirtil et al., 2015). Fat and protein oxidation promote myoglobin oxidation, whereby deoxymyoglobin and oxymyoglobin are converted into metmyoglobin, leading to discolouration (Mancini and Hunt, 2005). Texture, particularly softness and tenderness, is affected by protein and lipid oxidation, which are crucial for consumer sensory preferences. Increased hardness is an undesirable consequence of oxidation and has a negative effect on texture quality. This is particularly relevant for rabbit meat, owing to its higher UFA content, whereas meats with lower UFA content, such as beef, are less affected (Suman and Joseph, 2013). Reduced water holding capacity (WHC) is associated with the formation of protein cross-links, which widen the gaps between muscle fibres and consequently allow greater water release. Water loss is also influenced by genetic factors and muscle composition (Cayuela et al., 2004).

Therefore, the aim of this study was to evaluate the effect of dietary maca root powder supplementation on rabbit productive performance and selected physical, chemical, and quality parameters of meat.

Materials and methods

Animals and diets

All experiments were conducted in accordance with EU Directive 2010/63/EU and national guidelines for the care and use of animals. All experimental procedures involving animals were approved by the National Agricultural and Food Centre Ethical Committee (Permission code: SK CH 17 021).

Adult male rabbits (n = 54; 17.5 ± 0.9 weeks of age; average weight 4.701 ± 0.1425 kg) were divided into three groups, each consisting of 18 animals (three animals per cage). The lighting cycle throughout the trial was 16 hours light and 8 hours dark. Heating and forced ventilation maintained the building temperature at 18 ± 4°C, with relative humidity at 70 ± 5%. The choice of adult rabbits for dietary strategy experiment on meat quality traits is unusual, but it was subordinate to another experiment evaluating the reproductive traits on the same animal population.

The control group (C) received no feed supplement. Experimental group 1 (E1) received 0.3% maca root powder (*Lepidium meyenii*), while experimental group 2 (E2) received 0.6% maca root powder. The maca powder (Bio Maca, GymBeam s.r.o.) was incorporated into the feed components and subsequently pelleted. Water was provided ad libitum. The phenolic compound content of the dietary supplement was analysed by HPLC-UV–DAD (Russo et al., 2017) and is reported in Table 1.

The complete feed mixture (Humino Feed, Vetservis s.r.o., Nitra, Slovakia) was used throughout the experiment. Its basic composition was protein 15%, fibre 17%, ash 10%, calcium 0.80%, phosphorus 0.50%, sodium 0.14%, vitamin A 8000 IU/kg, vitamin D_2 800 IU/kg, and vitamin E 40 mg/kg. According to the manufacturer, the maca powder contained (per 100 g): fat 0.8 g (saturated fatty acids 42.7%, unsaturated fatty acids 53.4%), carbohydrates 76 g, fibre 18 g, protein 12 g, minerals 0.12 mg, vitamin B_1 0.21 mg, vitamin B_2 1.95 mg, vitamin B_6 0.3 mg, calcium 351 mg, potassium 1784.2 mg, magnesium 92 mg, iron 13 mg, sodium 92.1 mg, phosphorus 192 mg, and zinc 4.1 mg.

The experiment was conducted at the Institute of Small Farm Animals, Research Institute of Animal Production – National Agricultural and Food Centre (Lužianky, Slovakia). After 13 weeks of feeding, slaughter took place in slaughterhouse for rabbits at the Research Institute of Animal Production in Nitra. Samples were then subjected to further analyses at

Table 1. Polyphenols content (mg/kg DW) in the natural Maca supplement

Phyto-derivate family name	Compound	Amount in Maca*
Phenolic Acid	Dihydroxybenzoic acid	1.923 ± 0.025
	Vanillic acid	69.430 ± 1.170
Hydroxycinnamic acids	Tans p-coumaric acid	11.727 ± 0.230
	Resveratrol	21.697 ± 0.755
	Ferulic acid	9.371 ± 0.018
Flavonoids	Quercitin	8.238 ± 0.128
	Rutin	61.480 ± 0.459
	Myricetin	9.630 ± 0.111
	Kaempferol	⩽ LOD

* Limit of detection; values expressed as means (n = 4) ± standard deviation.

the Institute of Food Sciences, Slovak University of Agriculture in Nitra.

Experimental sampling

Animals were weighed at day 0 and at 30-day intervals throughout the trial. Feed intake was recorded weekly (feed offered and refused). These two parameters were used to monitor and to assess the health conditions of rabbits and the grade of acceptance of diets during the whole experiment.

At the end of the trial, rabbits were weighed and, after a 6-hour fasting period, 10 animals per group were randomly selected for slaughter. Rabbits were stunned electrically (100 V, 50 Hz, 2–3 s) and sacrificed by bleeding according to the guidelines established by the European Community (1099/2009/EC) for the protection of animals during slaughter.

Carcasses were chilled for 24 hours at +4°C and then dissected according to the recommendations of the World Rabbit Science Association (WRSA) (Blasco and Ouhayoun, 1996), with removal of the skin, distal parts of the limbs, genital organs, bladder, and gastrointestinal tract. Carcasses were then weighed, and dressing percentages were calculated. Samples of *Musculus longissimus dorsi* (MLD) and *Musculus vastus lateralis* (MVL) were collected. Physical parameters were measured on freshly cut MLD and MVL muscles. Whole muscles were sampled for chemical analyses, vacuum packed, and stored at –20°C.

Physical and chemical parameters

Physical determinations were carried out immediately after arrival at the laboratory. Within 45 minutes of slaughter, the pH of the MLD and MVL muscles (Hanna HI 99161; Hanna Instruments, Woonsocket, RI, USA) was measured, and the measurement was repeated after 1, 3, and 5 days of storage. Colour measurements were performed on day 0 and after 5 days of refrigerated storage at 4°C, using a Konica Minolta 2600D spectrophotometer (Konica Minolta, Tokyo, Japan). The instrument was calibrated in the CIE LAB colour space system using a white calibration plate (CR-A43, Minolta Cameras). The colourimeter had an 8 mm measuring area and was illuminated with a pulsed xenon arc lamp at a 0° viewing angle. Reflectance measurements were obtained at 0° with the spectral component included. To allow blooming, trays were opened and data were collected after 30 minutes. Each data point represents the mean of six replicates measured on the chop surface.

Moisture (method 985.41), ash (method 920.153), fat (method 960.39), and crude protein (method 928.08) contents were determined in duplicate on MLD and MVL muscle samples, following the methods of the Association of Official Analytical Chemists (AOAC, 2000).

Cholesterol content was determined according to Du and Ahn (2002) using gas chromatography. Cholesterol was identified based on the retention time of a standard (Sigma Aldrich, St. Louis, MO, USA) and quantified using Chrom Card Data System software (version 1.17). All samples were analysed in triplicate.

Nutritional Traits and Shelf-Life of Meat

Amino acids were determined in fat-free samples by ion-exchange chromatography (free amino acids) and by liquid chromatography (total amino acids) after acid hydrolysis in 6 M HCl. Sulphur amino acids were determined after hydrolysis with hydrogen peroxide and formic acid. Separation was performed using an Amino Acid Analyser AAA 400 (Ingos a.s., Prague, Czech Republic).

The fatty acid composition of intramuscular fat samples was determined after chloroform–methanol extraction according to Folch et al. (1957). Fatty acids were analysed as methyl esters (FAME) (Dal Bosco et al., 2004) using a ThermoQuest TRACE 2000 gas chromatograph (SAC™-5 column, 30 m × 0.25 mm; Supelco, USA). Fatty acids were identified on the basis of elution times corresponding to the standard (FAME PUFA2, Supelco, Bellefonte, PA, USA).

Health lipid indices were estimated according to Ulbricht and Southgate (1991). From the fatty acid composition, indices of atherogenicity (AI) and thrombogenicity (TI) were calculated using the following formulas:

$AI = [(4 \times 14{:}0) + (16{:}0)] \times [PUFA\ (n\text{-}6\ and\ n\text{-}3) + MUFA)]^{-1}$

$TI = [(14{:}0) + (16{:}0) + (18{:}0)] \times [(0.5 \times MUFA) + (0.5 \times n\text{-}6) + (3 \times n\text{-}3) + (n\text{-}3 \times n\text{-}6\ \text{-}1)]^{-1}$

Lipid oxidation during storage (1, 3, and 5 days at 4°C) was determined using the thiobarbituric acid reactive substances (TBARS) method of Meineri et al. (2010), in accordance with ASPA (1996) recommendations. All analyses were performed in duplicate. Absorbance at 532 nm was measured with a spectrophotometer. TBARS values, expressed as mg malondialdehyde (MDA)/kg meat, were obtained using a conversion factor based on a standard curve prepared with MDA (Sigma-Aldrich, Milan, Italy).

Statistical analyses

Statistical analyses were performed using SPSS (version 26.0; IBM, Armonk, NY, USA). The data on growth performance and meat quality parameters (physical and chemical parameters, amino acid profile, and fatty acid profile) were analysed by one-way analysis of variance (ANOVA), with dietary treatment as the main factor. Oxidative stability data were analysed by repeated-measures ANOVA to assess the effects of treatment, time, and their interaction. The experimental unit for growth performance was the cage, while the individual carcass served as the experimental unit for meat quality parameters. Data are presented as means ± SEM, and statistical significance was accepted at $P < 0.05$.

Results and discussion

Quantification of the polyphenol pofile

The qualitative profile of phenolic compounds in maca root powder and the concentrations of individual compounds are shown in Table 1. Rutin and vanillic acid (61.480 and 69.430 µg/kg d.w., respectively) were the main phenolic components, followed by resveratrol, trans-p-coumaric acid, myricetin, ferulic acid, quercetin, and dihydroxybenzoic acid. By contrast, kaempferol was not detected. In accordance with the literature (Jagdale et al., 2021), flavonoids and phenolic acids phyto-derivate families are the most abundant in maca root powder. Considering that the solubility of polyphenols in solvent of different polarity is determined by their structure, different types of extraction solvent and procedures may influence the efficiency of phenolic compounds extraction and their resultant content (Veličković et al., 2014).

Growth performance and carcass characteristics

Throughout the experimental period, the welfare status of the animals was consistently considered good. The present study did not focus on growth performance, as the animals were adults and the number of replicates was relatively low for the evaluation of productive traits. The dietary supplementation with maca root powder did not result in any statistically significant differences in body weight (Fig. 1) and no evident clinical signs were observed in rabbits during the 13-week trial, with an average feed intake of 180 g/day per animal. Similar to our findings, Uchiyama et al. (2014) reported no differences in body weight between experimental groups supplemented with

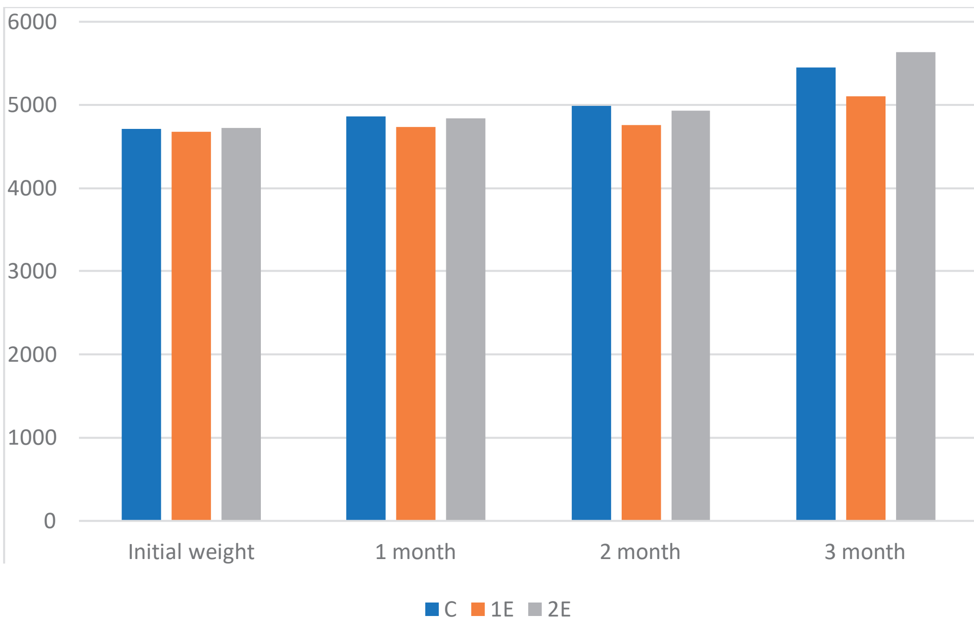

Fig. 1. Comparison of average rabbit live weights (g) during the experiment (months)

maca, whereas Lee et al. (2004) observed faster growth in fish fed with maca.

Chemical composition and nutritional value of meat

In the MLD muscle, protein content in group E2 (25.550 ± 0.549%) increased significantly ($P \leqslant 0.05$) compared with both the control (24.930 ± 0.493%) and group E1 (24.910 ± 0.293%), suggesting a different nutrient accumulation process in rabbits fed the higher dose of maca. In the MVL muscle, protein content in group E2 did not differ significantly from groups C and E1 (Table 2). All other determinations regarding meat chemical composition were not affected by dietary treatment. Comparable results were obtained by Semenova et al. (2021), who fed growing rabbits for 45 days with a powdered feed additive titrated at 70% dihydroquercetin. In contrast, other studies (Minardi et al., 2020; Vizzarri et al., 2014) reported no effect on rabbit and brown hare meat traits after supplementation with antioxidant feed additives. Analysis of the protein profile of rabbit meat revealed no significant differences in amino acid content in either of the muscles studied, although some variation among groups was observed (Table 3).

With respect to the lipid fraction (Table 4), the

Table 2. Chemical composition[1] of rabbit meat in the back and thigh rabbit muscles

Item[2]	Dietary treatment[3]				
	C	E1	E2	SEM	*P* value[4]
musculus longissimus dorsi					
Moisture, %	72.94	72.99	73.00	0.010	ns
Crude protein, %	24.93[a]	24.91[a]	25.55[b]	0.115	0.05
Crude fat, %	0.88	0.89	0.78	0.019	ns
Ash, %	1.25	1.21	0.67	0.103	ns
Cholesterol, mg/100g	36.30	35.60	32.60	0.622	ns
musculus vastus lateralis					
Moisture, %	71.86	71.50	71.85	0.065	ns
Crude protein, %	23.80	23.70	23.93	0.036	ns
Crude fat, %	0.76	0.68	0.84	0.025	ns
Ash, %	3.58	4.12	3.38	0.121	ns
Cholesterol, mg/100g	38.80	39.00	39.10	0.048	ns

[1]Data are reported as mean values and SEM, n = 10.
[2]Data expressed as percentage of wet weight.
[3]Control group (C); experimental group 1 (E1) with the addition of 0.3% of maca; experimental group 2 (E2) with the addition of 0.6% of maca.
[4]Different letters on the same row differed for $P < 0.05$; ns = not significant.

Table 3. Content of selected amino acids in individual experimental groups in the back and thigh rabbit muscles

Parameter[1] (g/100g)	Experimental groups[2]				
	C	E1	E2	SEM	*P* value[3]
musculus longissimus dorsi					
Arginine	1.124	1.144	1.142	0.003	ns
Cysteine	0.270	0.268	0.278	0.002	ns
Phenylalanine	0.724	0.733	0.733	0.002	ns
Histidine	0.729	0.745	0.738	0.003	ns
Isoleucine	0.686	0.701	0.696	0.002	ns
Leucine	1.416	1.436	1.433	0.003	ns
Lysine	1.495	1.522	1.521	0.005	ns
Methionine	0.555	0.566	0.577	0.003	ns
Threonine	0.855	0.861	0.856	0.001	ns
Valine	0.793	0.807	0.796	0.002	ns

Table 3 cont.

Parameter[1] (g/100g)	Experimental groups[2]				
	C	E1	E2	SEM	*P* value[3]
musculus vastus lateralis					
Arginine	1.190	1.227	1.202	0.006	ns
Cysteine	0.250	0.246	0.250	0.001	ns
Phenylalanine	0.759	0.777	0.766	0.003	ns
Histidine	0.769	0.776	0.771	0.001	ns
Isoleucine	0.736	0.760	0.742	0.004	ns
Leucine	1.481	1.520	1.492	0.006	ns
Lysine	1.578	1.625	1.598	0.007	ns
Methionine	0.559	0.566	0.566	0.001	ns
Threonine	0.869	0.880	0.870	0.002	ns
Valine	0.833	0.845	0.844	0.002	ns

[1]Data are reported as mean values and SEM, n = 10.
[2]Control group (C); experimental group 1 (E1) with the addition of 0.3% of maca; experimental group 2 (E2) with the addition of 0.6% of maca.
[3]ns = not significant.

Table 4. Lipid profile in the back and thigh rabbit muscles

Parameter[1] (g/100g FAME)	Experimental groups[2]				
	C	E1	E2	SEM	*P* value[3]
musculus longissimus dorsi					
MUFA	48.700	49.130	49.200	0.085	ns
PUFA	11.340	11.670	12.160	0.131	ns
SFA	35.090	34.340	35.080	0.136	ns
Omega 3	0.483	0.483	0.492	0.002	ns
Omega 6	9.226[a]	9.350[a]	10.020[b]	0.135	0.05
Essential FA	8.741	8.641	8.646	0.019	ns
musculus vastus lateralis					
MUFA	47.790	47.410	47.930	0.085	ns
PUFA	11.600	12.130	11.840	0.084	ns
SFA	33.230	32.910	33.560	0.103	ns
Omega 3	0.470	0.457	0.456	0.002	ns
Omega 6	8.563	8.613	8.760	0.032	ns
Essential FA	9.289	9.533	9.242	0.049	ns

[1]Data are reported as mean values and SEM, n = 10; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.
[2]Control group (C); experimental group 1 (E1) with the addition of 0.3% of maca; experimental group 2 (E2) with the addition of 0.6% of maca.
[3]Different letters on the same row differed for $P < 0.05$; ns = not significant.

content of omega-6 fatty acids in group E2 (10.020 ± 0.500 g/100 g FAME) was significantly higher ($P \leqslant 0.05$) than in groups E1 (9.350 ± 0.576 g/100 g FAME) and C (9.226 ± 0.547 g/100 g FAME). These results agree with those of Palazzo et al. (2015), who reported an increased proportion of polyunsaturated fatty acids in rabbit meat following supplementation with *Lippia citriodora* extract. Increases in omega-6 fatty acids were also observed by Staerfl et al. (2011) in bulls whose diets were enriched with maca and other natural substances. No significant differences were detected in the overall content of saturated, monounsaturated, polyunsaturated, or omega-3 fatty acids. For the selected individual fatty acids analysed, no differences were detected at any level of significance (Table 5).

Table 5. Content of selected fatty acids in the back and thigh rabbit muscles

Parameter (g/100g FAME)[1]	Experimental groups[2]				
	C	E1	E2	SEM	*P* value[3]
musculus longissimus dorsi					
Heptadecanoid acid	0.318	0.297	0.327	0.005	ns
Lauric acid	0.104	0.104	0.101	0.001	ns
Myristic acid	1.351	1.373	1.364	0.004	ns
Palmitic acid	24.380	24.410	24.470	0.015	ns
Stearic acid	10.790	10.630	10.700	0.025	ns
Linolenic acid	0.280	0.275	0.260	0.003	ns
Linoleic acid	5.090	5.157	5.547	0.078	ns
Oleic acid	37.860	36.720	38.190	0.244	ns
Vaccenic acid	4.861	4.875	4.834	0.007	ns
CLA	0.128	0.125	0.131	0.001	ns
DHA	0.035	0.033	0.035	0.000	ns
ARA	1.684	1.610	1.730	0.019	ns
EPA	0.106	0.097	0.102	0.001	ns
DPA	0.139	0.137	0.137	0.000	ns
musculus vastus lateralis					
Heptadecanoid acid	0.285	0.288	0.285	0.001	ns
Lauric acid	0.109	0.107	0.103	0.001	ns
Myristic acid	1.412	1.425	1.410	0.003	ns
Palmitic acid	24.530	24.500	24.550	0.008	ns
Stearic acid	10.650	10.490	10.630	0.028	ns
Linolenic acid	0.264	0.261	0.255	0.001	ns
Linoleic acid	4.534	4.466	4.384	0.024	ns
Oleic acid	29.060	26.520	28.340	0.414	ns
Vaccenic acid	4.975	5.011	4.970	0.007	ns
CLA	0.132	0.131	0.127	0.001	ns
DHA	0.029	0.031	0.030	0.000	ns
ARA	1.904	1.899	1.828	0.013	ns
EPA	0.100	0.101	0.095	0.001	ns
DPA	0.129	0.129	0.130	0.000	ns

[1]Data are reported as mean values and SEM, n = 10.
[2]Control group (C); experimental group 1 (E1) with the addition of 0.3% of maca; experimental group 2 (E2) with the addition of 0.6% of maca.
[3]ns = not significant.

Meat physical parameters

At 45 minutes post-mortem, the lowest pH values of the MLD and MVL muscles were recorded in group E1. The highest pH values were observed in groups C and E2, although these differences were not statistically significant. In the MLD muscle, a significant difference ($P \leqslant 0.0001$) was recorded on the first day of storage between group E2 (5.154 ± 0.050) and the control group (5.414 ± 0.140). The pH in group E1 (5.239 ± 0.082) was also significantly lower ($P \leqslant 0.01$) than in the control group. On the third day, the pH of group E2 (5.199 ± 0.063) was significantly lower ($P \leqslant 0.0001$) than in the control (5.493 ± 0.149). A significant difference was also observed between groups E2 and E1 (5.356 ± 0.118), with the latter having a higher pH ($P \leqslant 0.05$). By the fifth day of storage, group E2 again had a significantly lower pH ($P \leqslant 0.001$) than both group C and group E1.

In the MVL muscle, no differences among groups were observed at 45 minutes post-mortem. However, on the first day of storage, group E2 (5.324 ± 0.068) had a significantly lower pH ($P \leqslant 0.01$) compared with both group C and group E1. On the third day, the pH of group E2 (5.431 ± 0.090) was again significantly lower ($P \leqslant 0.01$) than in the other two groups. By the fifth day, the pH of group E2 (5.190 ± 0.157) remained the lowest of all groups (Table 6).

The pH of meat depends strictly on muscle energy metabolism and plays a key role in maintaining meat quality during storage. Low pH exerts a bacteriostatic effect, thereby regulating microbial growth (Dalle Zotte, 2002). Under our experimental conditions, the lower pH values observed in group E2 after five days of storage in both muscles suggest a biological effect of maca on rabbit meat.

Meat colour is also a critical quality attribute influencing consumer purchasing decisions (Kozioł et al., 2015). Colour measurements (Table 7) showed significantly higher b* values in MLD muscles of groups E1 and E2 after five days of storage. According to Münch (2004), this may be linked to free radicals produced by lipid oxidation during storage or handling, which can oxidise haem pigments and cause meat discolouration. Since no differences were detected in the lipid oxidation profile of meat, further investigations are warranted.

Oxidative Stability

Groups E1 and E2 showed no significant differences in malondialdehyde content compared with group C throughout the storage period (Table 8). Overall, lipid oxidation increased significantly ($P < 0.001$) with storage time across all groups. Maca supplementation did not alter this trend, with similar increases observed from day one to day five in all groups. In contrast, Staerfl et al. (2011) reported improved oxidative stability in bull meat, while Rossi et al. (2020) found that feeding growing rabbits brown seaweed and polyphenols enhanced the oxidative stability of meat.

Table 6. pH during storage in rabbit MLD and MVL

Parameter[1]	Experimental groups[2]				
	C	E1	E2	SEM	*P* value[3]
musculus longissimus dorsi					
pH					
45 min.	6.691	6.529	6.623	0.026	ns
1 day	5.414[a]	5.239[b]	5.154[b]	0.042	0.01
3 day	5.493[a]	5.356[b]	5.199[c]	0.047	0.01
5 day	5.176[a]	5.073[a]	4.949[b]	0.036	0.001
musculus vastus lateralis					
45 min.	6.704	6.486	6.617	0.035	ns
1 day	5.594[a]	5.570[a]	5.324[b]	0.047	0.01
3 day	5.711[a]	5.627[a]	5.431[b]	0.045	0.01
5 day	5.379[a]	5.429[a]	5.190[b]	0.040	0.001

[1]Data are reported as mean values and SEM, n = 10.
[2]Control group (C); experimental group 1 (E1) with the addition of 0.3% of maca; experimental group 2 (E2) with the addition of 0.6% of maca.
[3]Letters on the same row differed for $P < 0.01$; ns = not significant.

Table 7. Meat hardness and colour during storage in the back and thigh rabbit muscles

Parameter[1]	Experimental groups[2]				
	C	E1	E2	SEM	*P* value[3]
musculus longissimus dorsi					
Colour 24 hour post mortem					
L*	56.930	55.510	56.590	0.741	ns
a*	1.376	0.814	0.885	0.306	ns
b*	7.575	8.109	7.894	0.269	ns
Colour 5 days post mortem					
L*	58.010	58.230	58.730	0.369	ns
a*	1.271	0.939	1.204	0.176	ns
b*	7.923[a]	9.241[b]	9.558[b]	0.867	0.001

Table 7 cont.

Parameter[1]	Experimental groups[2]				
	C	E1	E2	SEM	*P* value[3]
musculus vastus lateralis					
Colour 24 hour post mortem					
L*	57.440	55.610	55.560	1.071	ns
a*	0.849	0.806	0.750	0.050	ns
b*	7.869	8.584	8.255	0.358	ns
Color 5 days post mortem					
L*	56.140	54.480	56.100	0.947	ns
a*	1.220	0.835	1.158	0.207	ns
b*	8.391	9.415	8.979	0.514	ns

[1]Data are reported as mean values and SEM, n = 10.
[2]Control group (C); experimental group 1 (E1) with the addition of 0.3% of maca; experimental group 2 (E2) with the addition of 0.6% of maca.
[3]Letters on the same row differed for $P < 0.001$; ns = not significant.

Table 8. Malondialdehyde content during storage in rabbit MLD and MVL

Malondialdehyde mg/kg*	Experimental groups+			*P* value§			
	C	E1	E2	SEM	D	T	Interaction
musculus longissimus dorsi							
1 day	0.170[1]	0.167[1]	0.175[1]	0.001	ns	ns	ns
3 day	0.185[2]	0.177[1]	0.190[2]	0.002	ns	0.01	ns
5 day	0.191[2]	0.203[2]	0.212[3]	0.003	ns	0.01	ns
musculus vastus lateralis							
1 day	0.170[1]	0.167[1]	0.175[1]	0.001	ns	ns	ns
3 day	0.185[2]	0.177[1]	0.190[2]	0.002	ns	0.01	ns
5 day	0.191[2]	0.203[2]	0.212[3]	0.003	ns	0.01	ns

*Data are reported as mean values and SEM, n = 10. +Control group (C); experimental group 1 (E1) with the addition of 0.3% of maca; experimental group 2 (E2) with the addition of 0.6% of maca. §Different numbers on the same column differed for $P < 0.01$; ns = not significant.

Conclusion

This study evaluated the effect of *Lepidium meyenii* (maca) as a feed additive in rabbit diets on selected chemical, technological, and quality parameters of rabbit meat. The results showed that dietary maca increased protein and omega-6 fatty acid content in the MLD muscle, thereby improving its nutritional value. The two maca dosages tested had no significant effect on the shelf-life of rabbit meat. Promising findings, such as improved pH values and higher yellowness in meat, support the recommendation of high-dose maca supplementation in rabbit diets as safe and without detrimental effects on rabbit production.

Ethical Statement

All animal experiments were conducted following the guidelines of EU Directive 2010/63/EU and national guidelines for the care and use of animals. All experimental procedures involving animals were approved by the National Agricultural and Food Centre ethical committee (Permission code: SK CH 17 021).

Acknowledgements

The work was carried out with the financial support of projects 12-GASPU-2018, KEGA 030SPU-4/2025, KEGA 035SPU-4/2023, APVV-21-0168, and VEGA 1/0698/22.

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