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Original scientific paper

Development, characterization and investigation of antimicrobial and antioxidant potential of sodium caseinate-based edible films infused with *Berberis pseudumbellata* fruit extract, and effects of the films on the quality of raw ground beef during refrigeration

Habiba Shah[1], Shakeel Ahmed[1], Faizah Urooj[2], Sidra Zaheer[1], Nilofer Fatimi Safdar[1]*

A b s t r a c t: The present study proposed to develop, characterize and investigate the antimicrobial and antioxidant potential of sodium caseinate (NaCAS) films infused with Berberis pseudumbellata (B. pseudumbellata) fruit extract and film application on ground beef at refrigerated temperature (7°C) for 9 days. The infusion of fruit extract enhanced the physical and optical characteristics of the films. Light transmittance and water solubility of the films decreased with the addition of the fruit extract, whereas the film thickness increased. In the agar disc diffusion test, the infused films showed maximum inhibition of Gram-positive bacteria, Staphylococcus aureus and Bacillus subtilis, compared with Gram-negative Salmonella Typhi and Escherichia coli. The films infused with B. pseudumbellata also exhibited increasing antioxidant activity with increasing B. pseudumbellata concentration. Infused films showed comparatively high antioxidant potential when evaluated before their application on ground beef. However, the differences in antioxidant activity of films (pre and post-application) were non-significant (p<0.05). Ground beef covered with infused NaCAS films (1, 1.5 and 3 %) maintained an acidic pH of 5.88 to 5.65, whereas the control ground beef (covered with NaCAS film) was pH 7.01 on day 9 of storage. NaCAS film infused with 3 % fruit extract also controlled the total viable counts compared to the control NaCAS film (p<0.05), with 3 % extract film perfoming better control than films with lower amounts of fruit extract.

Keywords: *Berberis pseudumbellata, edible film, sodium caseinate, beef, antioxidant, viable count.*

Introduction

Meat and related products, known causative sources of foodborne illnesses, are susceptible to deterioration due to their high perishability and protein content (*Kim et al.*, 2019). Along with uncontrolled biochemical and enzymatic reactions, the growth of microbes is another reason for the putrefaction of meat and its products during refrigeration (*Pellissery et al.*, 2020). Food industry and researchers are experiencing huge challenges in the preservation of meat and its products due to their great perishability. Incorporation of natural antioxidants from plant sources infused in the packaging matrix is one of the stable strategies to maintain the quality and improve the shelf life of meat and other food products.

Macromolecules, especially polysaccharides, lipids and proteins, are the basic source components used for the formulation of environment-friendly active packaging; these molecules serve as carriers for the active compounds and constituents including antimicrobials, antioxidants and oxygen scavengers (*Hassan et al.,* 2018). Protein film is desirable due to its enhanced mechanical and gas barrier properties (*Hanani et al.*, 2014). Currently, the formulation of protein-containing edible films, including milk proteins (casein and whey), has gained significant consideration due to the films' good functional properties (*Helal et al.*, 2015). The suitability of sodium caseinate (NaCAS) as a polymer for coating various food products, due to this protein's anti-

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oxidant potential and its use for the encapsulation of medicines and flavours, is reported in the earlier studies (*Khwaldia et al.*, 2004).

The traditional method to control the microbial growth and contamination in food includes the application of antimicrobial dips or sprays on the food surface (*Gutiérrez-del et al.*, 2018). To meet the requirements of consumers for more natural, biodegradable and preservative-free products for food packaging, the usage of plant-based antimicrobial agents, including bacteriocins and plant extracts, is getting more attention due to the safe nature and great potential of these agents (*Zhang et al.,* 2022; *Umaraw and Verma*, 2017). Earlier studies have proved the potential of natural antioxidants and antimicrobial infused in thermoplastics, thermosets and paper (*Zhong et al.*, 2020). Pervious findings have confirmed antimicrobial agents infused in packaging films might be active in decreasing the population of foodborne microorganisms in food systems (*Rahmasari and Yemiş*, 2022; *Sharma et al.*, 2020).

Berberis species are known for their medicinal benefits, edibility and nutritional value (*Andola et al.*, 2010; *Rawat et al.*, 2014). *Berberis pseudumbellata (B. pseudumbellata)* fruit is known for its high protein content and low anti-nutritive property (*Andola et al.*, 2011). Fruits of *B. pseudumbellata* are used abundantly as a folk medicine for the treatment of jaundice by the locals of Gilgit-Baltistan. Berberine and oxyacanthine are the main alkaloids reported in *B. pseudumbellata* (*Andola et al.*, 2010). The variation in berberine content in *B. pseudumbellata* and the nutritive value of barberry fruits of Gilgit-Baltistan have been reported by *Awan et al.* (2014) and *Andola et al.* (2010).

However, limited studies have testified to the antimicrobial and antioxidant activity of *B. pseudumbellata* fruit (*Awan et al.,* 2014). To the best of our knowledge, no study has reported the infusion of *B. pseudumbellata* fruit extract in any carrier matrix for film formulation or its application on the food matrix. Therefore, the aims of the present study were (i) to develop and characterize NaCAS-based edible film infused with the methanolic extract of *B. pseudumbellata* fruit; (ii) investigate the *in-vitro* antimicrobial and antioxidant potential of extract and formulated films; (iii) apply NaCAS films infused with *B. pseudumbellata* extract to cover ground beef, and investigate the change in antioxidant activity of the films; (iv) to study the packaging effect of NaCAS films (with and without extract) on the pH and total viable counts of stored beef on different days (0, 3, 6, 9) of storage.

Materials and Methods

Chemicals

NaCAS powder (food grade) and 99% pure glycerol (used as a plasticizer) were purchased from Sigma-Aldrich-USA. All reagents and chemicals used were analytical grades.

Plant

Sundried *B. pseudumbellata* fruits, collected from the hilly mountains of Gilgit-Baltistan, were lodged in the General Herbarium number 3534 with voucher number 01 at the Hazara University-Mansehra in the Department of Botany.

Extract preparation

For the preparation of fruit extract, the sundried *B. pseudumbellata* fruits, free from dirt and extraneous material, were ground using a mixer grinder into fine powder. Amounts (10 g) of finely ground sample were transferred into frosted glass containers and extracted in 100 mL of aqueous methanol for 24 h at 25°C with continuous shaking. The extract was passed through filter paper and further concentrated under a vacuum at 40°C for 6 h.

In-vitro antibacterial activity of extract

The agar disc diffusion method (*Bhuvana et al.*, 2018) was followed to find the antibacterial activity of the fruit extract against the isolated bacteria, *Staphylococcus aureus, Bacillus subtilis, Salmonella* Typhi and *Escherichia coli*. Crude extract at the concentration of 200 mg/mL was used for the evaluation of the antibacterial activity. Paper discs (5 mm) were impregnated with 2, 4 and 6 mg/disc of methanolic fruit extract. Discs with methanol acted as the negative control. Streptomycin (10 µg/disc) was considered a positive control against Gram-negative bacteria, whereas penicillin (10 µg/disc), was used as a positive control against Gram-positive bacteria. A disc loaded with methanol served as a negative control. Nutrient agar (NA) medium was used as a suitable medium to study the antibacterial activity. Bacterial lawns were prepared on the NA plates by using 48 h-old cultures. Loaded discs were placed on different peripheral positions of Petri dishes. The experiment was performed three times to check the robustness of the results. The plates were then incubated for 48 h at 37°C. The zone of inhibition against test organisms was recorded in mm.

Antioxidant activity of extract

The DPPH (2, 2-diphenyl-1-picrylhydrazyl) method with slight modifications to the method suggested by *Ruffino et al.* (2007) was followed to study the antioxidant property of formulated films. Volumes (60 µL) of sample extracts were added to tubes containing 270 µL of methanol and 2700 µL of DPPH solution of known concentration (0.0236 mg/mL). The mixtures were kept at room temperature for 30 minutes in dark. Finally, absorbance was measured using a UV-visible spectrophotometer (model UV-Vis 1900, Shimadzu, Japan) at 517 nm. The experiment was conducted in triplicate.

The formula used to calculate the % DPPH free radical scavenging activity of each formulated film was:

$$\text{Radical scavenging activity (\%)} = \frac{(\text{Abs}_{\text{DPPH}} - \text{Abs}_{\text{sample extract}})}{\text{Abs}_{\text{DPPH}}} \times 100$$

where

Abs_{DPPH} = Absorbance value of the methanolic solution of DPPH at 517 nm

$\text{Abs}_{\text{extract}}$ = Absorbance value for the sample extracts at 517 nm.

Film formulation

Film formulations were prepared using 5 g of NaCAS powder in 100 mL distilled water. The solution was mixed using a hotplate stirrer at 500 rpm at 85±5°C for 60 minutes. The temperature was reduced to 60±5°C during glycerol (3.6 w/v) addition with constant agitation for another 30 minutes. The temperature was further reduced to 25°C and 1% $NaHCO_3$ was added under mixing that continued for another 30 minutes. While stirring at 15,000 rpm for 2 min, fruit extract at different concentrations (0.1%, 1.5% and 3%) was infused into the film solution. Finally, 30 mL of each extract-infused film solution was transferred onto Petri dishes and stored for drying at 29°C for 48 h. After that, the dried films were removed from the dishes and were kept in sealed bags until future analysis.

Characterization of active films

The following characteristics of the protein-based formulated films were studied.

In-vitro antibacterial activity of films

The agar disc diffusion method suggested by *Kanmani and Rhim* (2014) was used with minor modifications to study the antibacterial activity of the extract-infused NaCAS films against the bacteria isolates, *Staphylococcus aureus, Bacillus subtilis, Salmonella* Typhi and *Escherichia coli*. A lawn of each bacterium was prepared in NA, and 5 mm discs prepared from each film were placed onto the NA lawn plates. The experiment was conducted in triplicate, and plates were incubated at 37°C for 48 h. The zone of inhibition was measured in millimetres.

Antioxidant activity of films

Pre and post-application antioxidant activity of films was estimated by the method defined by *Veiga-Santos et al*. (2018). Film solutions were prepared by vortex mixing 0.1 g of each film sample from the pre and post-application stage in 10 ml of distilled water for 5 minutes. Later, the vortex solution was centrifuged at 4000 rpm for 30 minutes. The centrifuged supernatant was filtered and used to estimate the antioxidant potential, which was expressed as percent radical scavenging activity (% RSA) as described above under the heading *Antioxidant activity of extract*.

Film Thickness

A digital micrometer (RexBeti No. 33178104, China) was used to measure the thickness of films by taking an average of six random position measurements over the test areas of each film. The measured values of the film thickness were reported in mm.

Film solubility in water

The method of *Tunc et al.* (2007) was used to determine the solubility of film in water. Films cut into $1 \times 4.2\,\text{cm}^2$ pieces were dried for 5 h at 105°C to reach constant weight. Films were then weighed on an analytical balance. Each dried film was then dipped in 50 mL of double distilled water and constantly stirred at 25°C for 24 h. For the determination of the final weight of the dry matter, insolubilized films were removed and dried for at 105°C for 24 h. The drying procedure for each film was replicated six times and means were used as solubility percentage.

Film solubility in water was calculated using the equation:

% Film solubility = {(initial film dry weight − final film dry weight/ initial film dry weight) *100}

Transparency of film

The modified method of *Tunç and Duman* (2007) was used to determine the transparency of film using a spectrometer, UV-Vis 1900, Shimadzu, Japan. Films with a measurement of 11×42 mm were placed in a desiccator with an absorbent (saturated magnesium nitrate) at ambient temperature. Transmittance mode was selected, and calibration was performed at 560 nm using an empty cell. Six measurements were taken for each formulated film.

Film application on meat

Meat free from connective tissues and excess fat was collected from a butcher, and ground meat samples were prepared using an electric meat grinder. The ground meat samples were distributed into five groups for the observation of the packaging effect on the shelf life of ground meat, as follows:

1. Control sample (NaCAS only without an antimicrobial agent)
2. Antimicrobial source (NaCAS film containing 1, 1.5 or 3% methanolic extract of *B. Pseudumbellata — BPFE*).
   - 2.1. 1% BPFE + NaCAS
   - 2.2. 1.5% BPFE + NaCAS
   - 2.3. 3% BPFE + NaCAS

For each of these four sets, 50 g of ground beef meat was measured into disinfected Petri dishes. Formulated NaCAS-based films were used to cover the ground meat samples. Three replicates for each film were used in this study. Covered meat in Petri dishes was kept at refrigerator temperature (7°C) for 9 days. The pH and total viable count (TVC) of the stored beef were recorded on day 0 (at the start of the experiment) and on days 3, 6 and 9 of refrigeration.

pH measurement of stored beef samples

The pH of meat samples on different days of storage was measured by using a Hanna pH meter. Briefly, 5 g of beef was taken from each stored beef sample and homogenized with 100 ml of distilled water for 1 minute. The homogenate was filtered, and the pH of the filtrate of each sample was noted three times.

Total viable count (TVC) in stored beef samples

Microbiological analyses included the determination of total viable count conducted with a slight modification to the method suggested by *Song et al*. (2011). Ground beef (5 g) taken aseptically from each Petri dish was homogenized in an electric blender for 10–15 minutes with 225 ml of 0.1% sterilized peptone water. Furthermore, 0.1% sterile peptone water was used for the serial dilution of the sample. An amount (1 mL) for serial dilution, from dilution 10^{-8}, of each sample was transferred onto plate count agar. The plates were incubated for 48 h at 35–37°C. The microbiological count data in triplicate were converted into logarithms of the number of colony-forming units per gram (CFU/g) and then averaged.

Statistical analysis

The software package SPSS-26 was used for statistical analysis. Individual experiments were executed in triplicate and results were conveyed as means and standard deviations. To study the properties of formulated films: thickness of the film (mm), transparency (%) water solubility (%), and antioxidant activity (%) means and standard deviations were calculated. The one-way ANOVA and Least Significant Difference (LSD) procedures were used to test for differences between means. Data obtained were subjected to General Linear Model (GLM) with repeated measures to find the effect of treatments (formulated films), storage period (days) and their interactions on the pH and total viable count of stored meat (beef). P-values of <0.05 were considered significant.

Results and discussion

In-vitro antibacterial activity of Berberis pseudumbellata fruit extract

Our study findings suggested strong antibacterial activity of crude fruit extract against Gram-positive as compared to Gram-negative pathogenic bacteria used in this study (Table 1). The maximum inhibition observed was in 6 mg/mL of crude extract (25 mm inhibition zone) against *S. aureus* followed by *B. subtilis, S.* Typhi and *E. coli* respectively. However, in 2014, *Awan et al.* reported the strong antibacterial potential of the methanolic extract of *B. pseudumbellata* fruits against Gram-negative bacteria (*E. coli, and Pseudomonas)* as compared to Gram-positive bacteria (*Bacillus cereus*). The antibacterial potential of the methanolic extract of *B. Pseudumbellata* might be due to the availability of secondary metabolites, mainly berberine, an isoquinoline alkaloid, and other alkaloids, which are highly soluble in polar solvents (*Awan et al.*, 2014). The strong antibacterial potential of methanolic extract of *B. pseudumbellata* fruit extract against Gram-positive bacteria as compared with the Gram-negative bacteria might also be the result of strong chemical interaction of Gram-positive bacteria with the active agent of *B. pseudumbellata* (*Helal et*

Table 1. *In-vitro* antibacterial activity of methanol extract of *Berberis pseudumbellata* fruit compared with streptomycin as standard control against Gram-negative bacteria and penicillin as standard control against Gram-positive bacteria.

Extract	Concentration (mg/ mL)	Zone of inhibition (mm)			
		Staphylococcus aureus	***Bacillus subtilis***	***Escherichia coli***	***Salmonella* Typhi**
Fruit extract	**Control**	0	0	0	0
	Positive control (P/S)	24.5	22	28	30
	2	14.5	12.5	11	12
	4	20	20	19	19.5
	6	25	24	22	23.5

Control = Methanol @10 µL/disc
S = Streptomycin @10 µL/disc
P = Penicillin @10 µL/disc
2 = *B. pseudumbellata* fruit extract @20 mg/discs
4 = *B. pseudumbellata* fruit extract @40 mg/disc
6 = *B. pseudumbellata* fruit extract @60 mg/disc

al., 2012). However, the comparatively less inhibition observed against Gram-negative bacteria might be due to their complex barrier system which regulates, and at times inhibits, the pathway of biocides into the cytoplasm through the cytoplasmic membrane (*Denyr and Maillard,* 2002; *Emiroğlu et al.,* 2010).

Antioxidant activity of Berberis pseudumbellata fruit extract

Figure 1 shows the DPPH free radical scavenging activity of fruit extract in different concentrations. The radical scavenging activity of extract increased with the increasing concentration of extract. The minimum concentration of the extract was 10 µg/mL, which gave 51.91% radical scavenging activity, whereas 180 µg/ml of methanolic extract of fruit exhibited high radical scavenging activity (57.18%), showing increasing free radical scavenging activity with increasing extract concentration. The strong antioxidant activity of the methanolic extract of *B. pseudumbellata* might be due to the availability of ascorbic acid, phenolics, flavonoids and carotenoids in its composition (*Awan et al.*, 2014). Thus, this study confirms that the studied plant extract is a potential source of antioxidants that can serve against lipid peroxidation in meat and relevant food products.

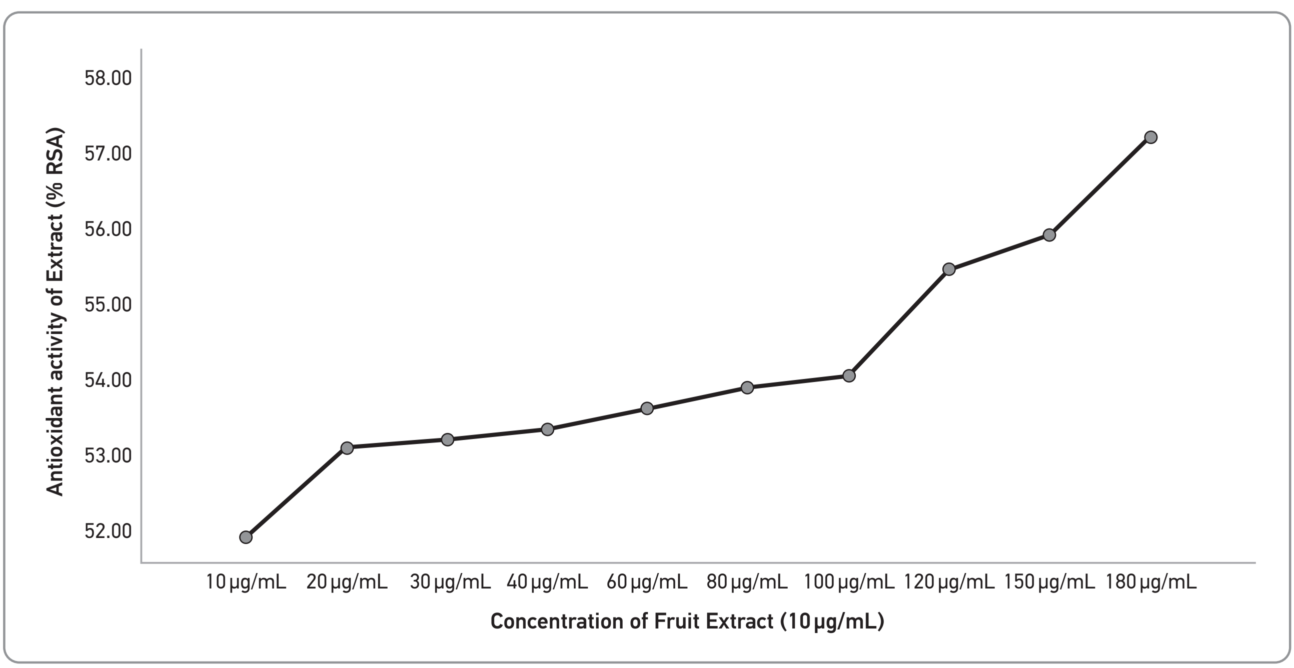

Figure 1. DPPH free radical scavenging activities of methanol extract of *Berberis pseudumbellata* fruit

In-vitro antibacterial activity of extract infused films of Na-Caseinate

NaCAS-only (control) films showed no antibacterial activity against tested bacteria, and our results are in agreement with the previous findings of *Kristo et al.* (2008). However, extract-infused NaCAS films successfully inhibited the growth of bacterial strains used in this study (Table 2). The maximum inhibition was observed in NaCAS film infused with 3% extract (inhibition zone 16.3 mm) against *S. aureus*, followed by *B. subtilis, S.* Typhi and *E. coli*, respectively. According to our findings, *S. aureus* and *B. subtilis* were more sensitive to *B. pseudumbellata* infused NaCAS films than were *E. coli* and *S.* Typhi. This might be due to the single-cell structure of Gram-positive bacteria or due to strong chemical interaction of Gram-positive bacteria with the active agent of fruit extract (*Helal et al.*, 2012). *Kaya et al.* (2018) reported the utilization of *Berberis crataegina* fruit extract and seed oil for the production of chitosan-based films and studied their *in-vitro* antibacterial properties. However, to the best of our knowledge, no study has reported the antibacterial potential of *B. pseudumbellata* infused NaCAS film. This study suggests the antibacterial activity of caseinate films infused with *B. pseudumbellata* extract might be due the bioactive compounds (berberine and alkaloids) in the plant extract composition.

Antioxidant activity of films

The antioxidant activity (pre and post) application of films on ground beef is reported in Table 3. In this study, the DPPH radical scavenging activity of films increased with the increase in extract concentration in the films, which might be due to the strong interaction between NaCAS and bioactive compounds of *B. pseudumbellata* fruit extract (*Helal et al.*, 2012). This strong antioxidant activity of coatings and gradual antioxidant discharge on food surface might result in the retardation of lipid oxidation in meat, thus extending its shelf life (*Helal et al.*, 2015; *Helal et al.*, 2012).

Table 2. *In-vitro* antibacterial activity of sodium caseinate (NaCAS) films infused with methanol extract of *Berberis pseudumbellata* fruit (BPFE)

Extract	Concentration (mg/ mL)	Zone of inhibition (mm)			
		Staphylococcus aureus	***Bacillus subtilis***	***Escherichia coli***	***Salmonella* Typhi**
Fruit extract	**Control (NaCAS only)**	0	0	0	0
	Penicillin/Streptomycin	19.3	20	31.6	34.6
	1% BPFE + NaCAS	10.6	9.6	10	10
	1.5% BPFE + NaCAS	11.6	11.3	10.2	10.6
	3% BPFE + NaCAS	16.3	15.3	12.5	13.6

Table 3. Pre and post antioxidant activity of sodium caseinate (NaCAS) films infused with methanol extract of *Berberis pseudumbellata* fruit (BPFE)

Treatments	Antioxidant activity of film-pre-application (% inhibition)	Antioxidant activity of film post application (% inhibition)	
	Mean ± SD	Mean ± SD	p-value[a]
Control (NaCAS only)	76.35 ± 0.24	74.26 ± 2.13	0.075
1 % BPFE + NaCAS	80.80 ± 0.65	79.54 ± 1.22	0.085
1.5 % BPFE + NaCAS	84.28 ± 0.55	82.65 ± 3.21	0.272
3% BPFE + NaCAS	92.52 ± 1.64	92.05 ± 0.60	0.534
p-value[b]	<0.001	<0.001	

Legend: [a] p-value calculated using t-test pairwise comparison; [b] p-value calculated using one-way ANOVA

Characteristics of films

Thickness of films

The thickness of the film was generally increased with the addition and increasing concentration of extract. However, this increase in film thickness became evident when the percentage of extract increased two-fold (to 3%) compared to the lowest concentration (1%). The increase in thickness was statistically significant ($p<0.05$) (Table 4). Other studies also showed the changes that occurred in the thickness of edible formulated films are due to the accumulation of active antimicrobial compounds. *Rad et al.* (2017) reported increased film thickness in Pullulan-soy films with the addition of *Zataria multiflora* and *Artemisia biennis* extract. The addition of extract may result in the development of soft and sponge-like structure which further increases the moisture content, causing the swelling of the film due to confined water molecules in the pores of formulated film, and thus, enhancing the film thickness (*Emam-Djomeh et al.,* 2015). On the contrary (*Pires et al.*, 2013), reported decreased film thickness was caused by the amalgamation of tarragon, lavender, thyme and coriander extracts as antimicrobial amalgams.

Water solubility

Addition of *B. pseudumbellata* fruit extracts increased film solubility (Table 4). However, at the lowest extract concentration (1%), the increased film solubility was only a non-steady trend and non-significant compared to the control (NaCAS only). At higher concentrations, the solubility of the film showed increasing water solubility due to improved pore size in the film's inner structure. Hence, the infusion of fruit extract effects the disruption of film structure and, thus, increases film solubility. Similar results have been reported in earlier studies (*Emam-Djomeh et al.*, 2015; Hosseini et al., 2009).

Film transparency

The addition of *B. pseudumbellata* fruit extract significantly ($p<0.05$) reduced the transparency of films (Table 4). The reduced film transparency was significant ($p<0.01$) in the highest concentration (3%) of added extract as compared to the control. Our findings are similar to those earlier reported in alginate films supplemented with ginseng extract (*Norajit et al.*, 2010). Considering the red color of *B. pseudumbellata* fruit extract, reduced transparency of formulated film was expected. Plant extracts are known for the provision of opacity to polymers, so films containing extracts are translucent (*Norajit et al.*, 2010). The added fruit extract serves as a light barrier, thus preventing the breakdown and loss of light-sensitive compounds (*Mir et al.*, 2018).

Effect of extract infused NaCAS films on ground meat quality

Change in the pH of stored ground beef

Figure 2 shows the fruit extract's effect compared with the control on the overall pH of ground beef samples stored at 7°C on day 0 and during the nine storage days. The ground beef had an initial pH of 5.62 prior to the film application and storage. In this study initially, the pH of all beef samples decreased with storage, but then it started increasing gradually in all treatments (Figure 4), which could be due to glycogen decomposition in the stored beef (*Song et al.*, 2011). However, the pH increase was comparatively less in ground beef samples that were covered with film infused with fruit extract as compared to the control

Table 4. Characterization of sodium caseinate (NaCAS) films infused with methanol extract of *Berberis pseudumbellata* fruit (BPFE): Thickness (Th), water solubility (WS) and transparency (T)

Films	Th (mm)	WS (%)	T (%)
Control (NaCAS only)	0.11 ± 0.01	27.40 ± 3.87	18.21 ± 1.73
1 % BPFE + NaCAS	0.14± 0.02**	28.47 ± 2.12	16.08 ± 1.67*
1.5 % BPFE + NaCAS	0.15 ± 0.01***	34.77 ± 2.19***	14.41 ± 1.69**
3 % BPFE + NaCAS	0.16 ± 0.02***	39.55 ± 1.32***	14.20 ± 1.61**
^P-value	<0.001	<0.001	0.002

Legend: Values are given as means ± standard deviation. ^P-value calculated using one-way ANOVA for each property. *Pairwise mean comparison was also computed with the control (NaCAS only) taken as a reference group. *p-value<0.05; **p-value<0.01; ***p-value<0.001

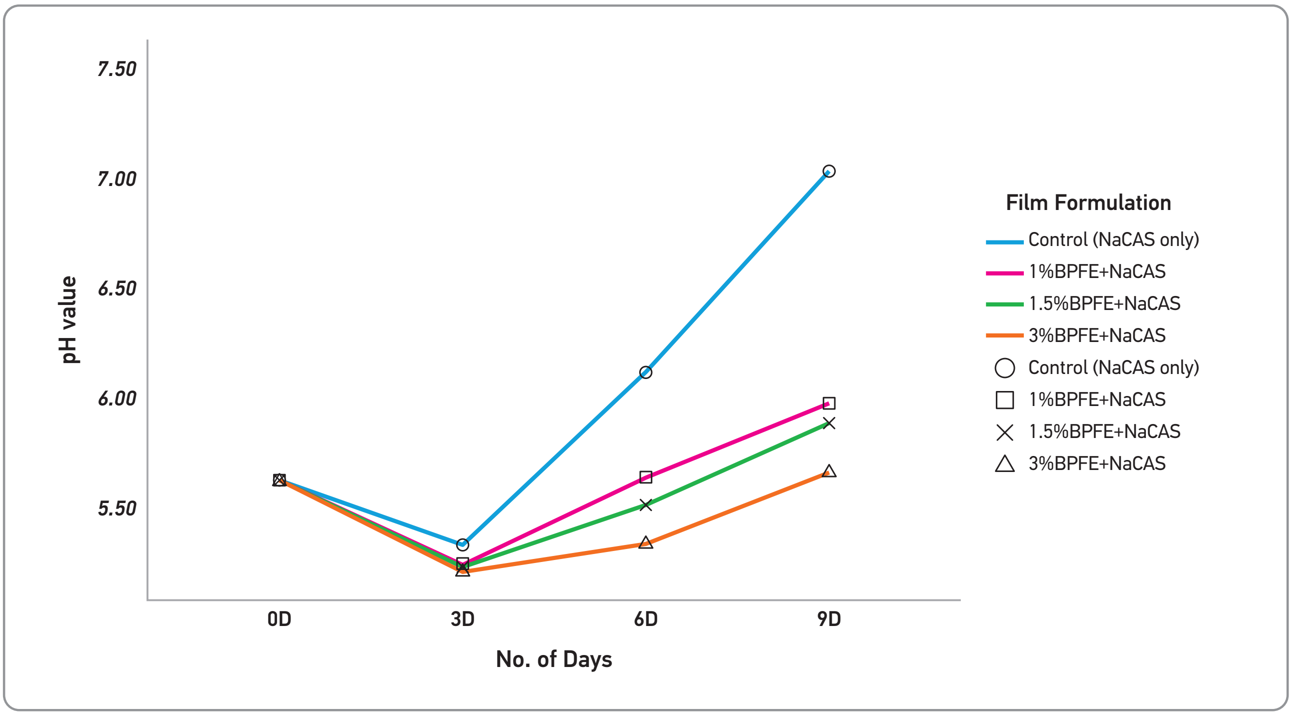

Figure 2. The pH of ground beef covered with NaCAS films with/without *Berberis pseudumbellata* fruit extract (infused/non-infused) during storage at 7°C for 9 days.

(NaCAS only film). The pH of ground beef covered with the 3% extract film ranged from 5.62 to 5.65. This mildly acidic pH might have inhibited microbial growth by inhibiting the endogenous enzymes, specifically proteases, at different proton grades, and thus resulting in comparatively few changes in pH. Earlier findings also reported the pronounced antimicrobial activity of plant extracts under acidic conditions (*Song et al.*, 2011). The difference in pH between treatments on different days was highly significant (interaction

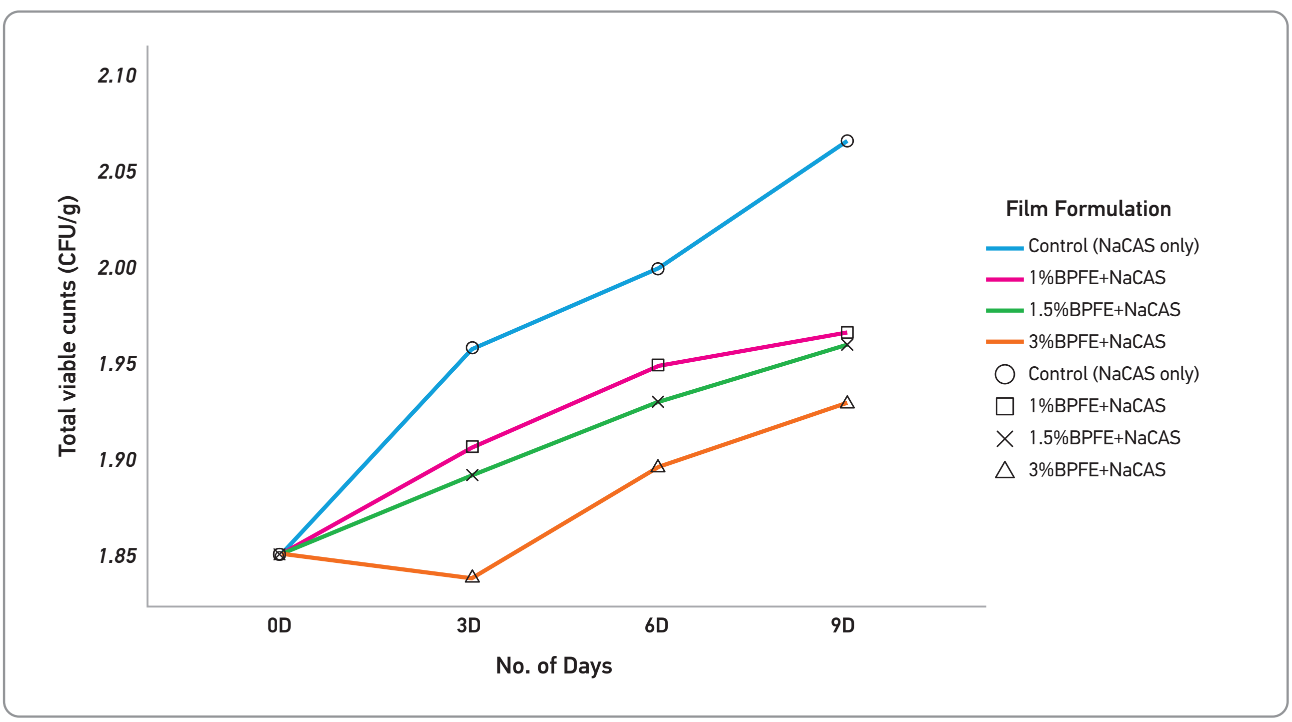

Figure 3. Total viable counts (TVC) of ground beef covered with NaCAS films with/without *Berberis pseudumbellata* fruit extract (infused/non-infused) during storage at 7°C for 9 days.

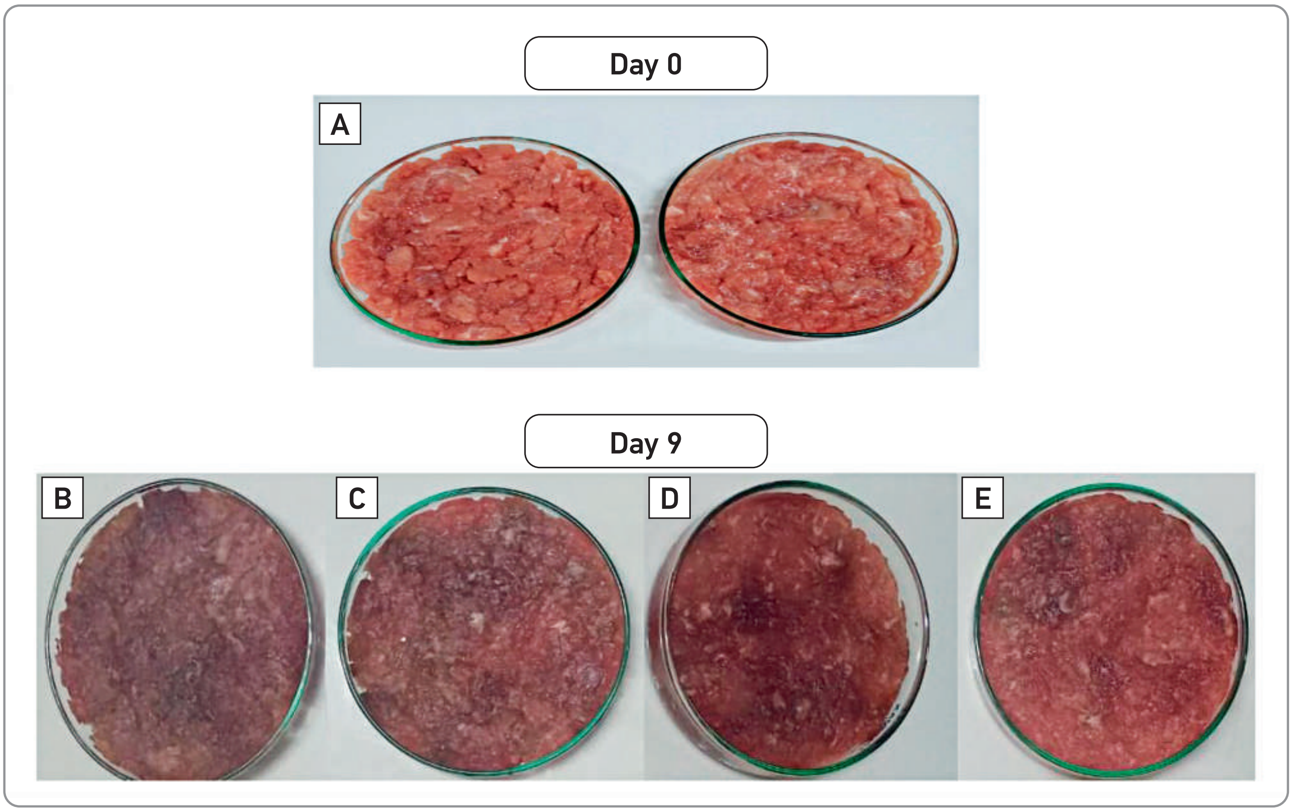

Figure 4. Effect of NaCAS films with/without *Berberis pseudumbellata* fruit (infused and non-infused) on the appearance of ground beef on day 9 of refrigerated (7°C) storage

Legend: A = ground beef on day 0 of storage; B = Control (sodium caseinate (NaCAS) only); C = NaCAS film infused with 1% of methanol fruit extract; D = NaCAS film infused with 1.5% of methanol fruit extract; E = NaCAS film infused with 3% of methanol fruit extract

p-value <0.001). The neutral but (for fresh beef) relatively high pH in the control ground beef (7.01) could be due to the formation of metabolic by-products by the native microbiota in the beef at the refrigeration temperature (*Ahn et al*., 2004).

Change in total viable count (TVC) of stored meat

On day 0, the TVC in ground beef was 1.85 log CFU/g, showing the acceptable quality of the beef utilized in the current study. Figure 3 shows the TVCs in all ground beef samples throughout the storage. The TVC in the control (NaCAS only) increased faster than that in ground beef covered with infused films. Compared with the control film, the NaCAS films successfully hindered the growth of TVC bacteria in the ground beef during storage. The lower TVCs noted in the ground beef covered with infused films might be due to the films behaving as an oxygen barrier, thus inhibiting the growth of aerobic bacteria. Bacterial growth in ground beef covered with 1.5% and 3% extract films was more effectively inhibited as compared to bacterial growth in the ground beef covered with 1% extract film. Studies have reported that films with incorporated active components, including phenolic compounds and other secondary metabolites obtained from plant extract, tend to effectively postpone microbial growth in foods including meat (*Umaraw et al*., 2020). Edible packaging films comprised of bioactive peptides and protein hydrolysates with added antimicrobial plant and spice extract have promoted the concept of safe food by demonstrating strong activity against the propagation of pathogenic microorganisms and lipid oxidation (*Aziz and Karboune*, 2018). Figure 5 shows the effect of control films (NaCAS only) and NaCAS extract-infused films on the overall appearance of stored ground beef on days 0 and 9 of storage.

Conclusion

This study revealed that the infusion of methanol extract of *B. pseudumbellata* fruit by high speed mixing imparts suitable physical characteristics to NaCAS biopolymer films. The infused films have strong antibacterial behaviour, thereby limiting aerobic bacterial growth (keeping the TVC low) and maintaining the acidic pH of ground beef. The reported antioxidant activity in extract infused NaCAS film also suggests its efficacy against oxidation reactions. Probable changes in the sensory characteristics of ground beef stored under such films, including colour and other quality indicators, must be considered in future studies.

Razvoj, karakterizacija i ispitivanje antimikrobnog, antioksidativnog potencijala jestivog filma na bazi natrijum kazeinata infuziranog ekstraktom ploda Berberis psedumbellata i njegov uticaj na kvalitet sirove mlevene govedine tokom hlađenja

Habiba Shah, Shakeel Ahmed, Faizah Urooj, Sidra Zaheer, Nilofer Fatimi Safdar

A p s t r a k t: Ova studija predlaže da razvoj, karakterizaciju i istraživanje antimikrobnog i antioksidativnog potencijala filmova natrijum kazeinata (NaCAS) infuziranih sa ekstraktom voća Berberis pseudumbellata (B. pseudumbellata) i njegovu primenu na mlevenu govedinu koja se drži u frižideru (7°C) tokom 9 dana. Infuzija voćnog ekstrakta poboljšala je fizičke i optičke karakteristike filmova. Propustljivost i rastvorljivost filma su se smanjili dodatkom ekstrakta voća, dok je debljina filma porasla. U testu difuzije agar diska, rezultati su pokazali maksimalnu inhibiciju gram-pozitivnih bakterija uključujući Staphilococcus aureus i Bascillus subtilis u poređenju sa gram-negativnim Streptococcus tiphi i Escherichia coli. B. pseudumbellata je takođe pokazivala sve veću antioksidativnu aktivnost sa povećanjem koncentracije. Infuzirani filmovi su pokazali relativno veći antioksidativni potencijal kada su procenjeni pre njihove primene na govedinu. Međutim, razlike u antioksidativnoj aktivnosti filmova (pre i posle nanošenja) nisu bile značajne (p<0,05). Uzorak govedine umotan infuziranim kazeinatnim filmovima (1, 1,5 i 3%) održavao je kiseli pH od 5,88 i 5,65, dok je kontrola pokazala pH od (7,01) devetog dana skladištenja. NaCAS filmovi sa 3% ekstrakta takođe su kontrolisali ukupan broj bakterija u poređenju sa kontrolom (p<0,05) sa povećanom količinom ekstrakta voća.

Ključne reči: *Berberis Pseudumbellata, jestivi film, natrijum kazeinat, goveđe meso, antioksidans, broj bakterija.*

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Determination of Quality Properties of Sucuk Produced Using Cattle Head Meat

Recep Kara[1]

A b s t r a c t: Sucuk is produced by mixing beef, animal fat and different spices. Usage of head meat, which is relatively more affordable, for sucuk production has started to increase, especially depending on red meat prices. In this study, 100% beef (group A) or 100% cattle head meat (group B) were used for sucuk production. Both groups of sucuk were heat-treated. Microbiological, chemical, sensorial and histological properties were analysed in sucuk. Enterobacteriaceae, coliform bacteria and Escherichia coli levels were all <2.00 log CFU/g in both sucuk groups; the numbers of total aerobic bacteria and Micrococcus/Staphylococcus were 4.95 log CFU/g and 2.13 log CFU/g in group A; 5.23 log CFU/g and 2.25 log CFU/g in group B, respectively. The pH of group A sucuk was lower than that of group B. Hydroxyproline and connective tissue contents of group B were higher than those of group A. Outer surface lightness value (L) was higher in group A, and redness (a) was higher in group B. Texture analysis showed that group B had higher hardness, cohesiveness and gumminess values, while group A had higher springiness and chewiness values. Striated muscle and adipose tissue were detected in group A, and sero-mucous tissues were found in group B during the histological analysis. Group A sucuk, in the sensory analysis, achieved higher general satisfaction scores than group B. As a result, head meat can be used in sucuk production.

Keywords: *sucuk, sausage, beef, cattle head meat.*

Introduction

Sucuk is defined as a fermented or heat-treated meat product. The cross-section of sucuk looks like a mosaic due to the fermentation and heat processes, which are applied after mincing and mixing the meat and fat of cattle and/or young cattle with flavours and filling them into natural or artificial casings under specific conditions. There are two types of sucuk in Turkey: fermented and heat-treated sucuk (*TFC*, 2019). With the increased sucuk production in Turkey, the increase in costs, and the development of competition in processed meat production, traditional sucuk has become increasingly appealing to only selective customers. Therefore, industrial sucuk production has started, and the final product is called heat-treated sucuk (*Degirmencioglu et al.,* 2006). There are many alternative types of sucuk in the world that are produced especially from edible offal, sometimes along with skeletal muscle (*Krishnan and Sharma,* 1990; *Santos et al.,* 2003; *Estévez et al.,* 2005; *Magoro et al.,* 2012).

Edible parts obtained from the head part of the animals, and that are composed of muscle tissue that do not contain skin, glandular tissues, brain, tongue, lymph nodes, pharynx muscle, mucosa, eye, gristle or bones, are defined as head meat (*TFC,* 2019). A significant amount of head meat is produced when the number of cattle butchered for human consumption is taken into account. After separating the parts (glandular tissues, bone, gristle etc.) that will not be consumed from the head meat, an average of 4–5 kg of meat can be obtained from an average adult bovine. In addition to its usage as ground meat and fried meat, head meat can also be used in products such as sucuk, salami and sausage in many countries. It seems that the usage of head meat, which is relatively more affordable, has now started to increase, especially depending on red meat prices. Additionally, it is known that sucuk produced from head meat also has a pleasant flavour and aroma. This study aims to determine the characteristics of heat-treated sucuk produced from cattle head meat.

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Materials and Methods

Production of Sucuk

For sucuk production, 80% beef (carcass meat, Group A) and 80% cattle head meat (Group B) was used in the sucuk batter. Sucuk batters were prepared by adding 20% fat and 2% salt (with sodium nitrite, $NaNO_2$), 0.6% sucrose sugar, 1% dried clean garlic, 0.7% red pepper, 0.5% powdered black pepper, 0.9% cumin and 0.25% pimento. Prepared sucuk batters were filled into 35 mm calibre intestinal casings and rested overnight, then processed by heat treatment for 15 minutes, to a central core temperature of 68°C (*Kara and Akkaya*, 2010). Analyses were conducted on sausages ready for consumption after production.

Physico-Chemical Analysis

Moisture, protein and fat content analyses of sucuk were performed according to (*AOAC,* 1990). The pH of sucuk was measured with a pH meter (Orion 420A, United States) standardised using buffer solutions at pH 4 and pH 7. The water activity (a_w) values of the sucuk were measured at 20°C using the a_w device (Novasina Lab-touch, Switzerland). L (lightness), a (redness), b (yellowness) values of the samples (inner and outer surface) were measured using a Minolta colour meter (Minolta CR300 Reflectance Colorimeter, Osaka, Japan). Determination of the level of thiobarbituric acids (TBA) was performed using spectrophotometric measurement (*Tarladgis et al.,* 1960; *Shahidi et al.,* 1985). The amounts of hydroxyproline and connective tissue in sucuk were determined according to *TS 6239* ISO 3496 (1997).

Texture Analysis

Hardness springiness, gumminess, cohesiveness, and chewiness features (Microstable TA.XT Plus, US) of sucuk were determined by texture profile analysis (TPA) (*Barbut*, 2006).

Microbiological Analysis

Sucuk (10 g) was homogenised with 90 ml of sterile peptone saltwater. Then, serial dilutions were prepared from the 1:10 reconstituted homogenates. The presence of *Salmonella* (*ISO*, 2017a), *Listeria monocytogenes* (*ISO*, 2017b) and *Escherichia coli* O157 (*ISO*, 2001) was determined, while counts of total aerobic mesophilic bacteria (TAMB) (*ISO*, 2013), Enterobacteriaceae (*ISO*, 2004), coliforms (*ISO*, 2006), *E. coli* (*ISO*, 2018a) and *Staphylococcus/Micrococcus* (*ISO*, 2018b) were determined.

Histological analyses

Histological analyses of sucuk were performed according to *Luna* (1968).

Sensory analysis

The sensory analysis of the sucuk was conducted by 10 expert panellists who were informed about the general characteristics of sucuks. Panellists evaluated the sucuk using a hedonic scale with a score range: 1–3 (very bad — unacceptable), 4–5 (medium), 6–7 (good), 8–9 (very good) in terms of appearance, colour, taste, texture and overall score (*Altug*, 1993).

Statistical analysis

Sucuk were produced in three repetitions, and the analyses were performed in two parallels. The difference between the sucuk groups was determined using the t-test.

Results and Discussion

Table 1 shows the findings of microbiological analysis of the two types of sucuk. Additionally, *Salmonella*, *L. monocytogenes* and *E. coli* O157 were not detected in the sucuk produced. The difference in the number of TAMB and in the number of *Staphylococcus/Micrococcus* between groups A and B was significant ($p<0.05$). Additionally, in both groups, *Enterobacteriaceae*, coliform and *E. coli* levels were <log 2.00.

Table 1. Microbiological Analysis (Family, group or species (mean log CFU/g)) of Sucuk

	TAMBS	Enterobacteriaceae	Coliforms	*E. coli*	Stap/Mic
A	4.95±0.07	< 2.00	< 2.00	< 2.00	2.13±0.04
B	5.23±0.04	< 2.00	< 2.00	< 2.00	2.25±0.01
	p<0.05	–	–	–	**p<0.05**

Legend: A: beef; B: cattle head meat; TAMBS: total aerobic mesophilic bacteria; LAB: lactic acid bacteria; Stap/Mic, Staphylococcus/Micrococcus

Table 2. Chemical Analysis of Sucuk

	pH	a_w	Moisture (%)	Fat (%)
A	5.65±0.02	0.826±0.013	45.25±0.82	33.46±0.06
B	6.40±0.01	0.837±0.014	41.06±0.33	30.99±0.02
	p<0.05	p<0.05	p<0.05	p<0.05
	TBA	**Protein (%)**	**Hydroxyproline**	**Connective tissue**
A	0.017±0.001	14.90±0.05	0.293±0.02	12.13±0.02
B	0.011±0.003	10.23±0.03	0.904±0.06	34.05±0.03
	p<0.05	**p<0.05**	**p<0.05**	**p<0.05**

Legend: A: beef; B: cattle head meat;; TBA: Thiobarbituric acid

The analysed parameters show the hygienic quality of the prepared sucuk. Thus, the incidence and numbers of Enterobacteriaceae in the head meat are reported as an effective indicator of hygiene and quality, especially concerning contamination of faecal origin (*Tornadijo et al.,* 2001; *Carney et al.,* 2006). Therefore, according to this study, it was determined that if the head meat, used as raw material, is obtained under appropriate conditions, the microbiological quality of the sucuk produced will be good. In our study, the microbiological properties of both groups of sucuk were found to be acceptable. However, Ranken (2000) reported that head meat should be used with caution as it is likely to be infected with a high level of bacteria.

Table 2 shows the results of chemical analysis of the prepared sucuk. Significant differences were found between groups A and B in terms of the analysed parameters (pH, a_w, moisture, fat, protein, TBA, hydroxyproline, and connective tissue) ($p<0.05$).

Chemical analyses provide important information about the quality and content of meat products. The pH (6.40±0.01) of group B sucuk was higher than that of group A (6.17±0.01). Similarly, *Verna et al*. (2008) found that the pH (6.41) of head meat was higher than that of skeletal muscle (5.85). *Verna et al.* (2008) reported that higher pH may be from head meat.

Considering a_w values of the sucuk, group A was 0.826, while group B was 0.837. a_w values in sucuk reported by *Kaban and Kaya* (2006) were 0.889–0.902. *Coskuner et al.* (2010) reported levels of 0.924–0.950. The a_w of sucuk in our study was lower than in these other studies.

In sucuk produced in the study, moisture contents were 45.25±0.82% in group A and 41.06±0.33% in group B. Fat content was determined as 33.46±0.06% in group A and 30.99±0.02% in group B. However, the fat and moisture contents of both groups of sucuk were found to be at acceptable levels according to the *Turkish Food Codex* (2019).

The TBA value of sucuks has a significant effect on colour quality, aroma, texture and nutritional value (*Demeyer et al.,* 2000) In our study, the TBA value was 0.017±0.001 in Group A sucuk and 0.011±0.003 in Group B sucuk ($p<0.05$). It was earlier reported that the TBA values >1.0 mg/kg cause bad odours (*Wu et al.,* 1991)

In the analysed sucuk groups, the protein content (14.90±0.05%) in the group with carcass meat was higher than in the group with head meat (10.23±0.03%) ($p<0.05$). Another study reported that the protein content of skeletal muscle is 19.84%; the protein content of head meat is 19.25% (*Verna et al.,* 2008). The study by *Dogu et al.* (2002) found an average protein content of 17.16% in sucuk. According to the Turkish Food Codex, the protein content should be 14% in heat-treated sucuk. The protein content of our sucuk that were produced using head meat did not meet this regulatory requirement.

Hydroxyproline contents were determined as 0.293±0.02 in group A sucuk and as 0.904±0.06 in group B sucuk. A significant difference ($p<0.05$) was found between the connective tissue level of the two types of sucuk, which were produced using carcass meat (12.13±0.02), or head meat (34.05±0.03). The fact that the head meat used was fibrous, rich in glandular tissues and had a high content of collagen would have impacted the sucuk produced from this meat type, causing low protein and high glandular tissue contents.

Table 3. Colour Analysis of Sucuk

	Inner Surface			Outer Surface		
	L	a	b	*L*	a	b
A	45.05±0.02	25.58±0.01	19.26±0.01	42.18±0.04	21.33±0.06	13.71±0.02
B	48.93±0.04	25.07±0.02	24.33±0.02	40.25±0.01	23.59±0.01	16.14±0.03
	p<0.05	**p<0.05**	**p<0.05**	**p<0.05**	**p<0.05**	**p<0.05**

Legend: A: beef; B: cattle head meat

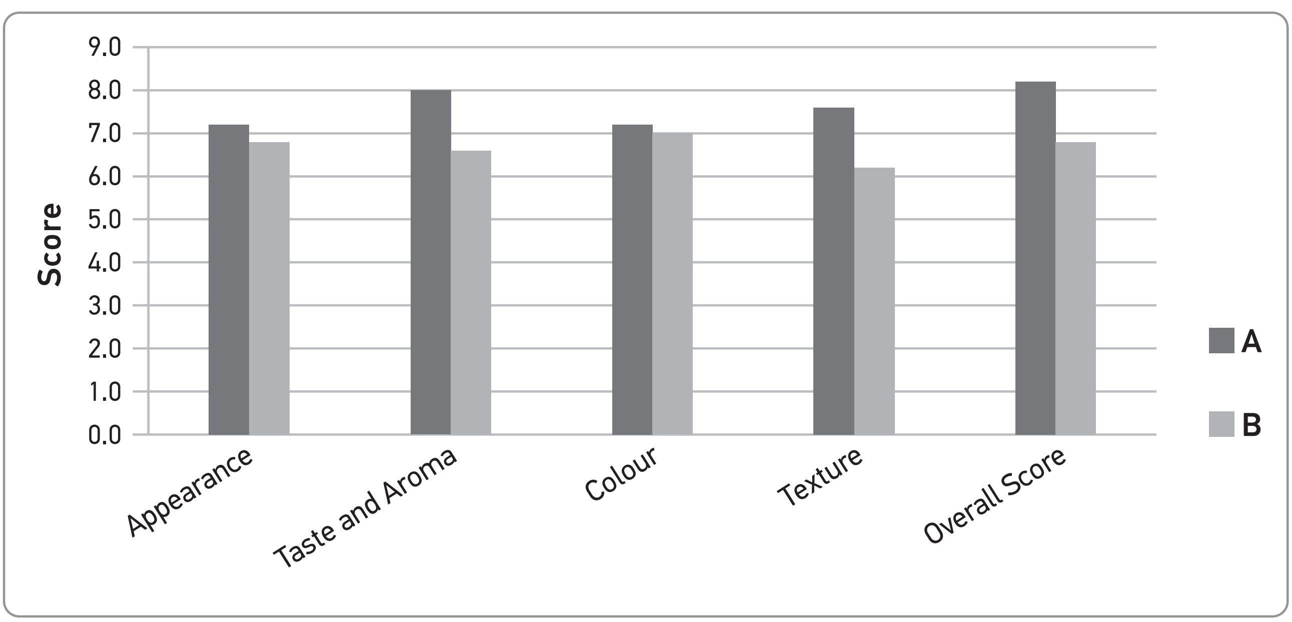
Table 4. Texture Analysis of Sucuk

	Hardness	Cohesiveness	Gumminess	Springiness	Chewiness
A	47.04±0.77	0.36±0.03	19.27±1.68	0.87±0.01	16.78±1.73
B	63.71±2.15	0.45±0.01	28.66±0.06	0.74±0.02	21.06±0.57
	p<0.05	**p>0.05**	**p<0.05**	**p<0.05**	**p>0.05**

Legend: A: beef; B: cattle head meat

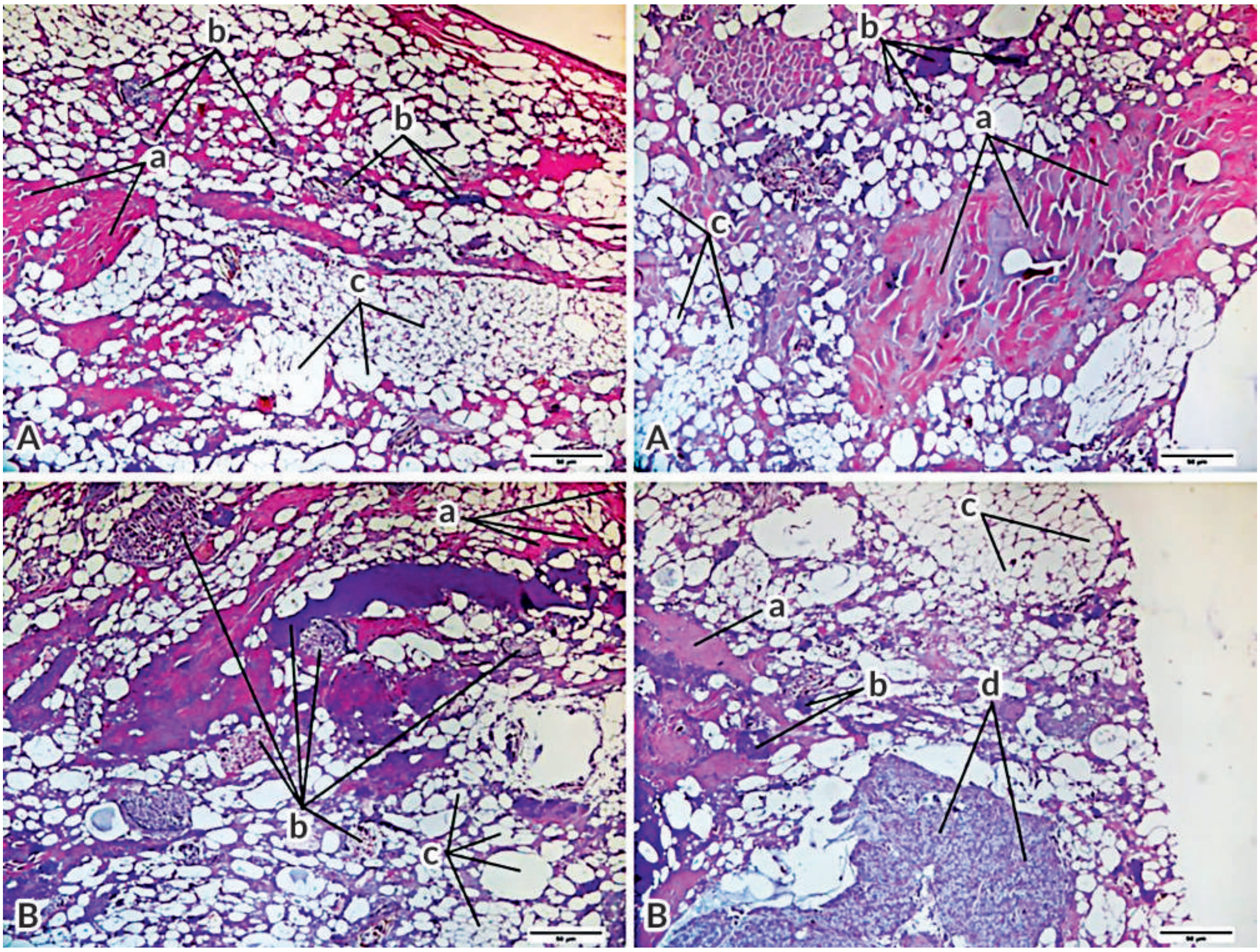
In meat products such as sucuk, physical properties, colour and organoleptic properties are the main factors that affect consumer choice. In general, these characteristics are measured by organoleptic techniques (*Bozkurt and Bayram,* 2006). Table 3 shows the cross-section surface colour and outer surface colour analysis results of the sucuk. A significant difference was observed between the two groups in both cross-sectional surface colour and external surface colour in terms of redness, yellowness, and lightness ($p<0.05$).

Table 4 shows the texture analysis results of the sucuk. There was no difference between the two groups in term of cohesiveness ($p>0.05$), but other differences between groups A and B were found to be significant (hardness, gumminess, springiness and chewiness) ($p<0.05$).



Legend: A: beef; B: cattle head meat

Figure 1. Organoleptic Analysis of Sucuk



Legend: A: beef; B: cattle head meat; a: skeletal muscle cell, b: spices, c: adipose tissue cell, d: seromucous glands

Figure 2. Histological analysis of the sucuk prepared from beef meat and cattle head meat

In the sensory analysis, no significant differences were found between the two groups of sucuk in terms of appearance and colour characteristics ($p>0.05$). Although group B scored lower in terms of taste, texture and general taste characteristics than group A, nonetheless, scores for group B were within the acceptable scoring range ($p<0.05$) (Figure 1).

Histological analyses identified striated muscle, adipose tissue and animal tissue in group A, while group B was found to contain striated muscle, adipose tissue and a small amount of seromucous tissue (Figure 2). During production, head meat should be separated from other tissues in the head: glandular tissue, lymph nodes, mucous membranes, eyes, cartilage and bones. The analyses conducted in the current study showed that this decomposition cannot be fully accomplished.

Conclusion

This study found that sucuks that are produced using head meat are acceptable in terms of microbiological, textural and organoleptic properties. However, sucuk prepared with head meat does not comply with the Turkish Food Codex, especially due to its high collagen content, low protein content and unacceptable hydroxyproline content. In order to evaluate and utilise cattle head meat with regard to high volume cattle production, novel legal arrangements will be necessary in the sucuk production process. It is recommended that all sucuks containing head meat are appropriately labelled for consumers by stating head meat as an ingredient on the product declaration.

Određivanje osobina kvaliteta sudžuka proizvedenog od goveđeg mesa

Recep Kara

A p s t r a k t: Sudžuk se proizvodi mešanjem goveđeg mesa, životinjske masti i različitih začina. Upotreba mesa od glave, koje je relativno pristupačnije, za proizvodnju sudžuka, je u porastu, posebno u zavisnosti od cena crvenog mesa. U ovom istraživanju, za proizvodnju sudžuka korišćeno je 100% goveđe meso (grupa A), odnosno, 100% meso glave goveda (grupa B). Obe grupe sudžuka su termički obrađene. U sudžuku su analizirana mikrobiološka, hemijska, senzorna i histološka svojstva. Enterobacteriaceae, koliformne bakterije i nivoi Escherichia coli bili su <2,00 log CFU/g u obe grupe sudžukqa; broj ukupnih aerobnih bakterija i Micrococcus/Staphilococcus bio je 4,95 log CFU/g, i 2,13 log CFU/g u grupi A, odnosno, 5,23 log CFU/g i 2,25 log CFU/g u grupi B, respektivno. pH vrednost sudžuka grupe A bio je niži nego u grupi B. Sadržaj hidroksiprolina i vezivnog tkiva u grupi B je bio veći nego u grupi A. Vrednost za boju spoljašnje površine (L) bila je veća u grupi A, a crvena boja (a) je je imala veće vrednosti u grupi B. Analiza teksture je pokazala da je grupa B imala veće vrednosti tvrdoće, kohezivnosti i gumavosti, dok je grupa A imala veće vrednosti elastičnosti i žilavosti (žvakanje). U grupi A detektovani su poprečno-prugasti mišići i masno tkivo, a u grupi B, sero-mukozna tkiva, koja su utvrđena tokom histološke analize. Sudžuk grupe A je u senzornoj analizi postigao više ocene opšte prihvatljivosti/zadovoljstva proizvodom od grupe B. Kao rezultat toga, meso glave goveda se može koristiti u proizvodnji sudžuka.

Ključne reči: *sudžuk, kobasica, goveđe meso, meso glave goveda.*

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Review paper

Intrinsic and extrinsic factors impacting fresh goat meat quality: An overview

Mohammed Gagaoua[1], Laura Alessandroni[2], Annada Das[3], Melisa Lamri[4], Dipanwita Bhattacharya[5], Pramod Kumar Nanda[6] and Arun K Das[6**]*

A b s t r a c t: Goat meat, known also as chevon or caprine meat, is an important source of protein and essential nutrients in many regions worldwide. To ensure high-quality goat meat production, it is crucial to understand the intrinsic and extrinsic factors that influence its sensory, technological and nutritional properties. This review aims to provide an overview of the factors affecting goat meat quality throughout the production and processing chain. The importance of different factors influencing goat meat quality were described. First, the focus was made on the intrinsic factors, including the effects of age at slaughter, gender (sex), breeds, slaughter weight, and the contractile and metabolic properties of the muscle by discussing their impact in terms of their influence on important intrinsic quality traits such as tenderness, flavor, color and overall quality of goat meat. Furthermore, the extrinsic factors such as production systems, husbandry practices, feeding strategies, types of feed and roughages, antioxidants, feeding systems, climate, season, and environmental conditions were examined in addition to the pre-slaughter treatments, transport conditions, and stress experienced by goats at the time of slaughter. Overall, this review synthesizes current knowledge on both the intrinsic and extrinsic factors affecting goat meat quality. The findings emphasize the importance of a better understanding and optimizing of these factors at each stage of production and processing to ensure the consistent delivery of high-quality goat meat. Further research in these areas will contribute to the development of improved practices and technologies in the goat meat industry.

Keywords: *Meat; Goat meat quality; Meat quality variation; Production and farming systems; Farm-to-fork factors.*

1. Introduction

Goat meat is popular globally due to its lean meat and favorable nutritional qualities. Further, it is an alternative source of low-fat content red meat with a healthy fatty acid profile compared to lamb and beef (*Rajkumar et al.,* 2015). There are different terms used for goat meat, based on the carcass weight. In France, Latin America, and the Mediterranean region, "capretto" is a term used to refer to goat carcasses weighing between 6–8 kg that are famous for their tenderness, juiciness, and flavor (*Pophiwa et al.*, 2020). In South Mediterranean countries, tender and fatless milk-fed kids weighing approximately 7–10 kg are preferred for grilling or roasting the whole carcass in traditional festivals like Easter and Christmas (*Rodrigues & Teixeira*, 2009). On the other hand, matured goat carcasses weighing between 16–22 kg are favored in South Africa and India, and this meat is known as chevon.

The quality of goat meat for consumption, as for other meat sources, is influenced by a variety of factors, both intrinsic and extrinsic, which encompasses the entire production and processing chain. In recent years, there has been a growing demand for goat meat due to its unique taste, perceived health benefits, and cultural preferences. As a result, ensuring high-quality goat meat production has become a key focus for producers, researchers, and consumers. Understanding

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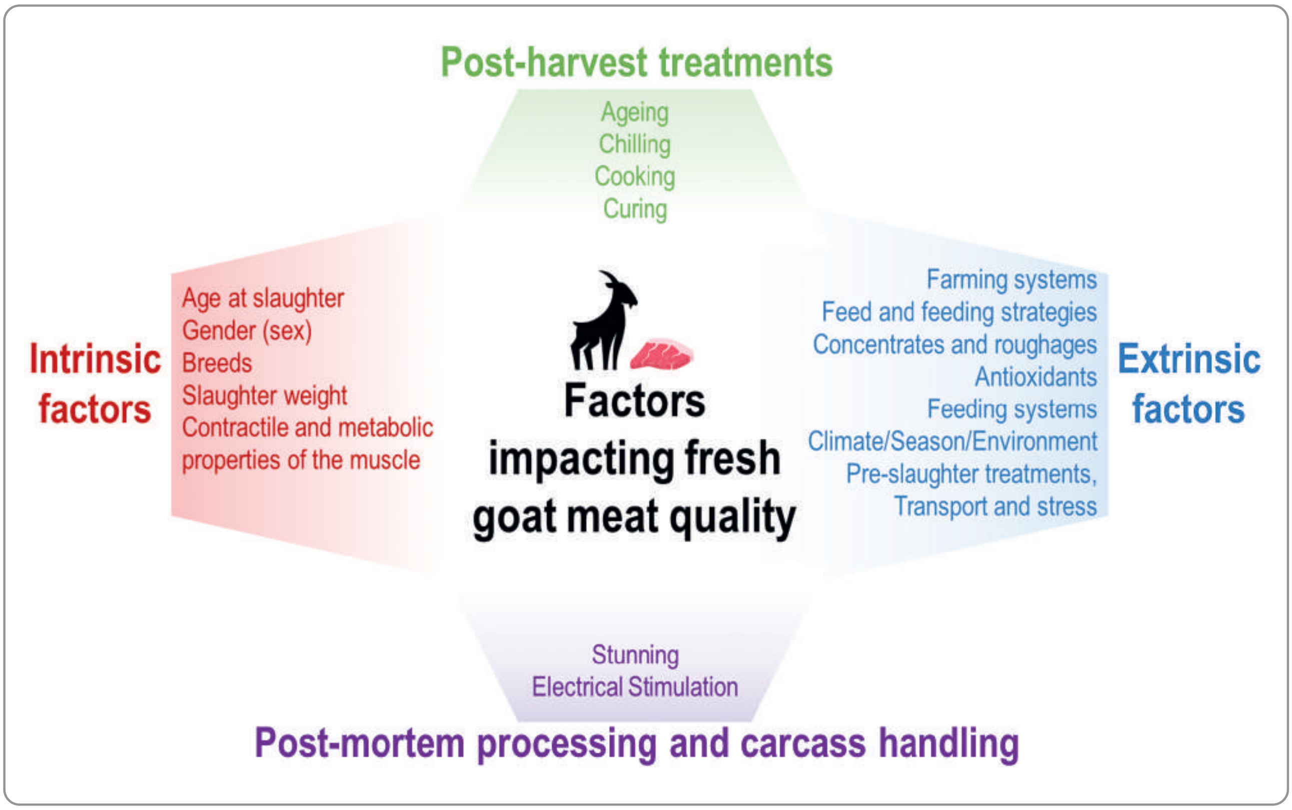

Figure 1. Multiple farm-to-fork factors impacting fresh goat meat quality

the factors at interplay and their impacts on meat quality is essential for producers and industry stakeholders to meet consumer expectations and maintain market competitiveness. This review aims to explore and synthesize current knowledge on both the intrinsic and extrinsic factors affecting goat meat quality (Figure 1).

Intrinsic factors affecting goat meat quality

The concept of "meat eating quality" is complex and multifaceted, and involves several dimensions, when we refer to the intrinsic qualities, these being sensory, nutritional, technological, safety, and many others (*Prache et al*., 2022). Several factors including feeding and rearing practices, genetic background, pre-slaughter stress of the animals and their handling, and post-mortem muscle processing and biochemical alterations, all interactively can influence the final quality of goat meat (*Gagaoua et al.*, 2022). The consumers' sense of smell play a significant role in determining meat eating quality *(Das & Rajkumar, 2010; Goetsch et al.*, 2011; *Pophiwa et al.*, 2020; *Webb et al.*, 2005). Despite goat meat being of satisfactory eating quality, it is not as preferred as other meat species (*Lamri et al.* 2022). For example, chevon is not preferred over lamb/mutton and beef due to its tough texture and strong peculiar flavor, particularly in western countries (*Webb et al.*, 2005). The acceptance of goat meat is also hindered by religious and caste dogma (*Webb et al.*, 2005). So, it is necessary to produce quality goat meat to promote its beneficial part among reluctant consumers *(Pophiwa et al., 2020; Lamri et al.* 2022). In the following sections, the main intrinsic factors that impact goat meat quality are described.

Effect of age at slaughter

Age is one of the most crucial parameters and indicators driving the final quality of goat meat, especially in terms of meat tenderness. Consumers generally have a hypothetical concept about slaughter age and meat-eating quality parameters, where they assume that meat from younger kids is better (more tender and palatable) than meat from older goats. Tenderness is one of the most critical sensory criteria for consumer acceptance, and it also determines the market value of meat animals (*Gagaoua et al.*, 2018a; 2019a,b). Numerous research studies have been conducted to reveal the age-associated integrated factors that influence meat tenderness or toughness. Intramuscular connective tissue and myofibers are main structural integrated factors that were intensively related to meat tenderness (*Listrat et al.*, 2020a,b). It was observed that the perimysium's (intramuscular connective tissue sheath of fascicles) quantity (90%), thickness and persistent organization are positively correlated with age and meat toughness (*Bakhsh et al.*, 2019). Other experiments in different species of meat like pork, horse etc. supported such statements (*Ke et al.*, 2019; *Roy et al.*, 2018). According to *Bakhsh et al.* (2019), the tenderness of post-mortem muscles is affected by the types of muscle fibers, their percentage, and their covered area. Muscle fibers undergo continuous changes up to the post-rigor condition to adapt to physiological changes. The authors found that the percentage of *Longissimus thoracis* muscle fiber type I increased with age, while type IIA and type IIB fibers decreased from the 9th to the 18th month of the experimental period. Fiber type I and perimysium thickness showed a positive correlation with the age of goats. Similar experiments conducted in South Africa suggest that 2-teethed goat kids had lower shear force values compared to 8-teethed matured goats, indicating greater tenderness in younger goats (*Simela et al.*, 2004).

Collagen is associated with age and has a significant influence on meat tenderness (*Listrat et al.*, 2020c). Matured animals have increased crosslinks in collagen fibrils, resulting in less solubility of collagen and toughening of meat after moist cooking. This factor is important in judging the tenderness of meat, and young animals are known to produce more tender meat than yearlings and older animals (*Schönfeldt et al.*, 1993). *Pratiwi et al.* (2007) found negative correlations between sensory scores for different taste attributes, including tenderness, juiciness, and slaughtered weight of carcass. However, in some countries, such as those that prefer chevon over capretto, the marketable slaughtered age should be between 1 and 2 years with a body weight of 25–40 kg to achieve better palatability. A carcass weight above 40 kg indicates lower quality characteristics of meat and lower appreciation by consumers.

Although aged does are preferred in some countries for preparing restructured and value-added processed meat products (*Webb et al.*, 2005), it has been reported that slaughtered goat kids between the ages of 3–5 months old are more tender, juicy, and flavorful compared to milk-fed kids (1–1.5 months) and older does (4–6 months) (*Borgogno et al.,* 2015; *Simela et al.*, 2004). Some studies suggest that younger kids produce less tenderness than mature ones. This may be because early age slaughter can lead to severe stresses that produces higher pH and consequently impacts cooking loss, shrinkage, color defects, etc. (*Kadim et al.*, 2014). Additionally, the deposition of intramuscular and subcutaneous fat is mainly seen in the mature body weight of goats. As a result, defects during carcass chilling, such as cold shortening, are common in young kids (*Pophiwa et al.*, 2020) due to a lack of subcutaneous fat. Intramuscular fat also contributes to the flavorful eating quality of meat (*Gagaoua et al.*, 2019c; 2020). Further scientific studies are required to investigate this debate on age and goat meat quality characteristics.

Effect of gender (sex)

Gender plays a significant role in the carcass composition and different quality characteristics of goat meat. However, after a thorough review of various scientific literature, it was observed that gender does not affect carcass dissected composition much, yet female goats tend to have more preferential internal fat deposition compared to males (*Todaro et al.*, 2004). In their study, *Santos et al.* (2007) found that female kids had significantly ($P < 0.05$) higher fat deposition, but dissected muscle and bone percentage were more for male kids. Pelvic limb tissue composition after dissection showed more muscle percentage in females, although the live animal weight, slaughter weight, and carcass weight were more for male goats (*Todaro et al.*, 2004). Flank firmness, streaking, feathering, and marbling are higher valued in females and sometimes in castrated goats rather than in intact males, and this trend may be due to the influence of the sex hormone testosterone in intact males (*Johnson et al.,* 1995). However, meat quality attributes are not always affected by sex alone; rather, a correlation was noticed with genotype and age. It was observed that the PUFA:SFA ratio was greater in males than females from different age groups and breed types (*Santos et al.,* 2007; *Todaro et al.,* 2004).

Cooking losses were found to be higher in meat from female kids due to less water holding capacity, whereas meat from male kids showed minimal cooking losses and more water holding capacity. These properties are linked to higher pH in male animals and more fat deposits in females (*Todaro et al.,* 2004). However, these differences have little effect on the acceptance range of quality characteristics in meat. Sex has very insignificant effect in texture attributes of meat, where males are preferred over females. This may be influenced more by extensive or intensive rearing management systems and feeding variations. Different researchers also concluded that Warner-Bratzler shear force values for meat from male or castrated males were lower compared to females indicating more tenderness in female goat meat except in *Semitendinosus* muscle (*Johnson et al.*, 1995).

Gender has a considerable importance for goat meat flavor and odor (*Carlucci et al.,* 1998). *Xazela et al.* (2011) found that the scores of aroma, flavor, juiciness, amount of connective tissue residue etc were higher for cooked meat in female goat meat, when compared to male under trained sensory panelists. The meat from female goat scored higher because of more intramuscular fat deposition and this marbling is directly associated with the juiciness, flavor and tenderness sensory traits of meat (*Xazela et al.,* 2011). Regarding aroma and flavor in cooked goat meat, interaction between slaughter age and castration has also a crucial role. After thorough experiments, *Madruga et al.* (2000) reported that meat from younger goat was tender, flavorful, juicy with a desirable aroma. But with aged animals, more goaty off flavor and stringy consistency of muscle fibers were detected in sensory analysis. Some branched chain fatty acids *i.e.* 4-methyloctanoic and 4-methylnanoic acids were the main goaty aroma producing components present in adipose tissue of goat. The fat deposition in castrated goats is greater than intact goats, therefore after thermal treatment, dissociation or fatty acid oxidation is more likely to produce different volatile hydrocarbons that actually enhances the goaty aroma in castrated goats (Zamiri et al., 2012; *Paengkoum et al.,* 2013).

Effect of breeds

Meat quality parameters like tenderness, texture, fatty acid profile and chemical composition may also differ within breeds or genotypes. *Stankov et al.* (2002) reported that crossbred of different native breeds of goat had higher amount of intramuscular fats and adipose tissue in muscles that correlates with better palatability, tenderness but less with moisture content. It was also noticed that local breeds and crossbreeds tended to narrow the proportion of unsaturated fatty acids with age. Meat quality variations of different breeds are related to age, diets and extensive or intensive management system (*dos Santos Souza et al.*, 2019). After extensive research in this particular area, *Johnson et al.* (1995) described that breed type has very minimal effects on carcass quality attributes such as carcass weight, fat and bone percentages. On the other hand, dressing percentage, water-holding capacity, especially flavor, Warner-Bratzler shear force value etc. were slightly affected by genotypes. Producers need to choose obligatory breeds with quality meat producing ability, resistance to emerging diseases and well accommodated to environmental disparity.

Goats are usually more prone to stress due to their anxious nature. Few breeds (Batina goat breed) are reported to have more responsiveness higher stress hormone concentrations (cortisol, adrenaline and nor-adrenaline) that indicate imbalances of acidification of different muscles (*Kadim et al.*, 2006). Ultimately this condition affects the quality of meat in terms of higher pH of muscle, darker meat, higher shear force value etc (*Kadim et al.*, 2014; *Pophiwa et al.*, 2020). Boer goats are considered the choicest supreme quality breed for quality meat production. This breed is preferred for genetic quality improvement of indigenous unproductive breeds by crossbreeding. Sometimes unimproved native goat breeds also produce acceptable quality attributes of chevon, especially at early ages of maturation. Therefore, it may be advised to producers to conserve and exert the indigenous breeds (*Pratiwi et al.*, 2007).

Effect of slaughter weight

Slaughter weight or carcass weight is another paramount factor that impacts the meat-eating quality (*Gagaoua et al*. 2018b). In the case of goat, both factors influence the dressing percentage, body compactness including carcasses size and conformation (*Martelo et al.*, 2020; *Rajkumar et al.*, 2014). Conducting research with different age groups of male and female goats, *Teixeira et al.* (2011) found that with the enhancement of ages and slaughter weight, carcass length, hot carcass weight, carcass width were also enhanced. The authors further reported that with the advancement of ages and slaughtered body weight, chump and breast weight, loin proportion, kidney and pelvic fat, especially in female were increased in significant proportion. Alternatively, leg, shoulder, fore ribs and bone proportions were diminished inversely with body weight. They also observed the carcass weight had a significant effect on muscle color, as reduced brightness and increased redness were noticed with enhancement of the body weight.

Interestingly, carcass weight has a significant role in shear force values of goat meat. It was noticed that with the increased body weights, shear force values dropped down notably. With the matured carcass weight, cutting forces also reduced down unlikely other studies that confirmed more shear force cutting values observed with higher carcass weights (*Argüello et al.,* 2005; *Santos et al.*, 2007). Specially in female goats, due to more deposition of body fats, cutting forces were significantly lower indicating more tenderness and flavorful meat (*Johnson et al.*, 1995; *Teixeira et al.,* 2011). *Pratiwi et al.* (2007) described a negative correlation between sensory scores and carcass weight, and it was found that above 40 kg body weight, quality parameters start deteriorating sharply.

Effect of contractile and metabolic properties of the muscle

In goat meat, almost 60% is dissectible lean muscle tissue, and up to 15% dissectible fat. However, because of their low subcutaneous and intermuscular fat deposits surrounding the carcass, there may be severe drip loss and cold shortening during the chilling process. This problem can be solved by improved nutrition management or conditioning before slaughter to deposit more subcutaneous and intermuscular fat over the carcass and viscera, leading to less shear force values and more sarcomere length (*Simela et al.,* 2011; *Webb et al.,* 2005). Pre-slaughter factors such as on-farm management practices, pre-slaughter transportation, and physiological and heat stress can lead to significant physiological and biochemical changes in the muscular components and hormonal imbalances of goats. Stress management is, therefore an essential part of minimizing glycogen depletion, shrinkage issues, and ensuring meat quality (*Pophiwa et al.,* 2020). These pre-slaughter factors are equally important in determining the contractile and metabolic properties of muscle fibers in the post-slaughtered condition (*Picard et al.*, 2014; *Picard and Gagaoua*, 2020, *Terlouw et al.*, 2021).

Skeletal muscle fiber types, intramuscular connective tissue, intramuscular fat and stored glycogen etc. are directly associated with post-mortem changes of muscle biology (*Listrat et al.*, 2016; *Gagaoua et al.*, 2015; *Gagaoua et al.*, 2016a*; Picard and Gagaoua*, 2020). After slaughter, carcasses are usually kept under refrigerated conditions for specific periods of time (not always the case in poor or developing countries) for facilitating post rigor resolution and natural conditioning of muscles. In this period, changes of sarcomere length, alteration of actomyosin cross bridges, ultrastructural changes of myofibrils and connective tissue or alteration of metameric organizations, myofibrillar fragmentation index, proteolytic deviations are foremost associated reasons for integrating the most desirable olfactory quality characteristics in meat (*Gagaoua et al.,* 2021; *Gagaoua et al.*, 2022). Enzymatic changes start soon after the killing process of the animal to restore the contractile and metabolic activity of skeletal muscles under deficiency of oxygen (*Ouali et al.,* 2013). Post-mortem glycolysis, pH decline and chill temperature and its decline in the carcasses are related consequences to initiate *rigor mortis* followed by complete depletion of creatine phosphate and ATP, the main energy sources for muscle contraction. A reduction in the efficiency of the calcium pump causes an increase in the net efflux of calcium ions from the sarcoplasmic reticulum, which activates the contractile mechanisms. This situation activates the endogenous proteolytic enzymes (calpain, caspases, cathepsin etc.) that can induce the morphological changes of proteins in muscle tissue and/or connective tissues (*Gagaoua et al.,* 2021). Ultimately the Z line ultrastructure of myofilaments, responsible for muscle stiffening, goes through the *rigor mortis* resolution by splitting it and collagen solubilization is also seen after cooking (*Purslow et al.*, 2021). In this period, major sensory attributes like tenderness, water-holding capacity, color and firmness are determined as ultimate meat quality parameters (*Listrat et al.*, 2016). The appearance of meat is primarily influenced by the oxidation and reduction of natural pigments, such as myoglobin, or their chemical state (*Purslow et al.*, 2021).

One of the challenges in preserving the quality of meat is cold shortening, which can occur during the rapid chilling process of animal carcasses. This results in tough meat with significant drip loss. To prevent cold shortening in goat carcasses, delayed chilling at temperatures of 10–15°C for 6 hours, followed by further cooling at 0–4°C for up to 24 hours, has been shown to be effective (*Kadim et al.*, 2014; *Simela et al.*, 2004). Another method to prevent cold shortening is by using electrical stimulation (ES) with medium voltage, which induces accelerated pH drop and proper temperature combination, thereby avoiding glycolytic potential and quality defects development. The application of ES technique to improve goat meat quality is addressed later in this review.

Extrinsic Factors affecting goat meat quality

Goat meat quality can be affected by different extrinsic factors, such as the system of rearing (extensive, intensive, semi-intensive, and organic), feeding strategies, environmental conditions (e.g., origin/region of production and climate/season), animal welfare (including pre-slaughter treatments, transport, and stress), and processing or post-harvest conditions (such as chilling, ageing, cooking, packaging, and storage). These extrinsic factors can significantly impact the final quality of goat meat *(Bernués et al., 2003; Dashdorj et al., 2015; Poveda-Arteaga et al.*, 2023). Information on extrinsic factors affecting goat meat quality is crucial for consumers concerned about credence quality issues such as safety, health, and ethical considerations. This information can help consumers make informed decisions about the goat meat they consume. Therefore, understanding the impact of extrinsic factors on goat meat quality is essential for ensuring high-quality goat meat products that meet consumer expectations (*Northen*, 2000; *Bernués et al.* 2003a, and *Corazzin et al.* 2019). Various extrinsic factors affecting goat meat quality are described here in the following sections.

Production or Husbandry or Farming systems

Production, husbandry or farming systems viz., extensive, intensive, semi-intensive and organic system of rearing have a great influence on goat meat quality traits (*Corazzin et al.,* 2019). Different farming systems can result in differences in growth rates, yields and various carcass quality parameters of goats (*Assan,* 2012; *Toplu,* 2014). For example, *Liotta et al.* (2020) conducted a study to investigate the effect of production system on the growth performances and meat traits of suckling Messinese goat kids. The researchers divided a total of 102 suckling kids into two homogeneous groups and reared them under two different systems: the extensive system (ES) and semi-extensive system (SES). The animals reared under SES were fed exclusively on spontaneous pasture diet and kept in the farm during the evening, while those reared in ES were fed exclusively on spontaneous pasture diet and kept exclusively outdoors. The study found that the production system did not affect the weight of kids at birth, but there was a significant difference in the performance of kids in relation to the breeding system. The chemical composition of the *Longissimus thoracis* muscle was not significantly affected by the production system. However, the ES group showed some differences in meat traits compared to the SES group. Specifically, the ES group showed lower final pH, hue angle values (color), and higher values of cooking loss and shear force affecting the texture and color of the meat. Furthermore, the production system significantly influenced the fatty acid composition of the meat. The meat from the ES group had the highest values of monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA), as well as the lowest ω-6/ω-3 ratio and thrombogenic index. These findings suggest that the production system can affect the nutritional quality of goat meat, which can have implications for human health. In summary, Liotta et al. (2020) showed that the production system can affect the performance, texture, color, and nutritional quality of goat meat. These findings highlight the importance of considering the production system when evaluating the quality of goat meat and making informed decisions about goat meat consumption.

Yalcintan et al. (2018) compared the carcass and meat quality traits of Saanen goat kids raised under natural rearing and artificial rearing systems. The artificial rearing kids were separated from their dams immediately after birth and fed with commercial milk replacer, while the natural rearing kids were fed milk from their does. The rearing type did not affect the average daily gain, slaughter weight, hot carcass weight, empty body weight, dressing %, subjective conformation and fatness scores of kids. It was also observed that the rearing type had no effect on instrumental meat quality traits, except for meat lightness (L^*) and hue angle (h°) values. Meat from natural rearing kids had higher L^* and $h°$ values at 1 hour and 24 hours after cutting than those of artificial rearing kids. From the sensory evaluation results, it was concluded that meat from natural rearing kids was more tender and juicier than that of artificial rearing kids.

In another study, *De Marzo et al.* (2018) reported that extensive farming represents the best system for goats living in Mediterranean environment, despite the fact that the productive potential is partly achieved, but the rusticity and frugality of goats reach their maximum. The researchers observed that extensive farming allows the maximum use of environmental resources enabling the two Italian goat breeds viz., Garganica and Girgentana reared in two different regions of Italy, to produce primarily milk and secondarily meat.

Quaresma et al. (2016) studied the meat lipid profile of suckling goat kids from three certified and one non-certified production system obtained from an intensive dairy farm. Goat reared in certified system displayed lower lipid contents (1.0 vs. 1.9 g/100 g of meat) but higher contents of total cholesterol (61 vs. 48 mg/100 g meat). Certified system goats displayed higher CLA content, α-tocopherol content, more than twice the total PUFA content and more than triple content of n-3 PUFA than of the non-certified systems.

Ozcan et al. (2014) documented that Gokceada kids reared under an extensive production system had lower meat lightness, high scores for meat color intensity evaluated by redness (a^*), flavor intensity and overall acceptability as compared to kids reared under semi-intensive systems. The pre-slaughter weight (17.44 and 12.51 kg), cold carcass weight (8.66 and 5.53 kg) and cold dressing % (54.9 and 49.28%) were always higher in animals reared under extensive than semi-intensive system, respectively. This study concluded that an extensive system of rearing was more appropriate than semi-intensive system for kid meat production.

Zurita-Herrera et al. (2013) determined the effect of three management systems on meat quality of 61 goat kids. Kids from the extensive management system displayed pink meats than intensive systems with natural and artificial rearing management. The type of management system had no effect on the pH, chemical composition and sensory evaluation. Intensive combined with artificial rearing system goat meat had the lowest capacity to retain water. Intramuscular fat deposits from the kids reared under extensive management system showed the lowest percentage of C14:0 fatty acid and the highest percentage of C18:1. The researchers observed that a strong influence of physical activity and trough grazing in extensive management system led to production of healthier kids with lower atherogenicity index of intramuscular fat.

Jambrenghi et al. (2007) conducted a study on the effect of goat production system on meat quality and CLA content in suckling kids. Twenty male Ionica suckling kids fed only on maternal milk were subdivided into two groups. One group (G1) was raised under dams reared by intensive system whereas the other group (G2) was raised under dams grazing on pasture. Upon slaughtering the animals on 45 days, it was found that the goat production system had no effect on kid's growth rates, slaughtering yield and other carcass characteristics. The animals under G1 had significantly higher pH of *Longissimus thoracis* muscle obtained after 45 minutes of slaughter. The conjugated linoleic acid (CLA) content, cooking loss and tenderness values of meat in G2 were higher, but the meat color was lighter and had greater yellowness and chroma values. However, the meat chemical composition of both groups did not differ in raw as well as cooked meats.

Feed and feeding Strategies

Feed and feeding strategies can have a significant impact on the quality of goat meat. The composition of goat meat can be influenced by the type and quantity of feed provided to the animals. Goats that are fed a balanced diet, with a proper ratio of carbohydrates, proteins, and fats, tend to produce meat with higher nutritional value and better sensory characteristics. Feeding of animals may influence the carcass and meat composition, muscle pH decline and the rate of post-mortem carcass cooling. Also, there is a requirement of dietary protein and energy for increased muscle maturity (*Kannan et al.*, 2014). It is also observed that dressing % can be improved by increasing the level of high nutritious diet, which can increase the proportion of muscle and fat as compared to bone in small ruminants (*Corazzin et al.*, 2019; *Das et al.*, 2008; *Gürsoy et al.,* 2011).

Feeding strategies such as grazing, browsing, and supplementation can also affect the meat quality of goats. Goats that are raised on pasture or allowed to graze freely tend to produce leaner meat with higher levels of omega-3 fatty acids and CLA, which are beneficial to human health. On the other hand, goats that are fed a high-grain diet, such as in intensive feeding systems, tend to produce meat with higher fat content and lower levels of CLA. In addition to the type of feed, the duration of feeding can also influence meat quality. Goats that are fed for a longer period of time tend to have meat with a richer flavor and higher levels of marbling, which is highly valued by consumers.

Overall, the feed and feeding strategies used in goat production can have a significant impact on the quality and nutritional value of the meat. Therefore, it is important for producers to carefully consider their feeding practices and make the necessary adjustments to ensure that their goats produce high-quality meat that meets consumer expectations.

Concentrates and roughages

Da Silva Pereira et al. (2020) studied the effect of diets containing cunha hay (CH) and forage cactus meal (CM) on carcass traits, fatty acid profile and meat quality of Boer crossbred goat. Carcass yield, fatty acid profile and commercial cut weights were higher in the animals fed CH and CM at any concentration than the control groups. Animals fed with CM feed resulted in better proportion of unsaturated fatty acids, desirable fatty acids, omega 6/omega 3 ratio and hypo-/hypercholesterolemic index.

Guzmán et al. (2020) studied the use of by-products of orange, *i.e.,* dehydrated orange pulp (DOP) at 0%, 40% and 80% levels in goat feed and its effect on physico-chemical, textural, fatty acid, volatile compounds and sensory characteristics of meat of suckling kids of Payoya breed. Meat from kids in the DOP-40 and DOP-80 groups exhibited characteristics favorable for human health, including the thrombogenicity index, PUFA/SFA ratio, and n-6/n-3 PUFA ratio. The meat also exhibited reduced MUFA content. In another study, *Hwang et al.*(2018) determined the effect of alfalfa feeding (ALF) and conventional commercial concentrate (CCP) pellets on meat quality and fatty acid profile of Korean native black goats. There were no significant differences in proximate chemical composition, collagen and myoglobin content, meat color, WHC and tenderness of meat between ALF and CCP groups. However, the proportion of oleic acid was significantly higher in ALF goats whereas, proportions of linoleic and arachidonic acids were significantly higher in CCP goats. These results suggested that Korean native black goats fed with alfalfa could result in meat with desirable fatty acids. In yet another study, *Ebrahimi et al.* (2018) investigated the effects of n-6: n-3 PUFA ratios in concentrate on meat quality, carcass characteristics, tissue fatty acid profiles and expression of lipogenic genes in growing Boer goats. This study concluded that the optimal n-6: n-3 fatty acid ratio of 2.27:1 exerted beneficial effect on meat fatty acid profiles, leading to enrichment in n-3 PUFA and CLA in goat intramuscular fat. In a separate study, *Abuelfatah et al.* (2016) studied the effect of n-3 PUFA supplementation (0, 10 and 20%) in diet of Boer bucks on meat quality, sensory evaluation and lipid oxidation at different post-mortem ageing times. The authors observed no difference in cooking loss, WBSF value and color of meat from all three groups on the first day of ageing. After 7 days of ageing, the color of meat was affected. The tenderness, juiciness and overall acceptability of groups supplemented with 20% n-3 PUFA rated better than other groups. No difference was observed in color, flavor and aroma of meats from all the three groups. In this experiment, the lipid oxidation in meat was positively correlated with the level of n-3 PUFA and ageing time.

Brand et al. (2018) suggested that the energy density of feedlot diets can be varied to produce chevon with uniform and desirable quality characteristics. Conducting a study in Boer goat castrates finished on diets varying in energy content (9.7, 10.2 and 10.6 MJ ME/kg feed), the authors noticed no significant differences in proximate composition and sensory parameters like flavor, aroma, texture etc. amongst the three goat groups. *Lee et al.* (2017) evaluated the quality characteristics of goat meat as influenced by condensed tannins-containing pine bark. In this case, Kiko crossbred male goats were grazed randomly and assigned to either Bermuda grass (BG) hay or pine bark (PB) supplementation for 55 days. No differences were found in average daily gain, proximate composition, WBSF values, cooking loss and TBARS values of meats of both groups. Further, no differences were found in $L*$ and yellowness ($b*$) color values. However, the $a*$ values of BG group were higher than that of PB group. Further, the PB group had lower CLA and PUFA contents and higher EPA content than the BG group. This study suggested that wood derived condensed tannins in PB might not impact the nutrient composition, eating quality and fatty acid profile of chevon. Similarly in other study, *Brassard et al.* (2017) studied the effect of inclusion of barley and corn in the ratio (100:0; 50:50 and 0:100) in the diet of concentrate-fed male Boer kids on growth performance, meat quality and muscle fatty acid composition. The researchers noticed that inclusion of barley in diet linearly increased concentrate intake and average daily gain, whereas no significant differences were observed in carcass traits and meat quality among the three treatments.

Moyo et al. (2014) and *Xazela et al.* (2012) observed that feeding Moringa (*Moringa oleifera*) leaf meal and sunflower cake, respectively, resulted in higher physico-chemical and sensory properties of goat meat as compared to meat of other test groups. *Marinova et al.* (2005) reported that fish oil supplementation in the diet of goats influenced the physico-chemical meat quality and led to higher deposition of body fat. Even *Rao et al.* (2003) found that feeding neem seed kernel cake improved the fatty acid content, decreased the cholesterol content of goat meat without affecting the meat quality.

Antioxidants

Chevon is prone to rapid lipid oxidation on refrigerated storage because of its high unsaturated fatty acid content (*Das et al.*, 2009; *Kannan et al.*, 2014). Dietary supplementation of antioxidants to goats has the potential to retard lipid oxidation. *Wang et al.* (2017) studied the effect of α-lipoic acid (LA) in different concentrations (0, 300 and 600 mg/kg) on carcass characteristics, antioxidant capability and meat quality in Hainan black goats. It was recorded that the goats fed with diet containing 600 mg/kg LA had a significantly higher average daily gain and feed conversion rate compared to control group fed on basal diet without LA. There was no difference in carcass characteristics, pH and intramuscular fat of all the three groups of goats. The meat from group of goats fed on 600 mg/kg LA had a significantly higher antioxidant enzymes like SOD, GSH-Px, catalase and higher T-AOC etc. This group had the lowest MDA concentration, low drip loss and lower WBSF values. This study indicated that diet supplemented with LA may influence the antioxidant capacity, meat quality and growth performance in goats. Likewise, dietary supplementation of seaweed extract has also been reported to affect the antioxidant activity and meat quality characteristics in goats *(Galipalli et al., 2004; Kannan et al.*, 2007).

Feeding Systems

The carcass composition and meat quality can also be affected by the feeding systems (*Corazzin et al.*, 2019). Confined feeding mainly with concentrate can affect various carcass characteristics resulting in heavier goats and higher fat levels than grazing goats (*Goetsch et al.*, 2011; *Ryan et al.*, 2007; *Toplu*, 2014). It is also observed that meat from animals fed on pasture grazing system is darker than that of concentrate feeding systems *(Priolo et al., 2001; Rodrigues et al.*, 2011). *Santos et al.* (2020) evaluated the effect of three feeding systems on the organoleptic and physico-chemical properties of goat meat. The three feeding systems included traditional System (TS), intensive feeding System without concentrate (IS) and intensive feeding System with concentrate (IS+C). The meat of goats under IS+C and IS presented higher intramuscular fat content and better flavor and aroma scores. The goats that received IS+C showed meat with more intense red color, high moisture, low fat, more tender and juicier than other groups. Overall, the meat from IS+C group of goats showed better attributes than others. *Kamatara et al.* (2014) reported that goats supplemented with non-molasses based and molasses-based concentrates produced higher carcass weights and carcass quality characteristics than that of goats fed on grazing system only. *Pearce et al.* (2010) reported that goats reared in saltbush-based pasture systems had higher meat quality and high vitamin E content.

Climate/Season/Environment

Goats are highly adaptable animals that can thrive in a wide range of climatic conditions, from arid desert areas to tropical rainforests. They have the largest ecological distribution of all domesticated animals and are well-suited for harsh environments. In fact, goats are the most beneficial animal to be reared in areas where almost uncultivable land is the main source of feed, such as resource-constrained environments with water scarcity and nutrient deficiencies (*Erasmus*, 2000; *Shinde,* 2000). This is exemplified by the Boer goat meat production in the arid and semi-arid regions of South Africa (*Webb & Pophiwa*, 2018). Asia and Africa are home to 88% of the world's goat population, with 80% of them living in the tropics and sub-tropics. Therefore, the goat is an important animal for meat production in these regions.

The climate change is seen as a significant threat to sustainability of many species including goats in many parts of the world, mainly due to its impacts on the availability of pasture and productive performance of goats (*Nardone et al.*, 2010), hence affecting the reproduction, disease, health and meat quality of goats. Further, various kinds of stress viz., physical, nutritional, chemical, psychological, and most importantly heat stress under the changing climate can affect the meat quality (*Gupta et al.*, 2013). In general, climate change could affect goat meat quality in two ways. First, affecting the organs and muscle mechanism directly pre-slaughter, which persists even after slaughter. Second, the changes in husbandry practices in response to climate change could indirectly lead to changes in meat quality (*Gregory,* 2010). For example, changing to heat-tolerant breeds of animals could lead to tougher, less juicy meat with less marbling. Also, pre-conditioning animals to heat stress may lead to more viable ultimate pH of meat (*McKee & Sams*, 1997; *Wheeler et al.*, 2001). Moreover, the impact of climate on meat quality varies between regions. High ambient climate can favor greater muscle marbling and internal fat depot of subcutaneous fat (*Gregory,* 2010). With the changing climatic conditions, the adaptive local breeds can be better alternatives as an appropriate bio-resource to sustain goat meat production (*Joy et al.*, 2020).

Several researchers have studied the impact of climate, season, temperature and environment on meat quality and adaptability of different livestock species. *Chergui et al.* (2017) studied the seasonal effects of plasma cortisol concentrations in Bedouin buck, native to Algerian Sahara Desert to understand the mechanism of adaptation to extreme climates. Another earlier study allowed better understanding the cellular stress response in terms of heat shock protein (HSP70, HSP27) gene expression against heat and cold challenge in goat peripheral blood mononuclear cells (*Jagan Mohanarao et al.*, 2014). *Archana et al.,* (2018) compared the impact of heat stress on meat production characteristics of Osmanabadi and Salem black breed goats based on changes in carcass characteristics, meat quality attributes, plasma leptin concentration, skeletal muscle myostatin and heat shock protein 70 (HSP70) gene expression patterns. The results of this study suggested that Salem black breed had a better resilience capacity as compared to Osmanabadi goats in maintaining meat production during heat stress. This study further established plasma leptin and HSP70 genes to be the ideal biomarkers to reflect the impact of heat stress on meat characteristics in indigenous goats. Another study investigated the effect of heat stress on blood parameter, carcass and meat quality of Black Bengal goat (*Rana et al.*, 2014). This study suggested that heat stress significantly affected the blood parameters, cooking loss, pH, by-product content of goats rather than non-heat stressed group of goats. *Kadim et al.*, (2008) studied the effect of seasonal temperatures on meat quality characteristics of hot-boned, *Psoas major* and *Psoas minor* muscles from Omani goats and Somali goats. Muscles collected during hot season had significantly higher ultimate pH, darker color and high myofibrillar fragmentation index than those collected during cool seasons. However, the meat collected during cool season had higher expressed juice than hot season meat. These results indicated that high ambient temperature had significant effects on meat quality.

Pre-slaughter treatments, transport and stress at slaughter

Animals perceive any unusual manipulation including transportation, fasting, slaughtering as stressful and these may ultimately have a negative impact on meat quality (*Biobaku et al.,* 2016; *Kannan et al.,* 2014; *Terlouw et al.,* 2021; *Terlouw and Gagaoua*, 2023). Transportation, involving handling, loading and unloading is an unfamiliar and threatening event in the life of an animal (*Terlouw et al.,* 2021). This can lead to distress, injury or even death of animal affecting the animal welfare and meat quality adversely (*Minka & Ayo*, 2010; *von Borell et al.*, 2007). The depletion of glycogen in muscle due to long-term pre-slaughter stress and the resultant elevated meat pH negatively affect meat quality (*Kannan et al.*, 2014; *Terlouw et al.*, 2021). Short-term acute stress, such as excitement or fighting immediately prior to slaughter produces lactic acid from the breakdown of glycogen. This results in meat with a lower meat pH, lighter color, reduced WHC and higher toughness. Psychological stressors, viz., excitement and fighting will often have a more detrimental effect on meat quality than pre-slaughter physical stressors like transportation, fasting and cold weather (*Grandin*, 1980; *Terlouw et al.*, 2021). Some of the available literature about pre-slaughter treatments, transport and stress at slaughter and their effect on goat meat quality are described in the following.

Biobaku et al. (2016) assessed the meat quality of Sahel bucks treated with ascorbic acid (400, 300, 200 and 0 mg/kg orally) and exposed to long term transportation stress during harmattan period. The animals were transported using high and low stocking density and ascorbic acid was administered prior to and midway of the journey. The group of goats treated with 400 mg/kg orally ascorbic acid had significantly higher dressing %, ultimate pH, excitatory score as compared to other groups of goats. Similarly, there were significantly higher dressing %, ultimate pH, excitatory score in high stocking density as compared to low stocking density. This study concluded that there was an interaction between the dose of ascorbic acid and the stocking density. Further, it showed that ascorbic acid could be used as an anti-stress agent to improve food animal welfare and chevon quality.

Alcalde et al. (2017) assessed the effect of on-farm management (high and low welfare-friendly) and transport duration on physiological responses and meat quality parameters in goat kids. Measuring carcass parameters like pH, color, WHC, shear-force value revealed that despite the marked stress status of kids during transportation, *Longissimus thoracis* muscle quality parameters were not much affected, but some pre-slaughter transportation stress effects were observed in fat cover and color of the kid carcasses.

Nikbin et al. (2016) investigated the effects of transportation and stocking density on carcass characteristics and meat quality traits of *Longissimus thoracis* and *Semimembranosus* muscles in Boer goats. The transported goats had significantly lower carcass shrinkage, glycogen content, drip loss, tenderness, lightness, yellowness, hue angle and chroma values as compared to non-transported goats. In contrast, transported goats showed significantly higher cooking loss and redness than the non-transported group. Goats transported in higher stocking density had significantly higher live-weight loss and lower dressing %. This study also reported that pre-slaughter transportation increased shrinkage loss and deteriorated meat quality of goats.

Kadim et al. (2014) studied the effect of transportation during hot season (42°C day temperature) on meat quality characteristics of *Longissimus thoracis* muscle of twenty male Dhofari goats. The transported goats had significantly higher plasma cortisol, adrenaline, nor- adrenaline and dopamine concentrations than non-transported goats. The meat from transported goats had significantly higher ultimate pH (5.84 *vs.* 5.67), expressed juice (40.2 *vs.* 36.8), shear force value (7.85 kg *vs.* 5.55 kg) but significantly ($p<0.05$) lower sarcomere length (1.53 μm *vs.* 1.60 μm). This study indicated that transporting goats for 6 hours during hot season can cause physiological responses and deteriorate meat quality characteristics. Moreover, *Kadim et al.* (2006) evaluated the effect of transportation during hot season on carcass and meat quality of three breeds of Omani goats. The meat from goats subjected to transportation had significantly higher ultimate pH, expressed juice, cooking loss %, shear force value but significantly lower sarcomere length, L^*, a^* and b^* color values.

Kannan et al. (2003) determined the effects of short-term (2 hours) pre-slaughter stress on meat quality of different age groups of goats. The transported groups of goats had higher plasma cortisol, glucose and non-esterified fatty acid concentrations, but had lower muscle glycogen reserve, *a** value and chroma of meat color. The pH, WHC, cooking loss and shear force values were not affected by stressor environment. These results indicated that short-term pre-slaughter transportation can cause noticeable changes in stress response and muscle metabolism in goats without affecting the ultimate pH of meat even with a significant glycogen breakdown.

Kannan et al. (2002) determined the effects of pre-slaughter isolation and feed withdrawal duration on physiological responses and shrinkage in Spanish goats. The results indicated that the novelty of environment during pre-slaughter holding and social isolation may be more potent stressors affecting meat quality than feed deprivation in goats, although shrinkage may increase the increasing feed withdrawal time.

Post-mortem processing and carcass handling: stunning and electrical stimulation methods

Stunning

According to the EU council directive (EU, 1993) and council regulations (EC No. 1099/2009), animals must be stunned at the point of slaughter to render them unconscious and insensible to distress and pain from the act of slaughter. Among various stunning techniques used in meat industry, the electrical stunning by passage of sufficient electrical current is most widely used in sheep and goats (*Robins et al.*, 2014). Stunning and slaughter procedures have great impact on meat quality as well as animal welfare (*Bourguet et al.*, 2011; *Terlouw et al.*, 2021; *Terlouw and Gagaoua*, 2023)

Bakhsh et al. (2018) assessed the effects of non-stunning (NS) and head-only electrical stunning (HOES) on meat quality traits of *Longissimus lumborum* muscle from Korean black goat. The results indicated that NS and HOES had no significant difference on blood loss%, the rate of pH decline, meat color properties and WHC. However, a marginal difference in WBSF values and sarcomere lengths were observed. It was concluded that, neither NS nor HOES during slaughter of goats resulted in poor quality meat. *Lokman et al.* (2016) compared the carcass and meat quality in Boer crossbred goats that were subjected to pre-slaughter head-only electrical stunning (HOES) (1A, 3 sec at 50Hz) and non-stunning (NS). The results indicated that no differences were observed in meat quality traits between NS and HOES goat carcasses. However, carcasses obtained from HOES goats had higher incidence of hemorrhages than NS goats. This study indicated that HOES prior slaughter increased carcass hemorrhages without adversely affecting meat quality traits of the studied goats.

Electrical Stimulation

Goat carcasses often have a high ultimate pH and low glycolytic potential, resulting in tougher meat that can be stringy and less desirable to consumers (*Webb & Pophiwa*, 2018; *Lamri et al.,* 2023a). To address this issue, technologies like electrical stimulation (ES) are used to improve the conversion of muscle into meat more effectively. ES can prevent cold shortening, accelerate proteolysis, and disrupt muscle fiber structures, leading to improved tenderness of the meat (*Kadim et al.*, 2010; *King et al.*, 2004). Various types of ES systems, including high, intermediate, and low voltage systems, have been studied extensively to enhance meat tenderness and prevent cold shortening (*Kannan et al.*, 2014). ES can also help to dissociate the myofibrillar and connective tissue structures, as well as accelerate proteolysis, resulting in increased tenderness and juiciness after cooking (*Biswas et al.*, 2016; *Pophiwa et al.*, 2020). However, high or very low voltage should be avoided as they may lead to improper stimulation and undesirable sensory attributes in meat. Studies have shown that electrical stimulation improves shear force values and water-holding capacity in muscles, which are indicators of tenderness and juiciness, respectively *(Gadiyaram et al.*, 2008).

In a study by *King et al.* (2004), the effects of high (550V) and low (20V) voltage ES and post-mortem storage on the tenderness and lean color of Carbito Boer cross kid carcasses were examined. Sixty carcasses were used, with half receiving ES and the other half serving as the control group. The authors observed no differences in muscle temperature, myofibrillar fragmentation index, and sarcomere length at any time measured. However, the high-voltage ES group had the fastest pH decline, higher instrumental color (in terms of *L**, *a**, and *b** values), increased aging responses, and greater tenderness 3 days post-mortem compared to the control group. In another study by *Kadim et al.* (2014), the effects of low voltage ES (90V, 60 seconds at 20 minutes post-mortem) on the physiological and meat quality characteristics of *Longissimus dorsi* muscle in twenty male Dhofari goats were investigated. The meat from electrically stimulated goat carcasses had significantly lower ultimate pH (5.68 *vs.* 5.84), higher expressed juice (39.5 *vs.* 37.45), lower shear force value (5.05 kg *vs.* 8.35 kg), longer sarcomere lengths (1.67 µm *vs.* 1.46 µm), and higher myofibrillar fragmentation index (77.25 *vs.* 71.45) than the non-stimulated goat carcasses. This study suggested that low-voltage ES may reduce the negative effects of transportation for 6 hours during the hot season on the meat quality characteristics of goats.

Cetin et al. (2012) investigated the effect of various ES voltages (50, 100 and 250V, 90 seconds, 50Hz frequency) on meat quality of 3–5 years old goats. The stimulated carcasses were examined for their textural, physico-chemical and sensorial characteristics as compared to non-stimulated carcasses. ES decreased pH values of goat meat and accelerated significantly *rigor mortis*. Additionally, ES enhanced water activity, water-holding capacity and drip loss of goat meat. Further, ES caused improvement in instrumental color parameters (L^*, a^* and b^* values), sensory characteristics and tenderness, thereby improving goat meat quality as compared to the non-stimulated carcasses. In an earlier study, *Gadiyaram et al.* (2008) studied the effects of post-mortem high voltage ES (580 V at 5s intervals during 120 seconds) on meat quality in two breeds of goats viz., uncastrated Spanish goats and crossbreds (Boar x Spanish females x Kiko males) as compared to non-stimulated carcass parts. The meat from electrically stimulated halves of goat carcasses had significantly higher (quadratically) pH decline to reach lower ultimate pH, higher (cubic) 24h-temperature decline and lower shear force value (3.0 kg *vs.* 4.2 kg) as compared to the control (non-stimulated goat carcass halves). The sarcomere lengths and instrumental color values were not affected by ES. The heated calpastatin activities were not influenced by ES, but the activities were lower at day 4 compared to day 1 of ageing. No significant effects were noticed on the myofibrillar protein concentrations (myosin, myomesin, desmin, actin and troponin-T; $p>0.05$). However, the desmin concentration of ES applied meat tended to decrease at day 4 of ageing. This study indicated that ES significantly accelerated post-mortem glycolysis and improved tenderness of goat meat.

Finally, in a study by *Biswas et al.* (2007), the authors studied the effect of ES (35, 110, 330, 550, 1100 V with fixed 50 Hz and 10 pulses/s for 3 min.) on quality of tender stretched chevon sides of 5–8 years old male Black Bengal goats. Changes in different quality parameters like decreased fiber diameter, WHC and pH, increased sarcomere lengths, increased tenderness as per taste panel scores and stable microbial counts were observed in electrically stimulated chevon as compared to the non-stimulated control chevon. The 330V, 50Hz and 10 pulses/s treatment showed superiority above other treatments in most of the quality parameters of chevon.

Post-harvest treatments

Ageing and Chilling

"Ageing" or "conditioning" or "maturation" of meat refers to the holding of meat cuts and carcasses under controlled refrigeration/chilling conditions just above the freezing point (2–3°C) in order to improve palatability traits (*Khan et al.*, 2016; *Gagaoua et al.*, 2022; *Lamri et al.*, 2023b). Ageing greatly alters the biological environment of meat by hydrolytic and proteolytic enzyme activity including changes in the taste-active compounds, which consequently lead to flavor and tenderness changes (*Dashdorj et al.,* 2015; *Kannan et al.*, 2014). The improvement of meat flavor may involve the release of free amino acids and peptides and breakdown of ribonucleotides to yield IMP, GMP, inosine and hypoxanthine during postharvest ageing (*Koutsidis et al.*, 2007). Different studies have been conducted on ageing of goat meat and its effect on palatability and other meat quality parameters.

Xiao et al. (2022) noticed changes in color, cooking loss, texture, protein, amino acids and the expression of 17 meat quality-related genes in *Longissimus thoracis* from goats during post-mortem ageing of 0, 12, 24 and 48 h at 4°C. With the development of *rigor mortis*, shear force value, texture and cooking loss had the highest value after 12 hours of ageing. Both myofibrillar and sarcoplasmic proteins were degraded 12 h onwards producing the degraded products like myosin heavy chain, troponin-T, desmin and actin. The expression of 17 genes peaked at 12–24 h. The color and contents of aspartic acid, serine, tyrosine, phenylalanine changed significantly within 24 h of ageing.

Lamri et al. (2023b) used a high-throughput shotgun proteomics approach to decipher the post-mortem changes in the *Semitendinosus* muscle young male goats of the Saanen x *Naine de Kabylie* crossbred reared under extensive production system in Kabylia region, Algeria. The evolution and comparison of the muscle proteome over three post-mortem times (1, 8, and 24 h) was assessed. The temporal proteomics profiling revealed several changing proteins that belong to myriad interconnected pathways. Briefly, binding, transport and calcium homeostasis, as well as muscle contraction and structure, exhibited an equivalent contribution during post-mortem, demonstrating their central role. Catalytic, metabolism and ATP metabolic process, and proteolysis were active pathways from the first hours of animal bleeding. Conversely, oxidative stress, response to hypoxia and cell redox homeostasis along chaperones and heat shock proteins accounted for the large proportion of the biochemical processes, more importantly after 8 h post-mortem. Overall, the conversion of goat *Semitendinosus* muscle into meat is largely orchestrated by energy production as well as mitochondrial metabolism and homeostasis through calcium and permeability transition regulation. The study further evidenced the role of ribosomal proteins in goat post-mortem muscle, signifying that several proteins experiencing changes during storage, also undergo splicing modifications, which is for instance a mechanism known for mitochondrial proteins. Thanks to the in-depth bioinformatics analyses and a new approach in studying meat tenderization by means of temporal shotgun proteomics, the authors evidenced for the first time the dynamic time-course changes and molecular signatures underpinning the conversion of goat muscle into meat. Twelve proteins (FHOD1, PDCD6IP, SIRT2, SLC25A3, GPD2, SPR, UCHL3, RPS3A, SGTA, MYOZ2, GSTM3, and NDRG2) were changing in their abundance throughout the storage period, from 1 h until 24 h post-mortem. Eleven of these proteins are suggested as candidate biomarkers to monitor the changes taking place in the goat muscle proteome during the tenderization phase (*Lamri et al.,* 2023b).

Pophiwa et al. (2017) evaluated the carcass and meat quality of Boer goats and unimproved indigenous goats of South Africa under delayed chilling conditions. This study shows that delayed chilling could be a useful strategy in improving the color and tenderness of goat meat. *Abuelfatah et al.* (2016) studied the effects of enriching Boer goat meat with n-3 PUFA on meat quality, sensory evaluation and lipid oxidative stability at different post-mortem ageing times (1–7 days). Although there were no effect on cooking loss, shear force and color at 1-day of ageing, the color of meat was affected at 7-day of ageing. The tenderness, juiciness and overall acceptability of 20% PUFA enriched groups were rated better. No differences in color, flavor and aroma was observed after 7 days of ageing by sensory evaluation. However, lipid oxidation increased with increasing PUFA content and post-mortem ageing time in goat meat.

Nagaraj et al. (2006) evaluated the effect of post-mortem ageing on pH, temperature, drip loss, sarcomere length, myofibrillar fragmentation index, myofibrillar protein solubility, released calcium and myofibrillar ATPase activity in different goat muscles stored at 5°C up to 20 days post-mortem. The results indicated that the rate of pH decline, temperature, myofibrillar ATPase activity and sarcomere length decreased during ageing. However, a significant increase in drip loss, myofibrillar fragmentation index and myofibrillar ageing was observed with increasing ageing period. Thus, the degree of ageing affected various biochemical indices of goat meat.

Kannan et al. (2006) determined the effects of different dietary treatments and post-mortem ageing on meat quality characteristics in castrated dairy goats. A decrease in pH and temperature of goat carcasses with increasing ageing time was observed, irrespective of treatments. The Warner-Bratzler shear force values, collagen solubility and cooking loss of goat meat aged 1-, 3- or 6-days post-mortem were not influenced by treatments. In conclusion, the diet did not influence meat quality characteristics, and shear force values of chevon did not decrease due to post-mortem ageing. Rapid heat dissipation from goat carcass during rapid chilling could have caused cold shortening and the meat did not respond to ageing properly.

Curing

The curing of meat involves the addition of nitrite and/or nitrate salts together with sodium chloride for improvement in oxidative stability, sensory attributes (color and flavor) and microbiological quality and stability (*Pegg & Honikel*, 2014; *Gagaoua and Boudechicha*, 2018). Several studies have investigated the effect of curing on goat meat quality. Teixeira *et al.* (2017) evaluated the physico-chemical and sensory characteristics of goat cured legs. The pH and water activity of cured meat was found to be adequate with respect to microbial growth to control meat deterioration, promoting safety and stability to shelf-life of products. The high protein, low cholesterol content, lower TBARS values and low fat of the goat cured legs showed the effect of salting and ripening processes. Physico-chemical and sensory characteristics indicated that producing cured goat legs from cull animals can be an interesting way to add value to animals with very low commercial prices or potential. In the frame of the evaluation of the influence of sodium nitrite inclusion on the quality parameters of restructured chevon jerky, *Lee et al.* (2017a) found increased redness, flavor scores, decreased TBARS values and fatty acid content. This study concluded that curing protected against lipid oxidation of chevon jerky. In another study, *Ortega et al.* (2016) compared the physical properties and color parameters in goat and sheep blanket “mantas” obtained after salting and air drying. Significant differences in physical characteristics of meat were obtained, as texture, color and WHC of goat “mantas” were most influenced by salting and ageing.

Cooking

The effect of cooking depends on the method, time and temperature and the response of muscles to heat treatment is influenced by pre- and post-mortem conditions (*Webb et al.*, 2005; *Gagaoua et al.*, 2016b; *Gagaoua et al.*, 2019d). Generally, cooking temperatures below 100ºC affect palatability, but have no severe effect on nutritive value of meat (*Casey et al.*, 2003). Cooking changes the composition of animal fat, increases energy density, improves sensory attributes like tenderness, juiciness, texture, flavor and appearance *(Forrest et al., 1975; Gagaoua et al.*, 2016b). Cooking further reduces enzyme activities, prevent against lipid oxidation and microbial spoilage of meat (*Domínguez et al.,* 2019). However, prolonged cooking results in production of cook-outs or cooking loss and damages the sensory and nutritional qualities of meat (*Guerrero et al.*, 2013; *Webb et al.*, 2005; *Lamri et al.*, 2023a).

Narayan et al. (2015) studied the effects of pressure-cooking, marination with citric acid and *cucumis* powder spray on quality attributes of goat meat curry. Significant differences were observed in protein and collagen content of meat cooked under pressure cooking as compared to other treatments and control. The pressure-cooked goat meat produced lower shear force value and higher sensory scores as compared to the control and other treatments. This study found that pressure-cooked goat meat curry was highly preferred followed by *cucumis* powder, citric acid treated samples and control.

Guerrero et al. (2014) compared the consumer preferences for laboratory-based and home-based cooking of Spanish goat meat. Sensory analysis was made by trained panelists where goat meat was cooked on a grill, without any condiments whereas, consumer testing was done at home conditions after conventional cooking of leg meat of goat in an oven with condiments, salt and oil. The differences in method and time of cooking of goat meat affected flavor, texture and consumer preferences. It was concluded that sensory scores were higher for conventional home cooked (oven) meat than laboratory cooked (grilled) goat meat.

Conclusion

The quality of goat meat is a consequence of factors standing from the farm level to the fresh and/or cooked meat (continuum from farm-to-fork). This review evidenced that the intrinsic factors refer to the inherent characteristics of the goat itself that influence meat quality. One such factor is the age at slaughter, which affects the tenderness, flavor, and composition of the meat. Younger goats generally produce more tender meat, while older goats may exhibit increased levels of connective tissue and a stronger flavor profile. The effect of gender, or sex, on meat quality is another crucial aspect to consider. Males and females can differ in terms of growth rate, carcass composition, and meat attributes. Breeds also play a significant role, as different goat breeds exhibit variations in meat quality. Additionally, the slaughter weight of goats can impact meat quality, with heavier animals potentially having tougher meat due to increased connective tissue development. The contractile and metabolic properties of the muscle are essential parameters at the muscle level that affect goat meat quality. These properties are related to the biochemical and physiological characteristics of the muscle fibers and energy metabolism pathways. Differences in muscle fiber type, myofibrillar protein composition, and enzymatic activities can influence the tenderness, juiciness, and flavor of goat meat.

Extrinsic factors, on the other hand, encompass various aspects related to goat production, handling, and processing. Production or husbandry systems, including grazing practices, housing conditions, and overall management, can significantly impact meat quality. The type and quality of feed, feeding strategies, and the ratio of concentrates to roughages in the diet also play a crucial role in determining meat attributes. Antioxidants, both natural and synthetic, have been studied for their potential to improve meat quality by mitigating oxidative stress and preserving color stability. The feeding systems implemented, such as pasture-based systems or intensive feeding systems, can influence goat meat composition, fatty acid profile, and overall sensory attributes. Climate, season, and environmental conditions are additional extrinsic factors that can impact goat meat quality. Extreme temperatures, humidity, and changes in forage availability may affect animal welfare, feed intake, and subsequently, meat quality. Pre-slaughter treatments, transport conditions, and stress experienced by goats during handling and at the time of slaughter can have significant effects on meat quality. Post-mortem processing and carcass handling practices also play a crucial role in determining goat meat quality. Electrical stimulation, a common post-mortem technique, has been shown to enhance meat tenderness by accelerating the post-slaughter glycolysis process. Stunning methods used during slaughter can affect the stress response of goats and subsequent meat quality attributes. Finally, post-harvest treatments, such as ageing and chilling, have a considerable impact on meat quality. Ageing, a process that involves storing the carcass at refrigeration temperatures, allows for enzymatic processes to improve tenderness and flavor development. Curing techniques, including dry-curing and brine-curing, are employed to enhance the flavor, color, and preservation of goat meat. Cooking methods and related parameters, such as temperature, cooking time, and moisture levels, greatly influence the sensory attributes and palatability of goat meat.

Overall, this review is the first to provide insights into both the intrinsic and extrinsic factors influencing goat meat quality throughout the production and processing chain. It highlighted the importance of understanding and optimizing multiple factors to ensure a consistent delivery of high-quality goat meat to consumers. However, despite the existing knowledge, there are still important research gaps and future perspectives to explore. First, we need to investigate the interactions between different factors and their cumulative effects on goat meat quality. For instance, understanding the combined influence of breed, feeding regime, and age at slaughter on meat attributes would provide valuable insights for optimizing production systems and achieving consistent meat quality. Second, more research is required to explore the potential use of natural antioxidants and innovative feeding strategies, in the frame of circularity, to enhance the nutritional profile and oxidative stability of goat meat. The effects of climate change on goat production systems and meat quality also warrant further investigation, as changing environmental conditions may impact animal welfare, feed availability, and subsequent meat attributes. Last but not least, advancements in post-mortem processing techniques and the use of omics tools (likely transcriptomics proteomics, metabolomics, lipidomics, …etc) and their integration should be explored to optimize goat meat quality and reduce its variability. Continued research on post-harvest treatments, including ageing, chilling, and curing methods, can further enhance the sensory attributes and shelf-life of goat meat.

Unutrašnji i spoljašnji faktori koji utiču na kvalitet svežeg kozjeg mesa: Pregled

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A p s t r a k t: Kozje meso, poznato i kao „chevon“, važan je izvor proteina i esencijalnih hranljivih materija u mnogim regionima širom sveta. Da bi se obezbedila proizvodnja kozjeg mesa visokog kvaliteta, ključno je razumeti unutrašnje i spoljašnje faktore koji utiču na njegova senzorna, tehnološka i nutritivna svojstva. Ovaj rad ima za cilj da pruži pregled faktora koji utiču na kvalitet kozjeg mesa u celom lancu proizvodnje i prerade. Opisan je značaj različitih faktora koji utiču na kvalitet kozjeg mesa. Prvo, fokus je stavljen na unutrašnje faktore, uključujući uticaj starosti prilikom klanja, pola, rase, težine pre klanja, uzimajući u obzir i kontraktilna i metabolička svojstva mišića, razmatrajući njihov uticaj na važne unutrašnje kvalitetne osobine kao što su mekoća, ukus, boja i ukupan kvalitet kozjeg mesa. Štaviše, spoljašni faktori, kao što su proizvodni sistemi, uzgojne prakse, strategije ishrane, vrste stočne i kabaste hrane, antioksidansi, sistemi hranjenja, klima, sezona i uslovi životne sredine su ispitani pored tretmana pre klanja, uslova transporta i stresa, koje koze doživljavaju u vreme klanja. Sve u svemu, ovaj pregled sintetizuje trenutno znanje o unutrašnjim i spoljašnim faktorima koji utiču na kvalitet kozjeg mesa. Rezultati naglašavaju važnost boljeg razumevanja i optimizacije ovih faktora u svakoj fazi proizvodnje i prerade kako bi se obezbedila dosledna isporuka visokokvalitetnog kozjeg mesa. Dalja istraživanja u ovim oblastima doprineće razvoju unapređenih praksi i tehnologija u industriji kozjeg mesa.

***Ključne reči:** meso; kvalitet kozjeg mesa; varijacije kvaliteta mesa; proizvodni i poljoprivredni sistemi; faktor od „njive do trpeze“*

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Original Scientific Paper

The profitability of the meat industry in Serbia: Did the COVID-19 pandemic have any impact?

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A b s t r a c t: The COVID-19 pandemic changed the circumstances of the business environment, affecting almost every industry and company one way or another. The pandemic disrupted the global economy, leading to significant changes in the business landscape. The meat industry in Serbia was not an exception. The aim of this study was to examine the impact of the pandemic on the profitability of the meat industry in Serbia by using a causal comparative design. The research sample included 88 business entities with top market share from the meat industry, analyzed through five years (2016–2020) (440 financial statements were the units of observation). The normality of dataset distribution was tested by Shapiro-Wilk and Kolmogorov-Smirnov tests, while the Wilcoxon statistical tool was used to confirm the impact of the pandemic. Results showed the COVID-19 pandemic did have a positive impact on meat industry profitability in Serbia (so the null hypothesis was rejected). Findings from this paper add to the existing literature regarding the economic effects of the pandemic and could be useful for business entities' owners and investors in their decision-making processes.

Keywords: *Return on Assets (ROA), Wilcoxon test, financial statements, meat industry, investors*

Introduction

The meat industry is one of the largest sectors of the economy, as meat and meat products are considered agricultural products with the highest added value (*Charan*, 2022; *Sama-Berrocal and Martínez-Azúa*, 2022; *FAO*, 2020). Livestock production and processing of livestock products are significant drivers of agricultural production and are key factors in the development of agro-economy.

From Serbia's perspective, agriculture is considered one of the most important economic branches (*Djordjevic et al.*, 2022; *Mitic et al.*, 2018; *Mijić et al.*, 2014). Improving the entire meat production chain in Serbia would have positive effects on social stability in rural areas, while at the macro level, it would have a positive effect on the export income of the domestic agro-economy.

As in many other sectors around the world, global meat supply chains experienced drastic changes due to the onset of COVID-19 in early 2020 (*Vucenovic et al*., 2021; *Hashem et al*., 2020; *Maric and Djurkovic-Maric*, 2020). Namely, different countries around the world took different restrictive measures, such as closing sales facilities, quarantine and closing borders, but also relaxed measures to mitigate the socio-economic crisis. The pandemic triggered long-term social and economic crises, interrupted supply chains, limited access to essential services, but also increased the demand and therefore the price of food (*World Bank*, 2020; *Allain-Dupré et al.*, 2020). Although it can be concluded that the COVID-19 pandemic highlighted the vulnerability of food systems, their problems were also caused by other events and shocks from earlier periods, such as: the oil crisis in the 1970s, the scandal with cattle infected with the Creutzfeldt-Jakob virus in Great Britain in 1980s and then in the early 1990s (*Aday and Aday*, 2020); SARS epidemic in Hong Kong in 2003 (*Kumari and Sharma*, 2023; *Lau et al.*, 2005); Ebola in West Africa in 2014 (*Buseh et al.*, 2015); bird flu in China in 2013 (*Zhou et al*., 2016) and; African swine flu in China in 2019 (*You et al*., 2021). According to the Food and Agriculture Organization of the United Nations, in 2020, there

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was an increase in world meat production by 1% (from 325 Mt to 328 Mt), including pork and poultry meat production that increased due to a sharp rise in demand in China.

On the micro level, the rapid spread of SARS-CoV-2, the virus that causes COVID-19, led to enforcement of social distancing measures that affected meat processing plants. That caused significant disruptions to the food supply chain, although the measures were necessary to protect workers and slow down further virus spread (*Selyukh,* 2020). Additionally, closures resulted in significant reductions in the amount of meat being produced, which led to a shortage of meat in grocery stores and higher prices for consumers (*D'innocenzio,* 2020). Additionally, the virus has been detected in meat processing and production plants in numerous economies, such as the United States of America (US), Canada, Brazil and European countries (*Weersink et al.*, 2021). Regarding customer behaviour, the pandemic decreased demand for dining out, which resulted in a decrease in demand for certain cuts of meat, such as steaks. At the same time, the increased demand for comfort foods and meals cooked at home led to an increase in demand for ground beef and other types of meat that are easier to prepare. To soften the negative effects of the pandemic, some meat producers resourced alternative distribution channels, such as online ordering and home delivery (*Thilmany et al.*, 2021). Despite these efforts, the meat production industry is still facing significant challenges due to the ongoing pandemic.

Taking into account these mixed effects of the COVID-19 pandemic, one may question whether the pandemic had any impact on the profitability level of Serbian business entities operating in the meat industry. Consequently, this paper will test the null hypothesis that *"Pandemic COVID-19 did not have an impact on the profitability of the meat industry in Serbia"*. To examine the normality of the dataset and confirm the pandemic's impact on the profitability of selected business entities, measured by the return on assets (ROA) financial indicator, the Shapiro-Wilk test and the Wilcoxon statistical test were utilized. The findings of this study should provide valuable insight into the economic impact of the pandemic and enhance the understanding of the financial implications to enable informed decision-making by key stakeholders in response to these challenges. Specifically, by analyzing the financial effects of the pandemic on meat industry businesses, it should be possible to identify areas of strength and weakness in terms of resilience to the pandemic. The paper is structured as follows: a brief review of the literature in this field is presented, followed by the methodology and results of the research. Finally, conclusions are drawn, and suggestions for future research endeavours are made.

Literature review

The COVID-19 pandemic highlighted the vulnerability of labour-intensive industrial sectors, such as the meat processing sector (*Amnim et al.*, 2021). Supply-side disruptions to the meat production chain included high employee absenteeism, social distancing, job swapping, and quarantine for workers, temporary closure of facilities, disrupted meat supply chains and processing blockages (*Hobbs,* 2021; *Luckstead et al.*, 2021). *Lusk et al.* (2021) report that during the last week of April and the first week of May 2020, daily beef and pork processing volumes in the US were about 40% below 2019 levels. That study found that in the two months under review, the volume of federally controlled cattle slaughter was on average 22% less than the same period in 2019, while pig slaughter was 13% less compared to the previous year (*Luckstead et al.,* 2021). The temporary closure of meat processing plants in the province of Alberta, Canada, caused disruptions in 75% of the meat supply chain (*Keogh*, 2020). The pandemic confirmed that the structure of food supply chains dominated by large and concentrated producers/sellers is more resilient than food supply chains with dispersed, small companies targeting localized markets. However, *Aday and Aday* (2020) believe that a concentrated oligopolistic industry with a small number of large companies creates holdups in the supply chain and, thus, causes drastic disruptions in the system. Due to COVID-19, the meat industry in the US suffered a loss of $US13.6 billion of total economic damage ($8.1 billion in the cow and calf sector, $2.5 billion in the storage sector, and $3 billion in the feedlot sector), and $9.2 billion of total revenue loss of $63 million of livestock (*Peel et al.*, 2020).

Various studies determined that the disruptions caused by the pandemic at the meat processing plants and at the market level were short-lived and had a limited impact only on agricultural holdings (*Almadani et al.*, 2022). It was established that disruptions in processing, declines in consumer purchasing power, and reduced volumes of business in the food service sector affected the global price of meat production, which remained on the rise throughout 2020. Developed countries have introduced economic stimulation programs as a form of support for meat consumption per capita (*IMF Fiscal Affairs Department*, 2021).

Studies conducted in South America showed that the pandemic has exacerbated for meat producers their already existing problems, stemming from political instability, weak economic growth, low consumer purchasing power, high inflation rate and rapid currency depreciation (*Almadani et al.*, 2021). The decrease in demand for meat and meat products was also contributed to by the media, which highlighted the zoonotic source of SARS-CoV-2, and thereby the question of the safety of consuming meat (*Attwood and Hajat*, 2020). An example of this is the introduction of a ban on the use of wild animals for human consumption in China (*World Economic Forum*, 2020). Outside China, media reports on SARS-CoV-2 have fuelled public interest in the way meat is produced in general, particularly the risk of intensive livestock farming creating antibiotic resistance (*Samuel,* 2020). In this way, the COVID-19 pandemic has played a role in high-income countries in increasing the awareness of consumers who demand transparency in meat production, giving consumers the opportunity to choose meat from animals that have been raised organically or on a natural diet (*Morrison*, 2020).

The pandemic has long-term implications for agri-food supply chains, and adaption strategies have had to be devised to foster resilience, adopting a systemic perspective that the food processing sector is affected by developments throughout the supply chain. The pandemic has brought this into focus in relation to the demand and supply shocks that appeared in meat supply chains in the northern hemisphere spring and summer of 2020 (Hobbs, 2021). *Lusk et al.* (2021) argue the combined effect of rising wholesale meat prices and falling livestock prices leads to a widening of the price range, which would happen even without the anti-competitive behaviour of the processors. That is a natural outcome of the forces of supply and demand within these supply chains.

Some studies have evaluated the impact of the pandemic on the prices and sharemarket returns of companies with primary activities being the production, processing and sale of food. The main conclusion of *Ramelli and Wagner* (2020) was that the food sector was less affected than other sectors, since the volatility of this sector's shares was lower compared to the market index S&P 500 (*Höhler and Lansink*, 2021). The conducted analysis showed that the capital loss of agribusiness stocks during the first four months of 2020 was higher than that in the financial crisis of 2008. The consequences of the COVID-19 pandemic included increasing insolvency, rising unemployment and food insecurity. The high volatility of share prices was a consequence of rising financing costs and high-risk premiums. During the pandemic, share prices in the sub-sector of fertilizers and agrochemicals recorded the highest volatility, due to dependence on oil prices. Also, shares of food distributors were relatively volatile due to quarantine and distancing measures that led to drops in sales. The mentioned sub-sectors had negative operating profits. On the other hand, food retailers and manufacturers of vacuum-sealed food did not have high volatility of stock prices, which had a positive effect on the operational profits that increased compared to the previous observed period of the mentioned research. In contrast to the results of *Ramelli and Wagner* (2020), *Höhler and Lansink* (2021) found a positive and statistically significant effect on profitability in the pandemic outbreak phase, because investors perceived profitable companies as more resilient. In agreement with this, *Ramelli and Wagner* (2020) and *Höhler and Lansink* (2021) confirmed the negative influence of the market β-coefficient on stock returns in the phases of growth in the number of infected people. Stocks that were riskier than the overall market had low cumulative returns. Companies that financed themselves by issuing financial debt instruments achieved lower returns in the phases of the highest number of patients, which indicates the importance of liquidity in times of crisis.

Research carried out on the domestic market in Serbia in the period 2010–2012 showed that the current liquidity ratio and sales growth have significant positive impacts on the profitability (measured by ROA) of companies that produce meat in Serbia, while financial leverage had a significant negative impact. Independent variables such as company size, fixed asset ratio, and investment had no significant relationship with the profitability of the Serbian meat industry (*Mijić et al.,* 2014). On the other hand, taking into account the period 2011–2015, *Mijic et al.* (2017) showed that companies with a high liquidity ratio and sales growth achieved a better ROA, while a high debt ratio negatively affected the level of ROA. Also, the results showed that the size of the company, the fixed assets ratio and the investment rate had no influence on the profitability of the meat processing industry in Serbia.

Research methodology

Data for the research were collected from the website of the Serbian Business Registers Agency, and the sampled entities were engaged in the production and processing of meat and meat products. The companies that were selected held a total market share of 78.5% and operated during the period from 2016 to 2020 in Serbia. The sample comprised 440 observation units, with 88 companies for each reporting period. The sample was divided into two parts, from 2016 to 2019 (pre-pandemic), and the 2020 reporting year (during the pandemic).

The dataset was subjected to causal comparative design, also known as ex-post facto design. Causal comparative design is used to establish a relationship between an independent variable and a dependent variable in a non-experimental setting where two or more groups that already exist but that differ in the presence or absence of the independent variable are compared. The purpose was to determine whether the independent variable (pandemic) caused a difference in the dependent variable (profitability). The Kolmogorov-Smirnov and Shapiro-Wilk tests were used to test the normality of the small dataset. As the test results indicated that the dataset did not feature normal distribution, the Wilcoxon rank-sum test was selected to confirm the defined null hypothesis. In general, a standardized test statistic is considered large if it exceeds 1.96 or −1.96, so p-value of <0.05 indicated the relationship between the two variables was statistically significant.

Selection of profitability indicators

Profitability can be described as a measure of an entity's ability to generate profits depending on the amount of its revenue, expenses and operating costs. It is often expressed as a percentage of revenue and can be used to evaluate the financial health of a company, its competitiveness and its potential for growth (*Lim and Morris*, 2023). A company's profitability can be influenced by many factors, including market conditions, competition, pricing strategy, cost structure and operational efficiency. The most common metrics used to evaluate the financial performance of a business entities and provide valuable insights into its profitability, efficiency and growth potential are the following: gross profit margin, operating profit margin, net profit margin, return on equity (ROE), ROA (*Ibrahim et al.,* 2023). In addition, other factors, such as market trends, consumer preferences and government regulations, can also have a significant impact on the profitability of a meat industry company.

Taking into account previous research, *Habiba* (2017) and *Brockman* (2015) measured profitability of public entities using net assets per share (NAPS), while *Amnim et al.* (2021) and *Oliveira et al.* (2015) used ROE. On the other hand, *Raheman and Chek* (2014), *Abd Hamid et al.* (2017) and *Rouf* (2016) used a combination of ROE and ROA indicators. Overall, the most common indicators used in such research are net and gross margins, ROA, and ROE (*Ledley et al*., 2020).

Specifically, in this paper, the following indicators were selected for consideration: ROE, ROA, and net margin. ROE was rejected since it is not uncommon for business entities in Serbia to have losses that exceed their capital, which can make it difficult to calculate this ratio and distort the image of their profitability. Moreover, the net result, which is used for net margin indicator calculation, as an income statement category is often subject to manipulation, either to report higher or lower results than achieved, or for tax evasion purposes. Therefore, selecting this indicator may not result in an objective presentation of the financial success of the selected entities. An indicator was needed that measures how much the observed entity earns on assets invested in the business. As a result, ROA was chosen as the dominant profitability indicator. This indicator shows how effective a company's management is in managing the entire assets with total invested capital in mind. ROA is obtained by dividing net profits, or similar income statement result line, by total or average assets. A higher ROA ratio indicates better performance, as it tells investors that the company is earning more with less investment.

Data distribution and applied tests

A test of normality is a statistical procedure used to determine whether a set of data is approximately normally distributed. This is important because many statistical techniques assume that the data is normally distributed. The choice of test often depends on the sample size and the level of normality that is desired.

Considering the fact that the research dataset was rather small (440 units of observations) compared to big datasets (more than 2,500 units of observations), the usual normality tests for small datasets, the Kolmogorov-Smirnov test and the Shapiro-Wilk test, were used for this research. The first is a relatively robust, nonparametric test that compares the sample data to a theoretical normal distribution, by comparing the sample's cumulative distribution function to the normal distribution's cumulative distribution function. Here, the test statistic value is used to measure the largest difference between the two cumulative distribution functions. The Shapiro-Wilk test is less sensitive to deviations from normality than the Kolmogorov-Smirnov test, which means it is more appropriate for smaller sample sizes. The Shapiro-Wilk test is based on the W statistic, which is a measure of the departure of the sample from normality. The W statistic ranges from 0 to 1, where values closer to 1 indicate a closer fit to a normal distribution. The result of W statistic is a p-value, which is the probability of observing a sample as extreme as the one being tested under the assumption of normality. If the p-value is small, it indicates that the sample is unlikely to have come from a normally distributed population, and the hypothesis of normality is rejected. It is recommended that quantile plots are used for interpretation of tests results and identifying outliers and non-normal patterns in the data. Namely, they can help determine if transformations or non-parametric methods are needed to better approximate the underlying distribution.

To confirm the hypothesis, the Wilcoxon rank-sum test, a non-parametric statistical test, was used in addition to the normality tests. This test is typically employed when the data fails to meet the assumptions for using a parametric test, such as the t-test, or when the sample sizes are small. It is used to compare the medians of two independent, yet related, samples. The test works by comparing the ranks of the values from each sample and determining whether there is a significant difference in the medians between the two groups. The test statistic U was calculated by summing the ranks of the values from one sample in the combined dataset:

$$U = W - \frac{n_2(n_2+1)}{2} \quad (1)$$

where W is test statistic, n_2 is the number of observations in the other group whose ranks were not summed.

Finally, the research date was processed and all tests conducted with SPSS IBM (*Statistical Package for the Social Sciences*).

Research result and discussion

First, the normality distribution of the data was checked. Table 1 shows results of normality tests for the two periods 2016–2019, and 2020.

Since p-value = 0 (i.e., $p<0.05$) for both the Kolmogorov-Smirnov and Shapiro-Wilk tests, the sample was unlikely to have come from a normally distributed population, and the hypothesis of normality was rejected. Figure 1 shows the data distribution of ROA values in both periods on normal quartile plots, where y-axis shows the value of observed financial indicator. As it can be noticed, some ROA values

Table 1. Tests for normality of the dataset

Research period	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	df	Sig.
2016–2019	0.240	88	0.000	0.670	88	0.000
2020	0.199	88	0.000	0.802	88	0.000

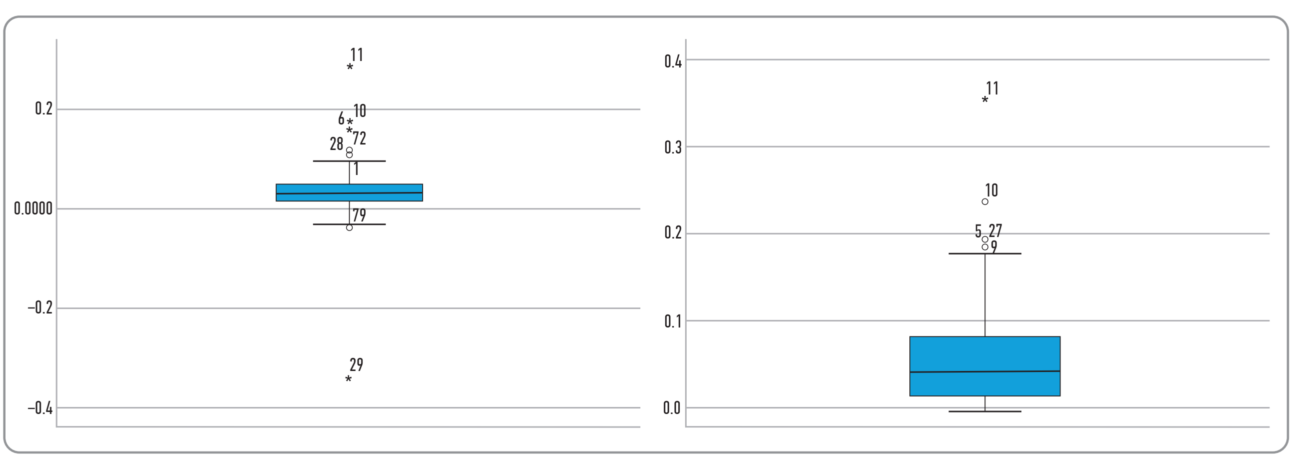

Figure 1. Quartile plots for 2016–2019 (left) and 2020 (right) research periods

Table 2. Null hypothesis test using Wilcoxon rank test

	Null Hypothesis	Test	Sig.	Decision
Asymptotic significances are displayed. The significance level is .050.	The median of differences between ROA 2016–2019 and ROA 2020 equals 0.	Related-Samples Wilcoxon Signed Rank Test	0.001	Reject the null hypothesis.

Table 3. Related summary of Wilcoxon test results

Total observations	88
Test Statistic	2,747.000
Standard Error	240.324
Standardized Test Statistic	3.283
Asymptotic Sig.(2-sided test)	0.001

were out of the normal distribution in both periods. Furthermore, it can be noticed that most companies in first period positioned themselves between 0 and 10%, with some of them having negative ROA. While in 2020 all companies had positive ROA, usually ranging between 0% and 20%.

The Wilcoxon test was used to test the null hypothesis. Table 2 shows $p<0.05$, which indicates that the there was a significant difference between ROA values of the observed entities before and during COVID-19 pandemic period. Therefore, the null hypothesis *"Pandemic COVID-19 did not have impact on profitability of meat industry in Serbia"* was rejected.

The descriptive statistics show the mean ROA before the pandemic was approximately 3.5%, but was approximately 6.1% during the pandemic. This suggests the pandemic had, on average, a positive effect on profitability measured by ROA of business entities from the meat industry in Serbia.

Figure 2 shows the positive and negative differences in ROA values calculated for the sampled entities when comparing the pandemic period of 2020 with the pre-pandemic period of 2016–2019. There were more positive than negative differences, indicating that the pandemic had a generally positive impact on the profitability of the observed entities, as measured by the ROA financial indicator. The following graphs (Figure 3) show ROA values in more detail for the observed reporting periods.

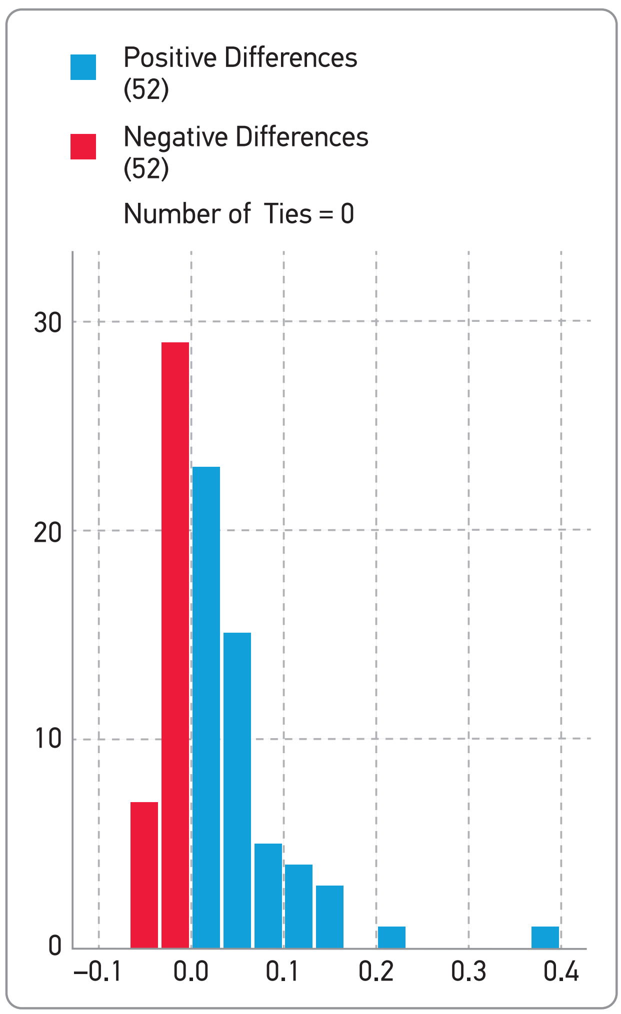

Figure 2. Related-Samples Wilcoxon signed rank test

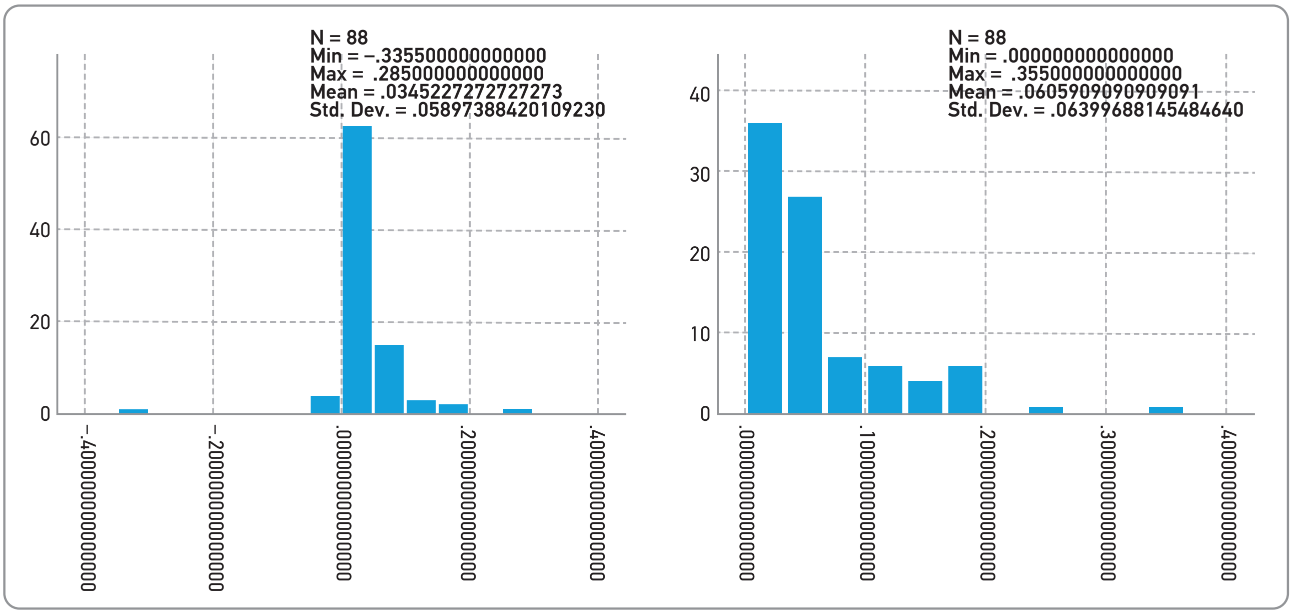

Figure 3. Descriptive statistics result for 2016–2019 (left) and 2020 (right) reporting periods

The mean ROA was higher in 2020 compared to in the pre-pandemic period, as were the minimum and maximum ROAs. Additionally, all sampled business entities recorded positive ROAs in 2020, which was not the case in the period before the pandemic. On the other hand, the standard deviation was higher in 2020 than in the pre-pandemic period, indicating that some business entities achieved above average ROAs after the pandemic started. Median values of ROA also shows difference between periods, with 3.9% in 2020 and 2.75% in 2016–19 period.

Conclusion

This study examined the impact of the COVID-19 pandemic on the financial performance of top grossing business entities from the meat industry. Research results can help businesses understand which aspects of their operations are most vulnerable to disruption and which areas they can focus on to improve their financial performance. By understanding the financial impact of the COVID-19 pandemic, businesses can develop effective recovery strategies to address the challenges posed by the pandemic. The research findings show the pandemic had a positive impact on the profitability of the meat industry, as measured by the ROA financial indicator. Specifically, there was a significant difference between the ROA values of observed entities before (2016–2019) and during the pandemic period (2020), with ROA average, minimum, and maximum values increasing by significant amounts. The average ROA value in 2020 was almost double the pre-pandemic value, while the standard deviation increased as well, indicating that some business entities adapted better to the changed circumstances than others and achieved higher than average ROAs. The explanation for the positive effect of the pandemic on the meat industry's profitability can be found in the increased demand and consumption of meat products, including exports, despite somewhat negative public media. As noted in the literature review section, the pandemic led to higher prices of meat products, which had a positive effect on the profitability of the meat industry and the overall returns of the food sector on worldwide stock markets. The findings of this study contribute to the current literature related to the economic impact of the pandemic and the challenges faced by businesses. They can also aid in enhancing public awareness of the wider consequences of the pandemic and support initiatives to address these difficulties. Future work in this area could focus on analyzing other aspects of business activities of entities from the meat industry sector or other sectors, such as liquidity or solvency. Such research could help to identify specific areas where businesses could improve their resilience and enhance their financial performance in the face of future crises.

Profitabilnost industrije mesa Republike Srbije: Da li je pandemija COVID-19 imala uticaj?

Olivera Mijailović, Maja Kljajić, Vule Mizdraković, Nataša Kilibarda

A p s t r a k t: Pandemija COVID-19 je promenila okolnosti poslovnog okruženja, imajući pozitivan ili negativan uticaj na gotovo svaku industriju i privredno društvo. Naime, pandemija je poremetila globalnu ekonomiju, što je dovelo do značajnih promena u poslovnom okruženju. Samim tim, industrija mesa u Srbiji nije bila izuzetak. Cilj ovog rada je da se ispita uticaj pandemije na profitabilnost mesne industrije u Srbiji pomoću kauzalno-komparativnog dizajna. Uzorak istraživanja je obuhvatio 440 finansijskih izveštaja, kao jedinica posmatranja, odnosno 88 privrednih društava iz mesne industrije sa najvećim tržišnim učešćem analiziranih tokom pet godina (2016–2020). Distribucija normalnosti podataka je testirana pomoću Shapiro-Wilk i Kolmogorov-Smirnov testova, dok je Wilcoxon signed-rank test korišćen za potvrdu uticaja pandemije na uzorkovana društva. Rezultati ukazuju da je pandemija COVID-19 imala uticaj i to pozitivan na profitabilnost industrije mesa u Srbiji meren Prinosom na imovinu (ROA). Rezultati ovog rada doprinose postojećoj literaturi o ekonomskim efektima pandemije i mogu biti korisni vlasnicima privrednih društava i investitorima u procesu donošenja odluka.

Ključne reči: *Prinos na imovinu, Wilcoxon statistički alat, finansijski izveštaji, mesna industrija, investitori*

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Original Scientific Paper

Mind Over Palate: Unveiling the Role of Neuromarketing in the Food Industry

Ivana Brdar[1*]

A b s t r a c t: This scientific paper investigates the application of neuromarketing research in the food industry and its impact on consumer behaviour and perception of food quality. Through a comprehensive review of the relevant literature, this study explores the fundamental concepts and techniques of neuromarketing research, as well as their practical application within the context of the food industry. Furthermore, it analyses the various factors that influence consumer perception of food quality and examines how neuromarketing research can contribute to a better understanding of these factors. By integrating theoretical and empirical findings, this paper offers valuable insights into the potential benefits and advantages of utilising neuromarketing research, while also acknowledging the ethical challenges associated with its implementation in creating effective marketing strategies and enhancing the overall consumer experience in the food industry.

Keywords: *neuromarketing, food quality, food industry, marketing, consumer behaviour.*

Introduction

Food is a fundamental human necessity, and the right to food is a guaranteed human right. Throughout human history, the motives behind food consumption have evolved. Initially, humans ate solely for survival and to alleviate hunger. While the primary purpose of food consumption remains survival, advancements in scientific knowledge have led to increased understanding of nutrition and the causal relationship between dietary choices and certain diseases (*Kilibarda et al*., 2018). Consequently, modern individuals place special emphasis on the nutritional composition and value of the foods they choose to consume (*Đorđević-Milošević et al*., 2021). In contemporary society, there is growing discourse surrounding the hedonic aspects of food, emphasising the pleasure derived from eating. This hedonic approach encompasses the exploration of new flavours, socialising, dining at restaurants and participating in celebratory events (*Clingingsmith and Sheremeta*, 2018). Moreover, food choices in specific contexts serve as status symbols, indicating affiliation with higher social strata. Examples of such behaviours include dining at expensive and renowned establishments, adhering to dietary trends and consuming organic food, which sometimes reflects a status syndrome rather than a commitment to a healthy lifestyle (*Shin and Mattila*, 2020; *Knaggs et al*., 2022).

The primary driving force behind food consumption is hunger; however, the selection of food is not solely determined by physiological or nutritional needs. Various factors influence our dietary choices, including (*EUFIC*, 2006):

- Biological factors (hunger, appetite, taste),
- Economic factors (price, availability),
- Physical factors (cooking skills, time required for food preparation),
- Social factors (culture, tradition, family, age, society),
- Physiological factors (mood, stress),
- Attitudes, beliefs and information about food.

The multitude of factors that impact food choices, which subsequently become integral parts of our diets, highlights the complexity of the decision-making process and the influence of personal taste preferences. Among these factors, biological factors, particularly the taste of food, emerge as one of the most significant determinants of food selection (*Zrnic et al*., 2021a). When referring to food taste, we encompass all sensory stimuli elicited by the consumption of food, including taste, smell, appearance and tex-

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ture (*deMan*, 1999). Certain taste preferences, such as a preference for sweet taste or aversions to bitter and sour flavours, are innate and present from birth. However, specific preferences or aversions towards tastes develop as a result of early-life experiences and are influenced by attitudes, beliefs and expectations, all of which significantly impact consumer behaviour (*Donkin et al*., 2000; *De Irala-Estevez et al*., 2000; *Devine et al*., 2003; *Shaikh et al*., 2008;).

The modern consumer is increasingly demanding in terms of food (*Živković and Brdar*, 2018; *Sarcevic et al*., 2018; *Kilibarda et al*., 2020;). They expect the food they consume to possess desired and consistent quality, ensure their safety and be affordable. Moreover, consumers seek food that aligns with their concept of a healthy lifestyle and possesses an appealing appearance (*Zrnić et al*., 2021b). Consequently, the food industry faces rigorous criteria that must be met to satisfy consumer expectations, expand market share, boost profits and outperform competitors (*Bertoch*, 2018). To meet consumer demands and secure a competitive edge, the food industry must continuously innovate throughout the entire production process, ranging from raw material procurement to product placement in the market (marketing). These innovations are pivotal for sustained market presence and for retaining existing, as well as attracting new consumers (*Brdar*, 2021). In today's highly competitive business environment, the food industry is constantly evolving to address the needs and desires of consumers. Within this context, marketing strategies play a crucial role in capturing consumer attention and influencing their decisions. A recent approach employed in the food industry is neuromarketing – an interdisciplinary scientific field combining neurology, psychology and marketing to investigate and comprehend consumer perception, emotion and behaviour.

Demystification of neuromarketing — definition and techniques

Neuromarketing is a relatively new research field that combines neuroscience and marketing with the aim of better understanding consumer behaviour and designing more effective marketing strategies. This discipline utilises neuroimaging techniques, measures of brain activity and emotional responses to uncover hidden motives, preferences and consumer reactions (*Pozharliev et al*., 2015; *Lim*, 2018; *Ramsøy*, 2019; *Mansor and Mohd Isa*, 2020; *Varlese et al.,* 2020; *Russo et al*., 2021; *Levallois et al*., 2021; *Siddique et al*., 2023).

The emergence of neuromarketing as a means of studying and exploring the human brain for the purpose of applying the findings to marketing campaigns and enhancing the profitability of advertising does not have a specific date. The techniques that we now consider as falling under the realm of neuromarketing were utilised before the term itself was coined (*Levallois et al*., 2021). Nowadays, neuromarketing employs various brain science techniques to measure consumer behaviour. According to Postma (2013), these techniques can be classified into three main categories:

- External reflexes (based on physiological signals),
- Input-output models (based on behavioural signals),
- Internal reflexes (based on brain signals).

When it comes to measuring external reflexes, Bergstrom et al. (2014) argue that it serves as a supplementary tool or an exclusive method within the field of neuromarketing. Several distinct approaches can be identified in this category. One such approach is empathic design, which involves objectively observing consumers as they interact with products and services in their natural environment, based solely on their behavioural patterns (*Leonard and Rayport*, 1997). Another method utilised is facial coding, which measures facial movements to determine emotions and levels of engagement. This includes capturing visible changes in facial expressions, such as smiling, as well as imperceptible micro-muscle movements. Eye tracking is an additional technique utilised to measure consumers' eye movements and pupil dilation when exposed to various marketing stimuli (*Telpaz et al*., 2015; *Boerman et al*., 2015; *Adhikari*, 2023). Moreover, the use of galvanic skin response (GSR) is prominent – an established physiological measure that assesses the electrical conductance of the skin, which undergoes changes in response to emotional arousal and other psychological processes.

The input-output model serves as both an independent tool and a complementary technique in neuromarketing research. Its primary function is to measure the impact of marketing stimuli on individuals' responses, achieved through online panel studies or various types of social media content analysis. According to *Postma* (2013), the objective is to explore the cause-and-effect relationship between input variables (such as photos, prices, words, features, etc. in advertisements and billboards) and specific outcomes, such as consumer behaviour, brand attitude and purchase intention.

Internal reflexes involve the analysis of consumer brain reactions to marketing stimuli and can be categorised into two main groups: blood flow measures and electrical measures. Blood flow measures rely on changes in blood flow to infer brain activity, with functional magnetic resonance imaging (fMRI) being the primary tool. Electrical and magnetic signals directly recorded from the brain constitute the other category. The main tools used in neuromarketing to measure internal reflexes are electroencephalography (EEG), magnetoencephalography (MEG) and fMRI. (*Ariely and Berns*, 2010; *Häusel*, 2013; *Adhikari*, 2023). EEG is a non-invasive procedure where electrodes are attached to subjects' heads to measure fluctuations in electrical activity beneath the scalp caused by nerve activity. Its primary objective is to gauge the intensity of intuitive and irrational consumer responses to marketing stimuli, such as excitement or frustration. MEG, similar to EEG in its electrical approach, utilises highly sensitive devices like a superconducting quantum interference device (SQUID) to examine electrical fields generated above the brain. Compared to EEG, MEG provides superior signal quality and high temporal resolution, offering a more precise scanning in time. MEG investigates brain activity by measuring blood flow, as active brain regions exhibit increased oxygen-rich blood circulation. Since oxygen-rich blood generates a smaller magnetic field than oxygen-poor blood, the resulting magnetic waves provide insights into the brain's active areas. The measurement outcome is a brain scan image with illuminated regions indicating activity during exposure to stimuli. For example, if the scan reveals activation in the hippocampus, it signifies heightened activity in the memory area as the subject stores or retrieves information from their memory.

In general, methods for measuring internal reflexes are highly favoured among researchers, primarily due to their higher accuracy and reliability compared to other techniques (*Morin*, 2011; *Hammou et al*., 2013; *Bergstrom et al*., 2014).

Exploring the implications, use and role of neuromarketing in the food industry

Neuromarketing research has significant implications for the food industry, providing a deeper understanding of consumer behaviour and their perception of food (*Javor et al*., 2013; *Agarwal and Dutta*, 2015; *Koc and Boz*, 2018;). These findings can be applied to various aspects of the food industry to improve business operations in this sector. The potential implications and applications of neuromarketing in the food industry are discussed below.

Neuromarketing offers the opportunity to explore consumers' emotional reactions to food. Analysing neurological responses enables the identification of brain centres associated with pleasure, reward and emotional experience of food (*Lagast et al*., 2017). Neurological analysis can reveal how emotions such as happiness, excitement or nostalgia can influence the experience of food and consumer preferences. In this regard, *Russo* et al. (2022) conducted a study using EEG to determine how two video advertisements for traditional cheeses from southern Italy elicit emotions and memory in consumers. Although both videos contained the same four narrative themes (territory, product, production techniques and natural landscapes), the authors found that the video characterised by an initial negative tone that transitions to positive evoked a stronger emotional response and better memory compared to the first video. Another study by *Mengual-Recuerda et al*. (2020) utilised EEG, eye tracking and GSR to measure emotional intensity for different dishes and courses in Haute Cuisine during presentations and tastings. The results showed that desserts elicited the strongest emotions, followed by main courses and snacks.

Neuromarketing research also offers valuable insights into the impact of personalisation and individual preferences on food perception. By analysing neurological responses in relation to personal characteristics such as age, gender or previous experiences, researchers can identify how individual differences manifest in the perception of food (*Van der Laan and Smeets*, 2015). This knowledge can be utilised to tailor food offerings to the specific needs and preferences of different consumers (*Howse et al*., 2021). Examining brain activity during the food decision-making process allows researchers to identify key factors and brain regions involved in motivation, reward and pleasure. *Enax et al*. (2015) confirmed in their research the positive effect of marketing strategies targeting children for healthy snacks when accompanied by cartoon characters. However, one should be mindful of potential abuses. *Campos et al*. (2016) found in their study that children in Spain are exposed to more unhealthy food advertising than healthy food advertising on television, which raises concerns.

Neuromarketing can also help identify the key factors that influence the perception of food quality. Through the analysis of consumers' neurological responses, researchers can pinpoint specific sensory characteristics such as smell, taste, texture and visual elements that contribute most to the perception of food quality (*Piqueras-Fiszman and Spence*, 2015; *Spence*, 2016; *Schulte-Holierhoek et al*., 2017). For example, *Velasco and Spence* (2019) conducted a study investigating the influence of typeface on the perception of taste. The results showed that participants associated round letters with the word "sweet", while they associated more angular letters with the taste words "bitter", "salty" and "sour". Based on these findings, food manufacturers can enhance different aspects of their products to align with consumers' expectations and provide them with a high-quality experience.

The visual aspect of food plays a crucial role in consumer choice and preference. Neuromarketing research has demonstrated that specific colours, shapes, packaging design and food presentation can activate distinct areas of the brain and elicit positive emotional responses in consumers, as well as increase their willingness to purchase and consume food (*Clement et al*., 2017; *Moya et al*., 2020; *Oswald et al*., 2022; *Semenova et al*., 2023). Through neuromarketing studies, brain activity can be analysed when individuals are exposed to visual food stimuli (*Vu et al*., 2016; *Schlintl and Schienle*, 2020; *Khan and Lee*, 2020; *König et al*., 2021; *Güney et al*., 2021; *Adhikari*, 2023). This allows researchers to identify which visual elements evoke positive reactions, stimulate appetite and enhance the appeal of food. For instance, colours such as red and orange can be associated with freshness and taste, while green and blue are often linked to healthy food (*Spence*, 2015). Additionally, dishes that are more colourful tend to be more attractive to consumers (*Jantathai et al*., 2013; *König et al*., 2021). Understanding these connections enables food manufacturers to adjust the visual elements of their products to attract and satisfy consumers. In terms of packaging, *Veflen et al*. (2023) found that the shape and colour of cheese packaging improve taste expectations and preferences, with a round shape eliciting the highest level of liking, and a round shape, high color brightness and low color saturation signalling a mild taste, while a triangular shape, low color brightness and high saturation signal a sharper taste.

Odours also play a significant role in our food experience and can evoke strong emotional reactions (*Berčík et al*., 2016; *Spence*, 2016; *Berčík et al*., 2020). Neuromarketing research allows for the identification of how olfactory stimuli of food affect the activity of specific brain regions and consumer preferences. For example, the smell of freshly baked bread can activate brain areas associated with pleasure and enjoyment, thereby positively influencing the consumer's perception and preference for a particular type of bread. Another study conducted by *Kline et al*. (2000) measured frontal lobe activation while consumers were exposed to different odours (pleasant: vanilla, unpleasant: valerian, neutral: plain water). The aroma of vanilla, the most pleasant smell, resulted in significantly higher activation of the left hemisphere of the brain compared to the other smells. Food manufacturers can leverage these insights to create products with specific aromas that will attract consumers and increase their desire to consume. Furthermore, neuromarketing research can provide information about scent combinations that work best and create synergy, which can be valuable when developing new products or enhancing existing ones.

Food taste has a significant impact on consumer preferences. Neuromarketing research employs sensory analysis of taste and combines it with neurological measurements to identify neurological patterns that occur during food tasting. This approach allows researchers to gain a better understanding of how various tastes, such as sweet, salty, sour and bitter, affect brain activity and consumer preferences. For instance, a sweet taste can activate pleasure centres in the brain, while a bitter taste can elicit negative reactions. Additionally, the taste of food plays a pivotal role in determining the acceptability of food products for consumers. It can evoke positive or negative emotions during and after consumption. Moreover, taste significantly influences consumers' food memory, as highlighted by *Ndaro and Wang* (2018). Food products that are flavourful tend to be well-received and sustainable in the market. By analysing neurological responses, researchers can identify preferred tastes among consumers and utilise this information to develop new products or modify existing flavours to meet consumer satisfaction.

It is of utmost importance to underscore that sensory stimuli, encompassing visual impressions, odours and tastes, frequently collaborate in unison to shape the overall gastronomic experience for consumers. Neuromarketing research focuses on studying the combination of these stimuli and their impact on consumer preferences. Through the analysis of neurological responses, researchers can identify synergies between sensory stimuli and determine the combinations that best satisfy consumers and pique their interest in specific types of food.

Neuromarketing research has the capacity to unveil consumers' implicit preferences that may not be consciously expressed. Unlike traditional research methods, such as surveys, which can be influenced by biases and subjective responses, the neuromarketing approach grants access to consumers' implicit or unconscious preferences (*Sung et al*., 2020). Analysis of brain activity can uncover genuine emotional reactions and preferences that consumers may not be cognizant of or able to articulate verbally.

Furthermore, neuromarketing offers an opportunity to evaluate the efficacy of changes in food composition or formulation. Additionally, it enables the testing of new products and food concepts prior to their market launch. By employing neurological techniques, researchers can assess consumer responses to different variations in food composition, including modifications in nutritional value, ingredient additions or substitutions. This allows manufacturers to make well-informed decisions regarding product enhancements and adjust their composition in accordance with consumer preferences.

Neuromarketing research offers valuable insights into the influence of context on food perception. By analysing neurological responses in various settings such as restaurants, shops, or home environments, researchers can uncover how contextual factors like ambience, music, or lighting contribute to the food experience and shape consumer preferences (*Spence and Piqueras-Fiszman*, 2014; *Hsu and Chen*, 2019). This knowledge is crucial for adapting the consumption environment to create a positive experience for consumers. A notable study conducted by *Tammela et al*. (2010) examined individuals with binge eating (BE) tendencies and found altered brain activity in frontal regions during food presentation. The results suggest that increased frontal beta activity could serve as an indicator of a dysfunctional disinhibition-inhibition mechanism, making obese individuals with BE more susceptible or sensitive to food and environmental influences.

Neuromarketing research also aids in the adjustment of marketing strategies. Drawing on neurological insights, food manufacturers can develop marketing campaigns that prioritise sensory stimuli known to have the greatest impact on consumers (*Harris et al*., 2019). EEG has particular utility in this regard, as it can detect pupil dilation, which serves as an index of stimulus interest, and the frequency of blinks, which indicates the emotional valence of the stimulus (*Stasi et al*., 2018). Thus, neuromarketing research provides valuable insights into how advertising messages shape the perception of food quality. By analysing neurological responses to marketing campaigns, manufacturers can comprehend how consumers interpret and respond to different messages, slogans and brand narratives (*Hamelin et al*., 2020). This knowledge enables better targeting of marketing efforts and the creation of messages that effectively convey product quality (*Venkatraman et al*., 2015).

Neuromarketing plays a pivotal role in enhancing food manufacturers' understanding of consumers' food purchasing decisions. By analysing consumers' neurological responses during the decision-making process, valuable insights into the neural patterns associated with motivation, attention and reward can be obtained. For instance, research conducted by *Simmonds et al.* (2018) demonstrated that transparent packaging increased consumers' willingness to purchase, the expected freshness and perceived food quality compared to packaging featuring food images. This knowledge enables manufacturers to tailor their marketing strategies and sales tactics to attract consumers and influence their purchasing decisions. However, it is important to note that not all measurement techniques are suitable for these purposes. For example, *Songsamoe et al*. (2019) argue that using EEG to measure consumers' motivational tendencies may be inappropriate when comparing foods with minor differences in hedonic ratings.

Moreover, neuromarketing facilitates the monitoring of consumer reactions during interactions with food brands. A study conducted by *Fehse et al*. (2017), which focused on the perception of both organic and non-organic, but popular food brands, contributes to the existing literature by providing converging evidence that the lateral and medial regions of the prefrontal cortex exert distinct and independent influences on decision-making. Brand information significantly influences the processing of food stimuli. Despite not being expensive or particularly rewarding in other aspects, the presentation of popular food brands elicited brain activation, suggesting a potential rewarding nature (high-calorie food). This valuable information sheds light on how consumers perceive brands and enables manufacturers to adapt their strategies to improve brand perception and foster loyalty (*Hamelin et al*., 2020). By analysing neurological responses over an extended period, researchers can track changes in brand perception, the establishment of an emotional connection with consumers, and the development of brand loyalty. Consequently, manufacturers can formulate long-term branding strategies that have a positive impact on consumers and foster strong relationships with them.

Neuromarketing research contributes to the understanding of factors that impact consumer satisfaction following food consumption. By analysing neurological responses during the post-consumption phase, researchers can identify elements that contribute to a positive experience, including satisfaction with taste, texture and the fulfilment of expectations. For instance, *Berns and Moore* (2012) discovered a significant positive correlation between reward-related brain areas and future purchase decisions. The neural responses observed can be regarded as predictive indicators of food evaluation, particularly in terms of cultural popularity. These insights are invaluable for food manufacturers seeking to enhance the quality of their products and ensure greater consumer satisfaction.

Additionally, neuromarketing research provides insights into the influence of social factors on food perception. Analysing neurological responses during group interactions or experiments within social contexts enables researchers to comprehend how consumers' opinions, attitudes and preferences are shaped by the influence of others (*Alsharif et al*., 2020; *Alsharif et al*., 2021; *Bočková et al*., 2021). This aspect holds significant importance in the food industry, where social aspects, such as communal meals or the influence of friends and family, can serve as key determinants in food choice and perception.

The Duality of Neuromarketing: Benefits and Ethical Challenges

Neuromarketing research is an innovative approach to studying consumer behaviour in the food industry, combining principles from neuroscience, psychology and marketing. These studies provide profound insights into consumer preferences, motivations and reactions to food. By combining objective biometric data with subjective consumer reports, a more comprehensive understanding of how consumers perceive, experience and react to food can be obtained. These insights enable food manufacturers and marketers to develop more effective branding, packaging and promotional strategies that align with consumer preferences and expectations. For instance, a study by *Smidts et al*. (2014) explored the application of neuromarketing research in the context of strategic marketing decisions. Their findings demonstrate that neuromarketing techniques, such as fMRI, can provide insights into the neural activity patterns that occur during marketing decision-making processes. This knowledge is of crucial importance for the development of effective marketing strategies in the food industry. Another example is the research conducted by *Krishna* (2012), which focused on the application of neuromarketing methods in the field of sensory marketing. The author highlights that by engaging the senses, such as smell, taste and touch, neuromarketing techniques can influence consumers' perception, judgment and behaviour. These findings can be applied in the food industry to enhance the consumer experience and establish a connection between the brand and the positive sensations associated with food.

Another key advantage of neuromarketing research is its ability to obtain objective data on consumer responses to food and study subconscious reactions. Traditional research methods, such as surveys and focus groups, often rely on subjective statements from consumers. In contrast, neuromarketing techniques like fMRI and EEG allow for direct observation of consumers' neurological activity when exposed to specific food stimuli. This enables researchers to gain objective and precise insights into consumer reactions, minimising the influence of subjective factors and facilitating the identification of subconscious processes and emotions that arise during food interactions (*Braeutigam*, 2017).

While the application of neuromarketing research in the food industry offers numerous advantages for understanding consumers, it also raises ethical challenges that require attention and consideration (*Sloan*, 2015; *Hensel et al.*, 2017). As these techniques become increasingly integrated into marketing strategies, it is important for researchers, experts and companies to be aware of the ethical issues that arise from such research. One key ethical concern is the issue of privacy and the rights of research participants. Neuromarketing research often involves measuring the neural activity of consumers, which can be perceived as an invasion of privacy. The collection of brain data raises concerns about data security and its use. Therefore, it is crucial for researchers to obtain informed consent from participants, provide detailed information about the research's nature and the use of data, and ensure that all data are stored and handled in compliance with relevant laws and guidelines (*Clark*, 2020).

The next challenge of neuromarketing research lies in the complexity of analysing and interpreting neuromarketing data. Utilising sophisticated techniques, such as fMRI or EEG, necessitates expertise and experience in data processing and interpretation. Without adequate knowledge and skills, the analysis and drawing of conclusions from research results can be challenging (*Murphy et al.*, 2020). Another challenge pertains to sample limitations and validity. Neuromarketing research often relies on relatively small sample sizes, potentially limiting the generalisability of findings to the broader population (*Cenizo*, 2022). Moreover, studies are typically conducted under controlled laboratory conditions, which could introduce discrepancies in consumer behaviour compared to real-world settings.

Another crucial ethical concern is research transparency. The outcomes of neuromarketing research can significantly impact marketing strategies and brands in the food industry. Therefore, it is essential for the results to be published and made accessible to the general public, enabling critical evaluation, reproducibility and further comprehension of the findings. Transparency also helps prevent any potential distortion or manipulation of data for marketing purposes (*Bartholomew*, 2018). For instance, there is a valid concern that utilising neuroscientific methods could lead to the creation of irresistibly appealing foods that cater to consumer needs to such an extent that they contribute to the problem of obesity, one of the major health issues of today (*Joy*, 2018).

Moreover, ethical considerations encompass questions regarding targeting and manipulation of consumers. Neuromarketing techniques possess the ability to influence consumers' emotions, attitudes and behaviour. To ensure the ethical application of these techniques, marketers should be aware of and acknowledge the limits of manipulating and exploiting consumers. Companies should take care to ensure that their marketing strategies, based on neuromarketing research, are honest, informative and fair to consumers (*Lee et al.*, 2017; *Stanton et al.*, 2017; *Samson and Buijzen*, 2019; *Cenizo*, 2022).

Furthermore, ethical aspects also pertain to the accurate interpretation of neuromarketing research results. In this realm, challenges exist in interpreting neural activity and connecting it to specific consumer behaviour (*Lynch*, 2004). Hence, it is crucial for researchers and marketers to present results transparently, avoiding exaggeration or excessively one-sided interpretations of the data (*Zuo et al.*, 2019).

Conclusion

Neuromarketing research holds significant potential for understanding consumer behaviour and food perception. Its advantages lie in the objective nature of data, the exploration of subconscious consumer reactions, and the deeper comprehension of the connections between visual stimuli and food perception. However, challenges arise in data analysis and interpretation, limitations in sample size and the external validity of research findings. Despite these challenges, neuromarketing serves as a vital tool for studying consumers and enhancing marketing strategies in the food industry. Through the analysis of neurological data, food manufacturers can gain better insights into consumer preferences, emotions and behaviours. This knowledge enables them to adapt their products, packaging and marketing campaigns to attract consumers and gain a competitive edge in the food market. However, it is crucial to use neuromarketing responsibly, while respecting ethical and moral principles. Additionally, it is essential to recognise that neuromarketing represents only one of the many factors influencing consumer decisions. Future research directions could focus on refining neuromarketing methods and techniques to overcome existing challenges and provide even more reliable insights. For instance, integrating multiple techniques, such as combining fMRI with EEG or with measuring emotional responses, can yield richer and more comprehensive data on consumer food perception. Furthermore, research can delve into studying individual differences in consumer perception of food. Each consumer is unique with their own preferences and reactions, and understanding how different factors influence consumers with distinct characteristics is crucial for personalising marketing strategies.

Um iznad nepca: Otkrivanje uloge neuromarketinga u industriji hrane

Ivana Brdar

A p s t r a c t: Ovaj naučni rad istražuje primenu neuromarketinških istraživanja u industriji hrane i njihov uticaj na potrošačko ponašanje i percepciju kvaliteta hrane. Kroz pregled relevantne literature, istražuju se osnovni koncepti i tehnike neuromarketinških istraživanja, kao i primena tih metoda u kontekstu industrije hrane. Takođe se analiziraju faktori koji utiču na potrošačku percepciju kvaliteta hrane i kako neuromarketinška istraživanja mogu doprineti razumevanju tih faktora. Kroz integraciju teorijskih i empirijskih nalaza, rad daje uvid u mogućnosti i prednosti upotrebe, ali i etičke izazove neuromarketinških istraživanja u kreiranju marketinških strategija i unapređenju iskustva potrošača u industriji hrane.

Ključne reči: *neuromarketing, kvalitet hrane, industrija hrane, marketing, ponašanje potrošača.*

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Original Scientific Paper

Application of machine learning technology to management methods

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A b s t r a c t: Multicomponent meat system — brine injected pork and cooked sausage "Doctorskaya" were was analyzed using neural network technologies and the conditions of uncertainty and risk of human error in a decision-making process in time domain were identified. The formation of a situational classifier (digital image-based histology — meat sample sections with a detailed description) and the system's knowledge base was described. The general steps of a histological section image processing are: 1) preprocessing of section images (noise removal, palette optimization, etc.); 2) color segmentation based on palette minimization; 3) approximation of boundaries of the areas highlighted in the image; 4) area size determination; 5) particle shape determination; 6) particle color determination; 7) identification of the presence of counterfeits; 8) results' output regarding the determination of the presence of counterfeits. The Jupyter Notebook and Colaboratory software environment was used to study and compare the influence of several activation functions (ReLu, tanH, eLu, sigmoid, softPlus, softSign) on the generated DataSet. The best result was obtained when with ReLu (0.9843) activation function, followed by SoftPlus (0.9765) and eLu (0.9687) activation functions. This stage of the study considered a kind of convolutional neural network (CNN) architecture with two layers of convolution (Convolutional, C-Layer) and pooling (Subsampling, S-Layer). An algorithm of the Error Back Propagation gradient was applied to train CNN. This is the first research stage for convolutional neural network applications in solution management.

***Keywords:** convolutional neural network, activation functions, intelligent system, control methods, database and knowledge, decision making.*

Introduction

The need for automation of visualization processes is out of the question. The question is how to implement artificial neural network (ANN) as effectively as possible in routine work avoiding mistakes made by the Digital Pathology Association, several years ago when using automatic diagnosing (*Van der Laak*, 2017; *Nikitina*, 2020a; *Nikitina*, 2020b). The statistical analysis of the application of this method in mammography featured many errors of the first kind (erroneous deviation from the null hypothesis).

For example, according to Korean scientists (*Kim et al.*, 2018), during medical studies, the number of errors of the first type in computer diagnostics of mammography data was about 70%. This means that when diagnosing healthy mammary glands, non-existent tumours were detected in more than half of the cases. A study (*Palazzetti et al.*, 2016) conducted by Italian scientists showed that when diagnosing malignant breast tumours such situation occurred in more than half of cases (a total of 250 cancer patients and 250 healthy women participated in the study). In the group of breast cancer patients, 138 patients (55.2%) had a truly missed cancer, 61 patients had a minimal signs and symptoms of the disease (24.4%), while a false negative result was obtained for 53 patients (20.4%). The source of errors among those who received a false negative result was in 42% of cases due to perception, in 15% — due to interpretation, 10% — due to atypical characteristics of the lesion, in 9% — due to errors during the search, in 7% — due to inherent limitations of mammography, in 4% — due to poor technique and in 13% — due to inadequate clinical management. That is, they are related to the human factor and subjectivism of perception.

The algorithm developed by specialists at the University of Nijmegen for the effective diagnosis of breast cancer based on the operation of a convo-

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lutional neural network (*Dalmış et al.*, 2018) reduces the proportion of false results.

Therefore, it is necessary to be very careful in choosing the architecture of ANN and its training. The main task is to facilitate the work of histologists and help them in making a conclusion (found/not found — compliance/non-compliance — counterfeit/not counterfeit), and not vice versa. Thus, when analyzing and classifying images, neural networks showed mediocre results, as noted above. This was observed until the development of a new architecture of ANN – convolutional neural network (CNN).

There are many methods and algorithms for solving the problem of recognizing objects in an image (*Gonzalez and Woods*, 2005; *Callan*, 1999; *Huang et al.,* 2017; *Hardt and Ma,* 2016; *Abadi et al.,* 2016), but all these ideas are not inferior in the accuracy of the result, simplicity, and speed of artificial neural networks (*Deepthi and Eswaran*, 2010). Modern deep neural networks are usually based on convolutional network-based architectures such as cognitron and neocognitron (*Yang et al.,* 2018). Their effectiveness and rapid development are due to a hybrid approach to architectural solutions, the development of learning methods, and additional error protection methods. Due to the growing popularity of deep convolutional networks, significant advances have been made in object recognition (*Lan,* 2016).

CNNs have achieved great success in image recognition, because they are arranged like the visual cortex of the brain – i.e., they can concentrate on a small area and highlight important features therein. CNN's work is usually interpreted as a transition from specific features of the image to more abstract details, and then to even more abstract details, up to the identification of high-level concepts. At the same time, the network adjusts itself and develops the necessary hierarchy of abstract features (sequences of feature maps), filtering unimportant details and highlighting essential ones. Currently, CNNs are widely used in solving medical issues.

An analysis of publications by keywords — ANN, falsification, meat products — in the ScienceDirect, Agris databases for 2014 — 2022 did showed no results. There are no studies related to artificial neural networks and meat.

An analysis of publications in the PubMed database by the keywords ANN, identification, neoplasms, showed many research related to the study of "neoplasms" in human soft tissues. In medical practice, large open databases have been collected, which are used by ANN developers. Such as: LIDC (Lung Image Database Consortium), LUNA16 (LUng Nodule Analysis 2016 Challenge), MURA (musculoskeletal radiographs), ABIDE (The Autism Brain Imaging Data Exchange), ADNI (Alzheimer's Disease Neuroimaging Initiative), DRIVE (Digital Retinal Images for Vessel Extraction), etc.

There are currently no such open or closed databases in the food industry. Therefore, the initial stage associated with the collection of input data is long and laborious. However, ideas, methods and algorithms tested in medical practice can be adapted and used in the food industry.

A few examples are given below.

Large databases have contributed to the emergence of deep learning algorithms that provide expert-level effectiveness in such tasks as the detection of diabetic retinopathy (*Gulshan et al.,* 2016), skin cancer (*Esteva et al.,* 2017), cardiac arrhythmias (*Hannun et al.*, 2019), brain hemorrhage (*Gulshan et al.*, 2016), pneumonia (*Huang et al.*, 2020) and hip fractures (*Oakden-Rayner et al.*, 2022).

In this regard, the possibility of integrating a CNN-based analysis tool to solve the problems of evaluating histological sections of food raw materials and products was of great interest.

We consider meat raw materials as muscle tissue, and the finished food product as a "biological system". That's why analogy between the identification of features on medical images and a histological images of raw meat or a finished product seems logical to us.

The study aimed at determining the main microstructural characteristics (classification parameters) for the identification of plant components in meat raw materials and finished products with CNN. By the term "finished product" we mean "ready to cook or/and ready to eat" product.

Concentration of the plant components and their nature (carrageenan, starch, soy isolate, vegetable gum) does not real matter in this case. CNN identifies them all regardless the concentrations. On the training sample, the percentage of correctly recognized samples is 97%, on the development sample — about 86%, on the test sample — 85.5%.

Materials and Methods

Samples of meat raw materials and finished meat products were used.

We use images (*.jpeg) of histological sections in RGB format to train our CNN. Histological sections were prepared according to the method from the State standard (GOST 19496-2013) "Meat and meat products. Method of histological research". The objects of the study were histological sections made from samples of: 1) cooked sausage "Doctorskaya" (recipe: pork, beef, milk, eggs, salt, black pepper) (n=50); 2) pork (m. L.dorsi) injected with brine containing plant components: soy isolate, carrageenan, gum (n=25). At least 9 sections were made from each sample. The significant minimal concentration of a plant component that can be identified with this histological method equals to 0.1%.

Histological analysis was carried out following GOST 19496-2013 "Meat and meat products. Method of histological research". The cuts 14 µm thick were prepared made using MIKROM-HM525 (Thermo Scientific) cryostat, mounted on Menzel-Glaser (Thermo Scientific) glasses, stained with Ehrlich's hematoxylin and 1% eosin water-alcohol solution (BioVitrum), and then embedded in glycerol-gelatin. Histological preparations were studied using AxioImaiger A1(Carl Zeiss, Germany) light microscope. Image processing was performed using AxioVision 4.7.1.0(Carl Zeiss, Germany) computer image analysis system and a connected AxioCam MRc 5 video camera.

To program neural networks, we used the Python language with the connection of Numpy, Keras and TensorFlow libraries (*Hoijtink and Planqué-Van Hardeveld*, 2022; *Magdin et al.,* 2022). The Numpy library helps develop a simple neural network that solves a prediction problem. The Keras library is used when programming feed-forward networks.

TensorFlow is a Google open source machine learning library used to build and train a neural network that solves the problem of finding and classifying images. The library is built on a dataflow programming paradigm that allows one to optimize mathematical calculations.

Convolutional neural network training was implemented in Jupyter Notebooks environment.

Jupyter Notebook is a tool for interactive development and presentation of software projects, a kind of notebook that combines program code in a single document.

To determine the classification accuracy, we use the activation function, which decides what should be fired into the next neuron. It takes the output signal from the previous cell and converts it into some form that can be used as input data for the next cell (Figure 1). The closer the value of the activation function to 1 (one), the more accurate recognition of the image and the assignment to the desired classification of the object.

Results and Discussion

A step-by-step solution to the problem of identifying an image of a histological cut is shown in Figure 2.

To solve this problem, it is required to collect a representative sample — DataSet with marked areas on histological cuts. Semantic segmentation is carried out in order to divide the image into separate groups of pixels that correspond to any one object (for example, carrageenan, vegetable gum, etc.).

For this purpose, a database structure has been developed, in which identification features and information about marks for testing and training are stored for each image. Before placing an image in

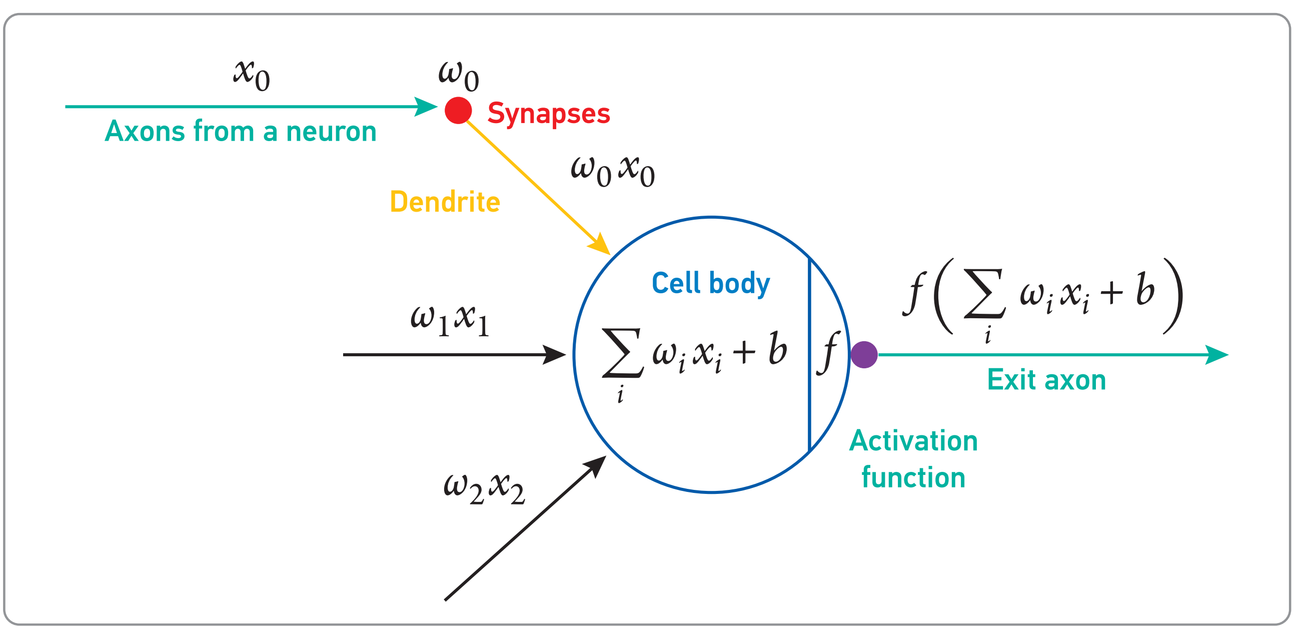


Figure 1. Artificial neuron structure

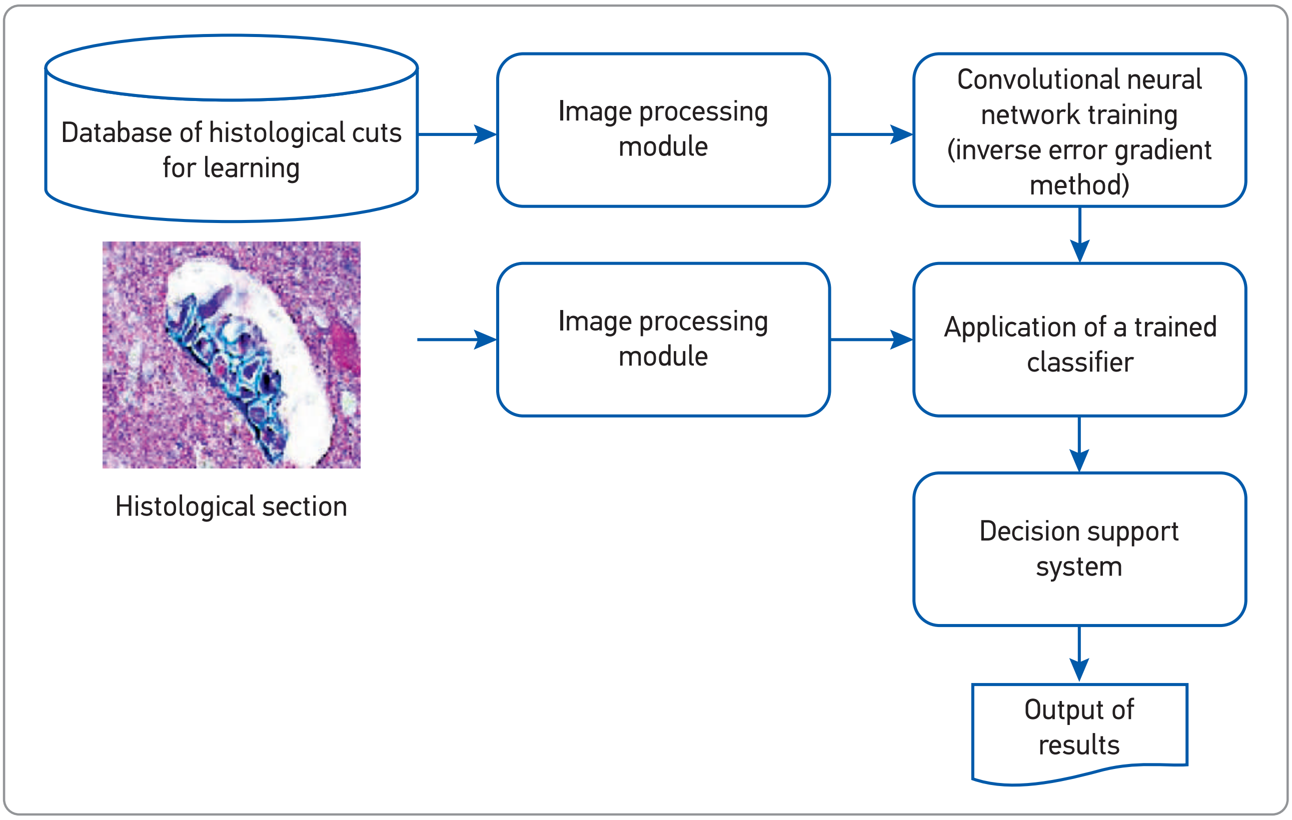


Figure 2. Step-by-step solution algorithm

the database, it undergoes pre-processing, segmentation and classification (assignment to a particular class of undeclared components).

At the training stage of the neural network, augmentation was used (changing the image, for example, flipping the image horizontally, vertically, at an angle of 45°) to increase the sample size. At least 10 variants of histological cuts were presented for each type of "inclusion". In our work, DataSet for one inclusion: the size of the training sample is 672, and the test sample is 168. The number of epoch wise trainings is 50.

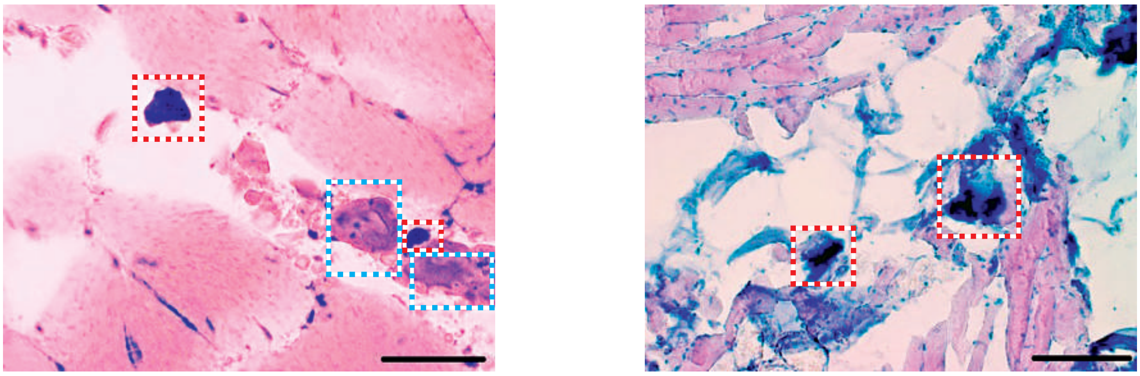
1. Database of Histological Sections

First it is necessary to collect a database of histological sections. The data must contain the same set of object classes for their segmentation. After collecting the data, it is necessary to mark up the images (Figure 3a, 3b). The marking means recording the coordinates of the polygons of each class object in a separate file in the *.txt or *.xml format.

To find the main microstructural characteristics (classification parameters/situational classifier) of identification, on the example of plant components in the composition of meat raw materials and finished products, the structure of a unified information database (DB) of histological indicators was developed in the course of the work.

The first stage included the selection of identification features that must necessarily be included in the database structure – particle shape, size, tinctorial properties of particles (the ability to be stained with histological dyes), and fragments of the soybean shell for protein components (*Lisitsyn et al.,* 2020). In this subject area, an Entity is a plant component, while an attribute is a data describing the properties/attributes of the Entity. Table 1 shows the database structure. A relational database is a (most commonly digital) database based on the relational model of data, as proposed by E. F. Codd in 1970 (*Codd,* 1970). A system used to maintain relational databases is a relational database management system (RDBMS). Many relational database systems are equipped with the option of using the SQL (Structured Query Language) for querying and maintaining the database (*Ambler,* 2009; *Khosiin and Umam*, 2023; *Hosny et al.,* 2023; *Nguyen,* 2022; *Lifschitz et al.,* 2022). Each attribute is assigned a letter designation (Table 1, Column 3).

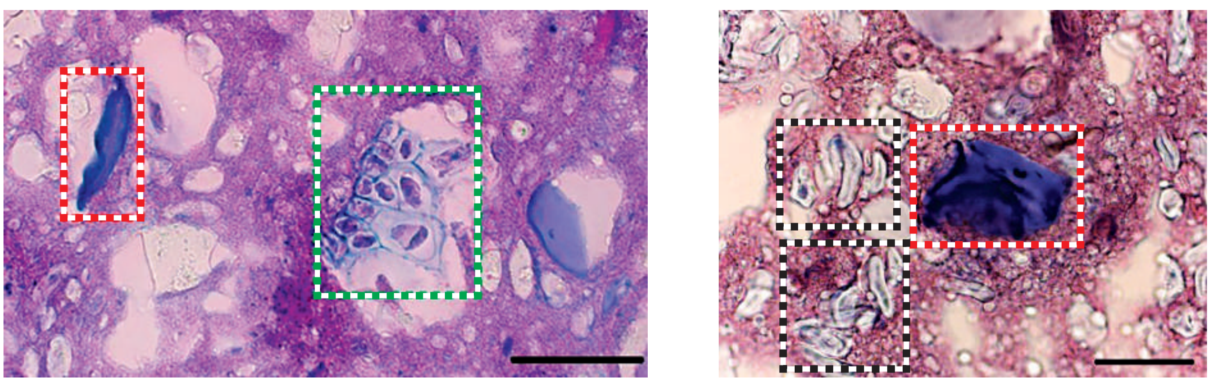
The signs specified in Column 3 corresponding to the key concepts can take certain syntactic values, which are considered as constants. If the attribute takes this value, it is assumed that the corresponding variable is equal to this value.



a) carrageenan – red;
soja isolate – blue
(Scale bar – 50 μm)

b) carrageenan – red;
(Scale bar – 200 μm)

Figure 3a. Identified plant ingredients in pork (m. L.dorsi)



a) carrageenan – red;
vegetable gum – green
(Scale bar – 50 μm)

b) carrageenan – red;
starch – black
(Scale bar – 50 μm)

Figure 3b. Identified plant ingredients in cooked sausage "Doktorskaya"

Based on the production rules, the process will be carried out as follows. An image of the histological section *A* is fed to the input, and then it is processed.

To implement the stages of processing images of histological sections of meat samples, the following algorithm is proposed for their implementation (Figure 4).

Processing of a histological section image *A*, in general, includes the following steps: 1) preprocessing of section images (noise removal, palette optimization, etc.); 2) color segmentation based on palette minimization; 3) approximation of boundaries of the areas highlighted in the image; 4) area size determination; 5) particle shape determination; 6) particle color determination; 7) identification of the pres-

Table 1. Relational Database Structure

Entity	Attribute value	Designation
Name of components	– particle shape	A_1
	– size	A_2
	– Tinctorial properties (at hematoxylin and eosin staining)	A_3
	– Tinctorial properties (at Lugol's solution staining)	A_4
	– characteristic microstructure (photo)	A_5

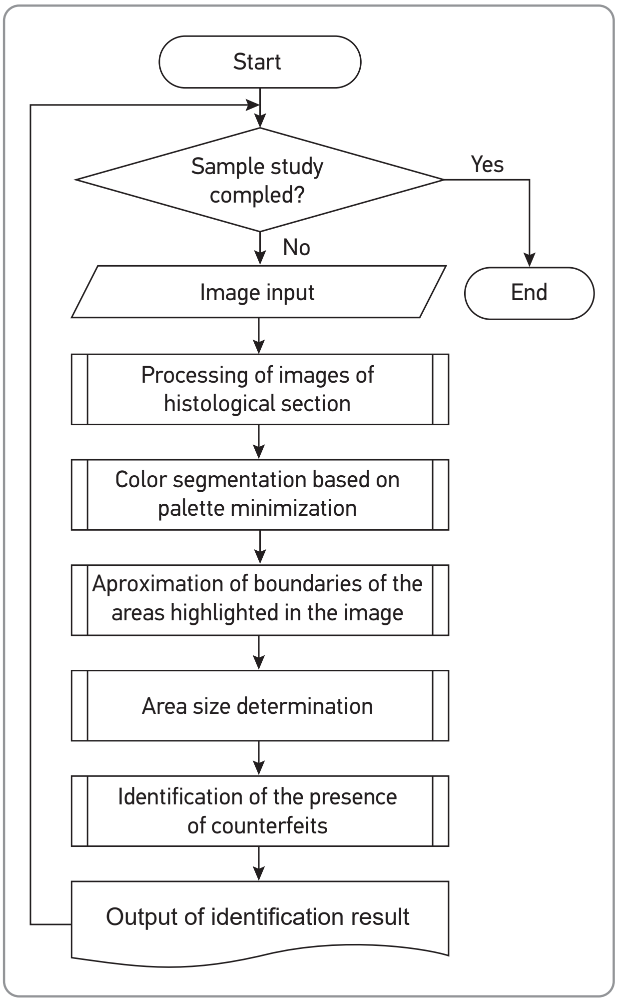


Figure 4. A block diagram of a histological section image processing algorithm to automate the detection of inconsistencies

ence of counterfeits; 8) results' output regarding the determination of the presence of counterfeits.

Consistent implementation of the above steps will allow for obtaining an informed decision on the presence or absence of certain types of counterfeits of meat products.

Based on the amount and type of a non-labeled additive (attribute *A2*), technologist, or other responsible person decides on non-compliance and further action. Like 1) return item to the supplier with complaints; 2) Send raw materials or finished product for further processing or 3) sent it to sale. This procedure is usually described in the QMS documents of an enterprise.

In neural networks, both the activation function and the error handling methods on each layer of the neural network play an important role. The accuracy of the classification made by the artificial neural network relative to the object on the histological cut depends on these two indicators. The network is considered trained when the comparison error is equal to zero or corresponds to the maximum allowable error value.

2. Activation Function

At this stage of the study, the *TensorFlow* library was used to study and compare the effect of several activation functions on classification results. The study of activation functions resulted in the obtainment of the following accuracy indicators.

We got the best result when using the ReLu activation function (0.9843). The next result was shown by the SoftPlus (0.9765), eLu (0.9687), Sigmoid (0.7851), SoftSign (0.7773), and TanH (0.7591)activation functions.

Thus, the most accurate classification is achieved by using the ReLu activation function to train a convolutional neural network (CNN) in this study.

3. Neural Network Architecture

At this stage of the study, a kind of convolutional neural network architecture with two layers of convolution (Convolutional, C-Layer) and pooling (Subsampling, S-Layer), which alternate one after another, is proposed. The CNN architecture receives a normalized image with a standardized size on the input layer, if required. Inner layers are consecutive convolution layers, with normalization and pooling layers. The main thing to understand is that a convolution layer means a layer that transforms a part of the input image, a 3×3 matrix, into a 1×1-pixel using matrix transformations. On the output layer of this type of architecture, we get a set of fitches of this image, as shown in Figure 5.

As can be seen from Figure 4, CNN consists of the following types of layers (from left to right): 1) *Convolutional* — this layer convolves the input matrix with the convolution kernel. The number of convolution kernels determines the number of feature maps — the first is equal to the second; 2) *Subsampling, or pooling layer* — this layer takes the result of the convolution of the previous layer in the form of a matrix and compresses this matrix. This is made in order to highlight low-level features and reduce the data size. The arithmetic mean of the elements over the window or the maximum value over the window is most often used as a compression function; 3) *Fully connected*. A one-dimensional vector is fed to this layer from the convolutional/subsampling layer in front of it, and this vector is obtained from the matrix by writing its elements line by line in one line.

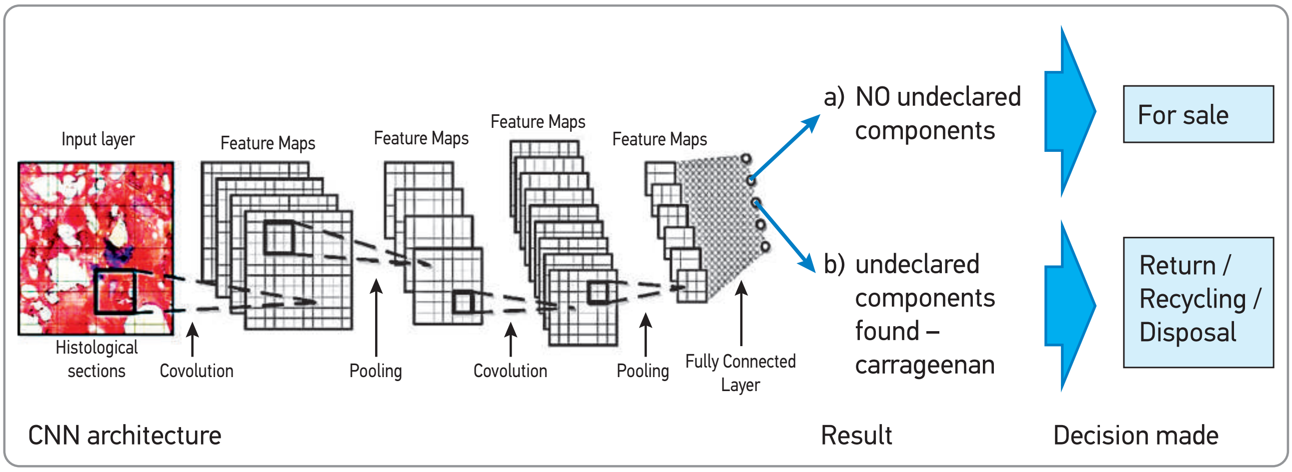


Figure 5. The CNN architecture for classification tasks of objects (undeclared components) in an image (histological section).

The main features of the CNN architecture for the classification of objects in the image are: a) the CNN *input* layer is convolutional, and the output layer is fully connected; b) *convolutional* and *subsample* layers alternate with each other, and their alternation is followed by fully connected layers (at least 1). Thus, the final part of CNN is nothing more than a fully connected perceptron.

An error back propagation algorithm, which refers to the methods of studying with a teacher, was used to train CNN.

Algorithm to train fully connected CNN layers. An error is formed on the last layer of CNN neurons and is defined as the difference between the output response of the network (values of neurons of the last layer of neurons) y and the standard t:

$$\gamma_j = y_j - t_j$$

Then there is a change in the values of weights and thresholds according to the formulas:

$$\omega_{ij}(t+1) = \omega_{ij}(t) - \alpha\gamma_j F'(S_j)\gamma_i$$

$$T_j(t+1) = T_j(t) + \alpha\gamma_j F'(S_j)$$

where α is the learning rate of the network; t and $t+1$ are the moments of time before and after the change of weights and thresholds, respectively; indi-

Algorithm SAG (Stochastic Average Gradient) *(Schmidt et al.,* 2017*)*

Initial data: sampling X^l, learning rate h, forgetting rate λ

Result: vector of weights w

1. Initialize weights $w_j, j = \overline{1,n}$
2. Initialize gradients $G_i = \nabla F_i(w_i), i = \overline{1,l}$
3. Initialize functionality evaluation $Q = \frac{1}{l}\sum_{i=1}^{l} F_i(w)$
4. **repeat**
5. select object x_i from X^l on a random basis
6. calculate the loss $\delta_i = F_i(w)$
7. calculate the gradient $G_i = \nabla F_i(w)$
8. make a gradient step $w = w - h\frac{1}{l}\sum_{i=1}^{l} G_i$
9. evaluate the functionality $\bar{Q} = \lambda\delta_i + (1-\lambda)\bar{Q}$
10. **until** the $\bar{Q}$ value and/or weights w converge

Figure 6. Gradient method algorithm for inverse error.

ces *i* and *j* denote the neurons of the first and second layer of neurons, respectively.

An error for the hidden layer with index *i* is calculated through the errors of the next layer with index *j* as follows:

$$\gamma_i = \Sigma_j \gamma_j F'(S_j)\omega_{ji}$$

Fully connected layers are trained according to the Rosenblatt training procedure, which presupposes that the value of the learning rate is constant during the entire training time and takes values in the interval (0;1].

Before getting to the convolutional layer or the pooling layer, the one-dimensional signal is converted into a two-dimensional one according to the same scheme.

The algorithm of the gradient method of inverse error is presented in Figure 6.

Training scheme of a convolutional neural network. First, it is necessary to initialize the weights of all layers of the neural network, set the maximum allowable error, and prepare a training set. Then the image from the first training pair is directly propagated through all layers of the neural network, while the resulting output of the neural network is compared with the required output, and the error is calculated. If the error is less than the maximum allowable value, then training stops, otherwise the error propagates backward from the last layer to the first one and the correction to the weights is calculated in each layer. After that, the weights of the neural network are modified following the gradient descent rule, while all iterations are repeated for the next training pair.

Conclusion

The state of a complex meat system in real-time under the conditions of uncertainty and risk of decision-making could be identified using neural network technologies. The paper demonstrates the formation of a situational classifier (marking of digital images of histological sections with a detailed description) and system's knowledge base. The Jupyter Notebook and Colaboratory software environment was used to study and compare the influence of several activation functions (ReLu, tanH, eLu, sigmoid, softPlus, softSign) on the generated DataSet. Classification results showed that when using the ReLu activation function, the convolutional neural network showed the most accurate classification of a given identification feature. The initial stage of solving the problems of monitoring and managing the quality of meat raw materials and finished meat products using convolutional neural networks is shown. The task of training neural networks is reduced to setting (obtaining) weight coefficients that ensure the correct operation of the neural network. Under conditions of uncertainty, evolutionary algorithms, which include genetic algorithms, show the greatest efficiency. Further research is related to the use of genetic algorithms in CNN training.

Primena tehnologije mašinskog učenja na metode upravljanja

Andrey B. Lisitsyn, Irina M. Chernukha, Xinqing Xiao, Marina A. Nikitina, Victoria A. Pchelkina

A p s t r a k t: Višekomponentni mesni sistem –svinjsko meso u koje je ubrizgana salamura, kao i kuvana kobasica „Doctorskaya“, analizirani su korišćenjem tehnologija neuronskih mreža i identifikovani su uslovi neizvesnosti i rizika od ljudske greške u procesu donošenja odluka u domenu vremena. Opisano je formiranje situacionog klasifikatora (histologija zasnovana na digitalnoj slici – delovi uzoraka mesa sa detaljnim opisom) i baza informacija/znanja sistema. Opšti koraci obrade slike histološkog preseka su: 1) prethodna obrada slika preseka (uklanjanje šuma, optimizacija palete, itd.); 2) segmentacija boja zasnovana na minimizaciji palete; 3) aproksimacija granica oblasti koje su istaknute na slici; 4) određivanje veličine površine; 5) određivanje oblika čestica; 6) određivanje boje čestica; 7) utvrđivanje prisustva falsifikata; 8) ishod rezultata u vezi sa utvrđivanjem prisustva falsifikata. Jupiter Notebook i Colaboratory softversko okruženje su korišćeni za proučavanje i upoređivanje uticaja nekoliko aktivacionih funkcija (ReLu, tanH, eLu, sigmoid, softPlus, softSign) na generisani skup podataka. Najbolji rezultat je postignut sa ReLu (0,9843) aktivacionim funkcijama, zatim SoftPlus (0,9765) i eLu (0,9687) aktivacionim funkcijama. U ovoj fazi istraživanja razmatrana je neka vrstu arhitekture konvolucione neuronske mreže (CNN) sa dva sloja konvolucije (Convolutional, C-Layer) i udruživanja (Subsampling, S-Layer). Za obuku CNN-a primenjen je algoritam gradijenta Error Back Propagation. Ovo je prva faza istraživanja za aplikacije konvolucionih neuronskih mreža u upravljanju rešenjima.

Ključne reči: *konvoluciona neuronska mreža, aktivacione funkcije, inteligentni sistem, metode upravljanja, baza podataka i znanja, donošenje odluka.*

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Technical report on the Food Standards Agency project G010008 (2002). Evaluating the risks associated with using GMOs in human foods, University of Newcastle, UK (http://www.foodsafetynetwork.ca/gmo/gmnewcastlereport.pdf).

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In Meat technology 63/2 2022, on page 1, Muhamed Smailovic is written incorrectly, it shoulwwd be Muhamed Smajlović. On the same page, next to the name Željko Sladojević, instead of Republic of Srpska, should be written Bosnia and Herzegovina.

All corrections were made in the Meat technology 64/1 2023 issue.

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