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Original scientific paper

Flavour intensity and acceptability evaluation of smoked sausages

Stenly Apata Ebunoluwa[1], Heather Farell-Clarke[2], Meredith M. Lane[3], Paige Cappello[4], Ricky Hairston[5], Anjie McCroskey[6], Lisa Prybolsky[7], Jacob Schnitzler[8], Jay VanWinkle[9], Danika Miller[10], Bruce Armstrong[11]*

A b s t r a c t: This study was conducted to investigate the effects of different spices on the flavour intensity and acceptability of cooked, smoked sausages. A total of 112,944.51g meat block was prepared containing 80/20 pork trim 56,245,46 g (49.8%) 80/20 beef 28,576.32 g (25.30%) and 50/50 pork trim 28,122.73 g (24.89%) to form batter with 11,339.80 g (10%) water, 2,494.76 g (2.2%) salt, 2,267.96 g (2%) corn sytrup solids, 1,153.98 g (1%) dextrose, 294.83 g (0.26%) ground black pepper, 2500 ppm (283.50 g; 0.25%) sodium phosphate, 156 ppm (283.50 g; 0.25%), curing salt, (6.25% $NaN0_2$), and 547 ppm (56.70 g; 0.05%) sodium erythrobate. The batter was divided into five treatments. Thus, T1 Wisconsin style = batter + coriander + msg + ground celery; T2 = andouille = batter + red pepper, white pepper + garlic powder + ground thyme + onion powder; T3 chipotle = batter + chilli powder + ground chipotle pepper + garlic powder+ smoke flavouring powder + ground oregano; T4 old fashioned = batter + msg + ground nutmeg; T5 whiskey fennel = batter + whiskey + dextrose (0.60) + whole fennel. The sausages were stuffed into natural hog casing (32–35mm), hand linked and smoked cooked at 85°C for 150 min and 78% humidity to 70°C internal temperature, cold showered and kept overnight. They were oven-warmed and evaluated for flavour intensity and preference by a 10-member taste panel using a hedonic scale on which 1 = not intense and 10 = intense, while the preference ranked on the scale on which 1 = favourite and 5 = least favourite. The results showed that T2 had the most intense flavour ($p<0.05$), while T1 was most preferred ($p<0.05$) and T4 was least preferred. It is suggested that changing the spices to create varieties of sausages for consumers be encouraged and that T1, T2 and T3 be given wider publicity for consumer acceptability in order to increase their production and placement on the market and to provide better justification and recommendation from a marketing strategy aspect.

Keywords: *evaluation, flavour intensity, preference, smoked sausage, spices.*

Introduction

Sausage is one of the earliest forms of food processing and became an art distinctive to particular locations during the Middle Ages and as a means of preserving meat. Sausage is minced meat or a combination of meats blended with seasonings and spices stuffed into a casing or container (*Savell and Smith,* 2009). It consists of communited meats ranging from coarsely ground to fine emulsions such as hot dogs or bologna, and products can be cured, smoked or heat processed and be fresh, dry, semi-dry or fermented sausages. Each product has its own processing method with intricacies and tradition according to Sausage Technology Journal (*STJ*, 2008). Smoked sausages are very popular and are of two types, uncooked and cooked; uncooked smoked sausages are made from cured or uncured meat that is ground and mixed with spices, salt or other non-meat items and stuffed into casings to form sausges that are then smoked and refrigerated. Cooked smoked sausages include emulsion type and coarse ground sausages (*Topel et al.*, 2013).

Sausages are made to add value, apart from storing meat and to produce products with variety and unique tastes. The unique taste comes largely from

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[4] *The Hershey Company, 1025 Reese, Ave, Hershey, PA, USA;*
[5] *Monogram Meat Snacks, 305 First Street Marjinsville, V.A, USA;*
[6] *Land O'Frost, 911 Hastings Ave: Searcy, AR, USA;*
[7] *NV Products Seasoning Company, 20 Potash Road, Oakland, NJ, USA;*
[8] *Vienna Beef Limited, 590 Woodrow, Denmark, WL, Denmark;*
[9] *B & B Foods, LLC, 21 Tower Drive, Newport, KY, USA;*
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spices that add flavour to sausages, according to Basic Sausage Making (*BSM*, 2004). The increased interest in food with healthy properties has led to many studies on meat products in which meat is integrated or substituted at different levels with other ingredients, such as fibre, cereals or nuts *David et al.*, (2019). It was reported that healthier frankfurters could be produced by incorporating walnut and fat into the product *(Ayo et al.,* 2008; *Jimenez-Colmenero et al.,* 2010). The growing trends in development of dietary fibre-rich meat products as well as advances in ingredient and processing systems for meat and meat products have given way for varieties of sausages to be produced (*Mehta et al.,* 2015; *Weiss et al.,* 2010). Also, the presence of non-meat ingredients or additives are usually adopted to improve shelflife and food safety, even though consumers are interested in healthier meat and meat products either without synthetic additives or with natural substitutes that could increase aspects of both commercial stability and safety (*Roila et al.*, 2008; *Agregan et al.*, 2019). It was reported by *Apata et al.* (2006) that spices had a significant influence on the flavour of cooked meat, and that flavour is one of the most cherished eating qualities of meat products, as stated by consumers (*Apata et al.*, 2014). However, there are scanty reports of the effects of spices on the acceptability of flavour of cooked, smoked sausages in the literature, so to fill the gap, this study, therefore, investigated the effects of different spices on the flavour intensity and acceptability of smoked sausages.

Materials and Methods

This study was carried out in the Meat Science Laboratory, Iowa State University, United States in July 2018. A total of 112,944.51 g of meat block was prepared containing 80/20 pork, 56,245.46 kg (49.80%), 80/20 beef, 28,576.32g (25.30%) and 50/50 pork trim, 28,122.73 g (24.89%) as shown in Table 1. The ingredient composition of the sausage is presented in Table 2 (*Armstrong*, 2018).

Grinding — Meat block (Table 1) of 112, 944.51 g was ground through a ½ grinder — Hollymatic grinder plate (*Ranucci et al.*, 2018).

Mixing — The ground meats and the ingredients, salt and curing salt (6.25% $NaSO_2$) were added, and the mixture was comminuted in a chopper (Holymatic) for 1 min. Pork trim was added, seasoning and additional water and ice were included and mixed for another 5 min. The batter was reground through a Holymatic 3/16" mixer grinder plate. (*Ranucci et al.*, 2018).

Division of batter — The batter was divided into five portions of 22,588.90g representing five treatments. Each batter treatment was transferred into the mixer and the non-meat ingredients in each treatment were added and the whole mixed further for 2 min. Next, each of the batter treatments was

Table 1. Composition of the meat block

Meat	Grams	%
Total meat block	112,944.51	–
Pork 80/20	56,245.46	49.80
Beef 80/20	28,576.32	25.30
Pork trim	28,122.74	24.90

Table 2. Ingredient composition of the sausage batter

Ingredient	PPM	Grams	% of Meat Block
Meat block	–	112,944.51	–
Water	–	11,339.80	10.04
Salt	–	2,494.76	2.21
Corn Syrup Solids	–	2,267.96	2.01
Dextrose	–	1,153.98	1.02
Ground Black Pepper	–	294.83	0.26
Sodium Phosphate	2,500	283.50	0.25
Curing Salt (6.25%)			
Sodium nitrite	156.00	283.50	0.25
Sodium Erythrobate	547.00	56.70	0.05

Legend: PPM = parts per million

transferred into a clean bucket, hand mixed properly to further homogenise the batter with the ingredients (*Savel and Smith* 2009, *Armstrong*, 2018) and allotted to sausage treatments as follows:

- T1 Wisconsin style = batter + coriander + monosodium glutamate (MSG) + ground celery
- T2 Andouille (Cajun) = batter + red pepper + white pepper + garlic powder + ground thyme + onion powder
- T3 Chipotle = batter + chill powder + ground chipotle pepper + garlic powder + smoke flavouring powder + ground oregano
- T4 Old fashioned = batter + monosodium glutamate (MSG) + ground nutmeg
- T5 Whiskey fennel = batter + whiskey + dextrose (0.60) + whole fennel

Stuffing — Each of the batch/treatments was fed into a Talsa Piston and stuffed into natural hog casings (32–35 min) following the procedures of *Savel and Smith* (2009).

Linking and Thermal Processing/Cooking — The stuffed sausages were linked manually and hung on a smokehouse truck with 10 rods ready for thermal processing. The linked sausages were allowed to stand in the processing room at a temperature of 7.22°C for between 30–60Xmin before being moved into a smoke house (Mauer) and cooked/smoked for 150 min (2 h, 50 min) at 85°C and 78% relative humidity (RD) to 70°C internal temperature according to *Savel and Smith*, (2009).

Cold Shower and Standing — This was done on and off at 1 min intervals with cold water. The cooked, smoked sausages were allowed to stand overnight before peeling (*Savel and Smith*, 2009).

Peeling — The sausages were warmed, one batch/treatment after the other, and were manually peeled then allowed to cool before serving for organoleptic evaluation (*AMSA*, 2015; *Lawrie and Ledward*, 2006).

Sensory Evaluation

Each of the sausage batches/treatments was warmed in an electric oven at 160°c for 5 min and sliced onto dishes. A 10-member taste panel comprising students and staff of Department of Animal Science (Meat Science Laboratory) of Iowa State University Ames evaluated the sausages for flavour intensity using a 10-point hedonic scale in which 1 = not intense and 10 = intense. Panel members also marked their preference ranking on a 5-point hedonic scale in which 1 = favourite and 5 = least favourite following procedures of AMSA (2015).

Experimental Design and Statistical Analysis

The experimental design for this study was completely randomized design. One way analysis of variance (ANOVA) was used (*Genstat,* 2009) and all significant means were separated with the Duncan's multiple range test of the same software at $p<0.05$.

Results

Figure 1. presents the results of the mean interaction between the sausage treatments.

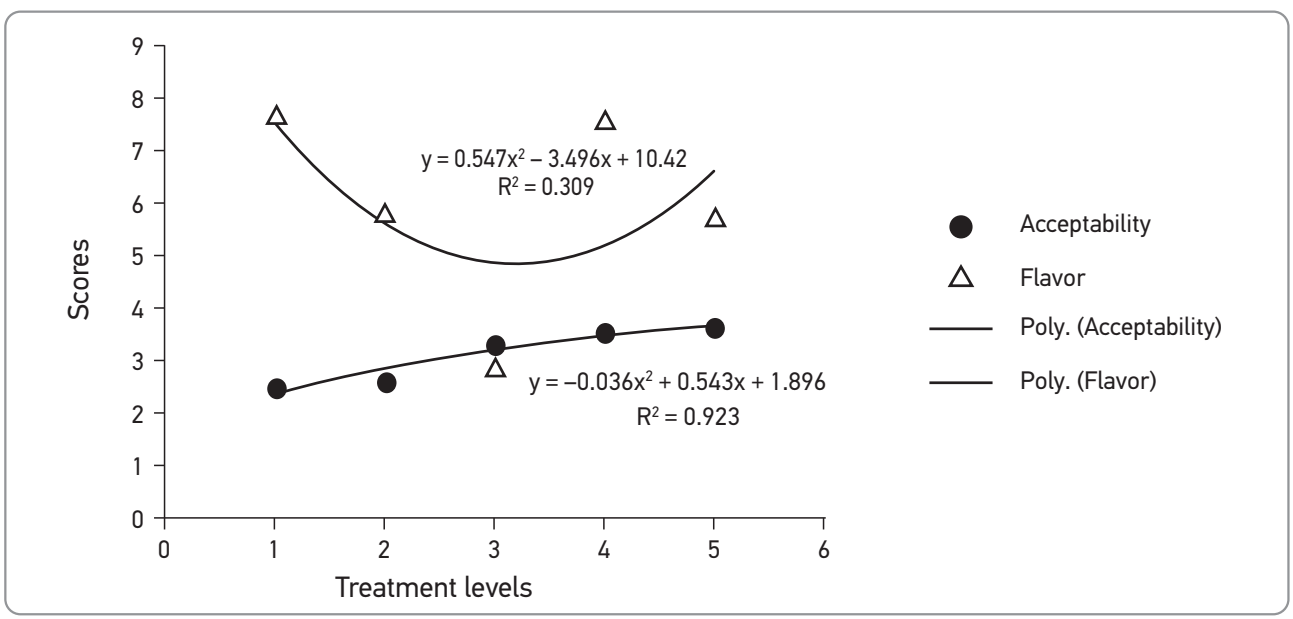

Figure 1. Relationship among the treatment organoleptic scores with increasing level of treatment and preference/acceptability and flavor.

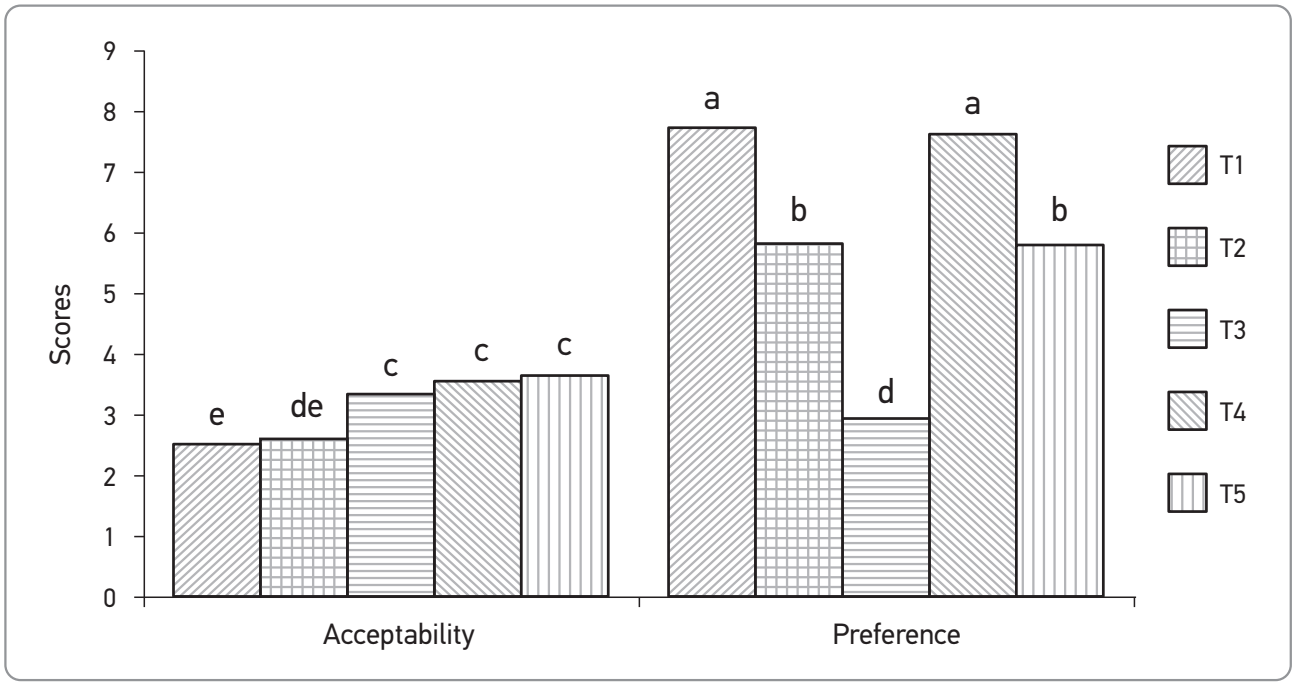

Figure 2. Acceptability and preference scores and statistical differences of the different score types between the different sausage treatments. Scores for sausage types with the same letters (a-e) are not statistically different. T1-T5: see Materials and Methods.

It was observed that the relationship between the treatments was best explained by a quadratic equation which captured about 30% of the variation in scores for flavour.

The statistical significance of differences in the acceptability and preference scores between the different treatments are presented in Figure 2.

Discussion

The same quadratic equation captured about 92% of the variation in the scores for acceptability. This implied that with increasing treatment levels from T1 to T5, the scores for flavor initially experienced a decline then followed by increase ($p<0.05$). The lowest ($p<0.05$) score for flavour was observed between the third (T3) and fourth (T4) treatment levels. The acceptability scores however, increased ($p<0.05$) with the increasing treatment level, which might likely decline at a higher treatment level. The good flavour scores for T2 and T3 might be due to inclusion of white pepper, garlic, thyme and onion in the ingredient mix for T2 and chipotle pepper, smoke flavouring powder and oregano in T3, which gave the sausages in these treatments their characteristic, highly-scored flavours (*Heinz and Hautzinger*, 2010). Also garlic and oregano were reported to add desirable flavour to food (*Topel et al.*, 2013; *Ranucci et al.,* (2015).

The scores for acceptability were generally low compared with the flavour scores. Among the preference scores, T1, T3 and T4 were significantly ($p<0.05$) more preferred than T2 and T5. For flavour, inconsistent scores were observed for T3 while T1 and T4 as well as T2 and T5 had similar ($p>0.05$) scores; thus, the paired treatments produced similar results. The higher preference scores observed in T1, T3 and T4 could be as a result of a long-standing habit of consuming Wisconsin style, chipotle and old fashioned sausages by the majority of members of the taste panel, despite the andouille sausage (T5) receiving a higher flavour score than the chipotle sausage (T3). It was reported by *Apata et al.* (2016) that it is difficult, once they are formed, to sever people's habits of consuming a particular meat or food. However, in another work involving the use of another spice/additive, it was reported that consumers could change their inherent habit of consuming one particular meat product, depending on the major characteristics of the product, such as texture, juiciness, flavour and appearance (*Mendez-Zamora et al.*, 2015). Therefore, the overall acceptability of any meat product would be decided by consumers based on the eating qualities of such a product, not necessarily on the eating habits of the consumers. It can be deduced from the results of this study that sausages of Wisconsin style, chipotle and old fashioned sausages, in that order, were highly accepted by the taste panel mem-

bers. This might not merely be due to the fact that the panel members had formed their habits with regard to consuming these sausage types, but perhaps due to the fact that these types of sausages are relished for their eating qualities as evident in this study.

Conclusion

It can be concluded from the results of this study that andouille followed by chipotle was the favourite sausage in terms of flavour, perhaps as a result of the full balance of ingredients in the mix, while the acceptability was highest for Wisconsin style followed by chipotle and old fashioned, probably due to an outstanding habit of consuming these sausages and despite the higher flavour score of our andouille sausage. This suggests that spices can be changed to create varieties of sausage to encourage consumer acceptability while T1, T2 and T3 should be given wider publicity that would raise consumer awareness of these products; this is in order to increase production and marketability.

Ocena intenziteta ukusa i prihvatljivosti dimljenih kobasica

Apata Ebunoluwa Stenly, Farell-Clarke Heather, Lane M Meredith, Cappello Paige, Hairston Ricky, McCroskey Anjie, Prybolsky Lisa, Schnitzler Jacob, VanWinkle Jay, Miller Danika, Armstrong Bruce

A p s t r a k t: Cilj ove studije je bio ispitivanje efekata različitih začina na intenzitet ukusa i prihvatljivost kuvanih, dimljenih kobasica. Pripremljeno je ukupno 112.944,51 g mesnih blokova koji sadrže 80/20 trima svinjskog mesa 56.245,46 g (49,8%), 80/20 junećeg 28.576,32 g (25,30%) i 50/50 trima svinjskog mesa 28.122,73 g (24,89%), kako bi se napravila smesa sa 11,339,80 g (10%) vode, 2.494,76 g (2,2%) soli, 2.267,96 g (2%) čvrste supstance kukuruznog sirupa, 1.153,98 g (1%) dekstroze, 294,83 g (0,26%) mlevenog crnog bibera, 2500 ppm (283.50 g; 0.25%) natrijum fosfata, 156 ppm (283,50 g; 0,25%), soli za sušenje, (6,25% NaN02) i 547 ppm (56,70 g; 0,05%) natrijum eritrobata. Smeša je podeljena u pet tretmana. Dakle, T1 Viskonsin stil = smeša + korijander + msg + mleveni celer; T2 = Andouille = smeša + crvena paprika, beli biber + beli luk u prahu + mlevena majčina dušica + crni luk u prahu; T3 Chipotle = smeša + čili u prahu + mlevena chipotle paprika + beli luk u prahu + prah arome dima + mleveni origano; T4 tradicionalni tretman = smeša + msg + mleveni muškatni oraščić; T5 Viski komorač = smeša + viski + dekstroza (0,60) + ceo komorač. Kobasice su punjene u prirodnom svinjskom omotaču (32–35mm), ručno povezane i dimljeno kuvane na 85°C, 150 min i 78% vlažnosti do unutrašnje temperature 70°C, tuširane na hladno i držane preko noći. Zagrejane su u rerni i ocenjenivane u pogledu intenziteta i preference ukusa od strane 10-članog panela za ukuse koristeći hedonističku skalu na kojoj je 1 = nije intenzivan, a 10 = intenzivan, dok je preferenca rangirana na skali na kojoj je 1 = omiljeni i 5 = najmanje omiljeni. Rezultati su pokazali da je T2 imao najintenzivniji ukus (p<0,05), dok je T1 bio najpoželjniji (p<0,05), a T4 je bio najmanje poželjan. Predlaže se korišćenje začina za kreiranje vrsta kobasica za potrošače, kao i da T1, T2 i T3 dobiju širi publicitet sa stanovišta prihvatljivosti potrošača, kako bi se povećala njihova proizvodnja i plasman na tržište i dalo bolje opravdanje i preporuka iz aspekta marketinške strategije.

Ključne reči: Evaluacija, intenzitet ukusa, preferenca, dimljena kobasica, začini.

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Original scientific paper

Vacuum frying below the triple point of water (VFBTPW) of frozen unmarinated beef slices

Lemuel M. Diamante[1*]

A b s t r a c t: The study was carried out: a) to conduct vacuum frying below the triple point of water (VFBTPW) of frozen unmarinated beef slices using constant amount of sample used and frying temperature with different frying times and to determine the moisture and fat contents, product yield and rehydration, colour, and texture properties of the resulting vacuum fried products; b) to compare the physicochemical properties of VFBTPW and freeze-dried products; and c) to evaluate the structure of the vacuum fried beef slices using the scanning electron microscope. Vacuum frying of frozen unmarinated beef slices at 79±1°C, the lower the frying time the higher the moisture content of the vacuum fried product. The fat contents of the products were not significantly different with each other The frying time of 5 minutes gave the highest product yield due its high moisture content. The rehydration rate and rehydration ratio of the products were not affected by frying time despite a decreasing chamber pressure with increasing frying time. The chroma value of the products were not different from each other. The integrated force of the products decreased with frying time above 7.5 minutes. The vacuum fried product had lower moisture content but had higher fat content and product yield compared with the freeze-dried product. The rehydration rate and rehydration ratio of the vacuum fried product were lower than the freeze-dried product. The beef muscle fibres of the low moisture product were looser and more porous compared with the high moisture product which were more compact. The freeze-dried product was more porous than the low moisture vacuum fried unmarinated beef based on a transversal cut, but the reverse was observed when it was based on a longitudinal cut.

Keywords: *vacuum frying, beef slices, physicochemical, rehydration properties.*

Introduction

Meat drying may be fundamentally defined as the removal of most of the water present in meat by evaporation of liquid water or sublimation of ice (*Sanchurn et al*., 2012). Drying is a complex process involving simultaneous heat and mass transfer. It results in significant changes in the chemical composition, structure, and physical properties of foods. The heating process and loss of water cause stresses in the cellular structure that lead to changes in microstructure, such as the formation of pores and shrinkage (*Laopoolkit and Suwannaporn*, 2011).

Dehydrated meat, seafoods and vegetables are usually used to enhance the product value of instant noodles. Instant noodles are one of Japan's favourite foods. The taste of instant noodles has been improving significantly in past years and some of them can easily compete the fresh noodles (*Nihei*, 2021). The addition of dried meats sachets add value to instant noodles.

When processing meat, several physicochemical changes appear when different treatments are applied. During heating, the different proteins in meat denature and these cause structural changes, such as destruction of cell membranes, shrinkage of fibres, the aggregation and gel formation of myofibrillar and sarcoplasmic proteins and solubilisation of the connective tissue (*Garcia-Segovia et al.*, 2007). When frozen storage is required, as in freeze-drying, quality deterioration cannot be avoided during freezing because of the formation of ice crystals, which leads to distortion of tissue structure and mechanical damage and denaturation of protein (*Jeong et al.*, 2011).

A freeze-dried process could provide a porous structure product with little shrinkage, superior taste and aroma retention, and better rehydration capability. Even though high-quality dehydrated foods could be obtained by this process, it is usually considered too expensive to be used in the instant noodle industry. The freeze-dried process is uneconomical due to the large capital outlays required, high operating cost, and relatively long drying time (*Laopoolkit and Suwannaporn*, 2011).

Several attempts have been made to reduce freeze-drying costs by using newer drying technol-

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ogies like vacuum frying. Vacuum frying of meat is another method of drying meat. In this process, the hot oil serves as the heating medium to drive out the water from inside the meat and evaporated accordingly but under chamber pressures below atmospheric pressure (vacuum) which speeds up the drying process. When frozen meat is used, and the chamber pressure is below the triple point of water of 0.01°C and 0.611 kPa (*Guildner et al.*, 1976) then the ice particles sublimes resulting in a porous structure and with minimal shrinkage. Hence, vacuum frying of frozen foods at very low chamber pressure can hopefully yield products with similar characteristics as freeze drying but with a shorter processing time.

However, vacuum frying is the technique of deep-fat frying foods under pressures well below atmospheric levels, preferably below 6.65 kPa, which serves to reduce oil content, discolouration and losses of vitamins and other compounds normally associated with oxidation and high temperature processing (*Garayo and Moreira*, 2002). Vacuum fried products are prepared using fresh fruits and vegetables that are peeled and cut into small pieces. The operating pressure used is usually lower than 7 kPa which produces a good reduction in the boiling point of water and allows the frying temperature to be lower than 90°C (*Dueik and Bouchon*, 2011). *Fan et al.* (2005) reported to have vacuum fried frozen carrot chips at –18°C but use a vacuum frying pressure of 5 kPa which was still above the triple point pressure of water mentioned above. *Diamante and Yamaguchi* (2021) were able to carry out vacuum frying of selected frozen shellfish products at a pressure of 0.4 kPa using a special design of a vacuum fryer where their condenser was similar to that used in freeze dryers in order to achieve chamber pressure below the triple point pressure of water. Hence, they carried out vacuum frying below the triple point of water (VFBTPW) of frozen shellfish products. Unfortunately, they did not present supporting data such as the products porosity and structure for this new technology.

The development of pores and shrinkage depended upon the variation in moisture transport mechanisms and the external pressure. The strength of the solid matrix can also be affected by ice formation, case hardening, permeability of crust, and matrix reinforcement (*Rahman*, 2003). Thus, the drying method and conditions applied has a significant effect on product characteristics such as porosity, shrinkage, and bulk density. The % rehydration of dehydrated foods depends on its water absorption capability and water holding capacity (*Lewicki*, 1998).

It is hypothesized that the VFBTPW of frozen unmarinated beef slices would give a product with closer rehydration properties with the freeze-dried product, and hopefully give a product with a porous structure nearly like a freeze-dried product.

Hence, a study was carried out: a) to conduct vacuum frying below the triple point of water (VFBTPW) of frozen unmarinated beef slices using constant amount of sample used and frying temperature with different frying times and determine the moisture and fat contents, product yield and rehydration, colour, and texture properties of the resulting vacuum fried products; b) to compare the physicochemical properties of VFBTPW and freeze-dried products; and c) to evaluate the porosity and structure of the vacuum fried and freeze-dried beef slices using the scanning electron microscope.

Materials and Methods

Materials

The topside cut meat used in this study was taken from cross breeds of Angus/Hereford beef which were raised in Geraldine, New Zealand, fed with grass and slaughtered at the age of 18 months. After 3 days of chilling by hanging carcasses, the muscle fiber rich meat was used for the experiments.

Sample preparation and storage conditions

The meat was sliced into 4 mm thickness and were hand cut into 2–3 cm slices. The beef slices were spread on aluminum trays and frozen at –35 ± 2°C at an air velocity of about 1.7 m/s in a blast freezer (Skope Refrigeration, Christchurch, New Zealand). The freezing was interrupted after 18 hours to take out the meat slices from the trays and put them into polyethylene bags each with 525 g ±15 g frozen unmarinated beef slices. The samples were stored at –25°C in a laboratory freezer until use.

Vacuum frying system

The equipment used for the experiments consisted of a sealable fryer vessel connected to a condensation unit and a vacuum pump as shown in Figure 1. The heating of the oil was done using band

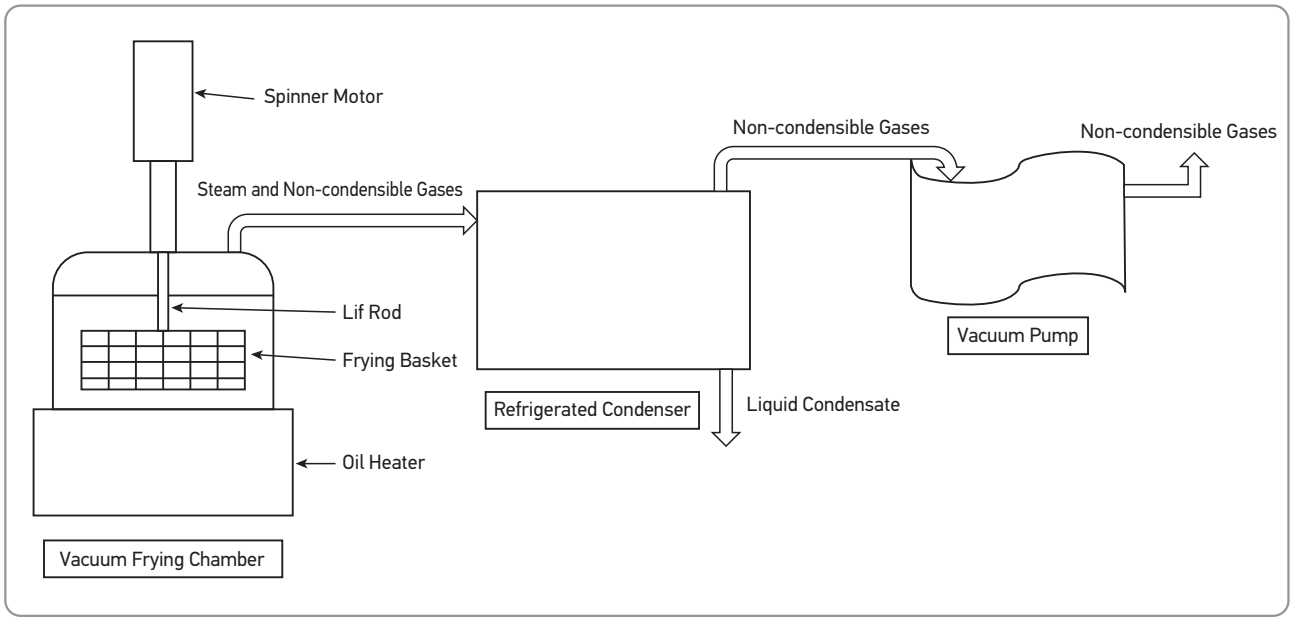

Figure 1. Schematic diagram of the vacuum frying system for the experiments (*Diamante et al.*, 2015).

heaters on the fryer walls and the condenser was cooled using a refrigeration system. Inside the vessel, a frying basket was located, which can be rotated within the chamber. For every trial, 20 litres of canola oil (Seafrost, Kuala Lumpur, Malaysia) were poured in the frying vessel and heated up to the target temperature which took approximately one hour.

The content of a bag of frozen sample was loaded into the frying basket. After closing the vessel lid, the valve to an already operating vacuum pump was opened. When a pressure of 0.4 kPa was reached, the basket with the samples was immersed into the hot oil at the target temperature. From this moment, the time was started, the temperature and chamber pressure were recorded. With the help of the vacuum pump and condensation unit, the escaping steam was taken out of the vessel. Because of the high amount of steam generated at the beginning, the pressure increased for a short period and dropped down again to about 0.4 kPa. The temperature fluctuated with decreasing amplitudes and settled down to the required temperature due to the temperature controller. When the required frying time was reached the basket was completely brought out of the oil and centrifuged using 670 rpm for 4 minutes still at the same chamber pressure to enhance the removal of residual oil from the sample surface. After this procedure, the system was pressurised back to atmospheric pressure. The product was removed out of the basket, cooled down to room temperature, placed inside aluminium laminated bags and then stored at room temperature until analyses.

Freeze-drying of frozen unmarinated beef slices

Freeze-drying of 0.5 kg and 4 mm thick frozen unmarinated beef slices was carried out in another laboratory using the following conditions: chamber temperature of 60°C and chamber pressure of 0.0.01 kPa for about 30 hours

Moisture content determination

The moisture content of the VFBTPW product from each trial run were determined using the air oven method. The products were dried at a constant temperature of 105°C in an air oven (Watson Victor Ltd, Clayson Laboratory Apparatus Ltd, NZ) for exactly 16 hours after which time a constant weight was reached (Diamante et al., 2010). The weight of samples was determined in an analytical balance with an accuracy of 0.0001g (Mettler Toledo, Greifensee, Switzerland) before and after drying in the air oven in 5 replicate measurements. The moisture content was calculated by using the equation,

$$M_{DB} = \frac{B - C}{C - A} \quad (1)$$

where:

M_{DB} = moisture content calculated on % dry basis
A = weight of container [g]
B = weight of container and product before drying [g]
C = weight of container and product after drying [g]

Product yield calculation

The product yield of the VFBTPW product was obtained from its initial and final weights. The amount of frozen sample was determined using a weighing balance with an accuracy of 0.01g (Mettler Toledo, Greifensee, Switzerland). After vacuum frying, the product was cooled down before weighing. The product yield was determined using the following equation,

$$\text{Product Yield} = \frac{\text{Weight of the final vacuum fried product}}{\text{Weight of the initial frozen sample}} \times 100 \quad (2)$$

Fat content determination

The fat content of the ground VFBTPW product was determined gravimetrically by solvent extraction using the Soxhlet technique as described in Bouchon *et al.* (2003). The fat content of the samples was calculated on a percent dry basis and the average value of the 5 replicate measurements were used.

Integrated force analysis

The texture property of the VFBTPW product was determined by measuring the integrated force of the sample using a texture analyser (Texture Analyser Model: TA-XT plus, Serial No: 10781, Stable Micro Systems, Surrey, UK) equipped with a 5 kg load cell. The integrated force measures the area of force versus time curve of the sample. When the integrated force value is low, the product easily breaks up indicating a crunchier product. A ball probe (5 mm diameter) was used to penetrate the samples at a constant speed rate of 1.0 mm/s. Measurements were done on 5 pieces of samples for all the products.

Colour properties determination

The colour properties of the VFBTPW product were determined using a Minolta Reflectance Chroma Meter CR 210 (Minolta Corp., Osaka, Japan) by measuring the L*, a* and b* colour values. The L* value range from 0 (Black) and 100 (White), the a* value from −a* (Green) and +a* (Red) while the b* value range from −b* (Blue) and +b (Yellow). The different products were ground in a multi grinder (Sunbeam Corp., Botany, NSW, Australia) and then a 10g sample was placed on a petri dish without cover. Five sets of ground samples were obtained from each trial run and the average of five readings was used. Before each measurement, the instrument was calibrated using a white ceramic tile (L = 98.06, aX= –0.23, b = 1.88). The Chroma which is the saturation and intensity of colour of the vacuum fried products were determined using the following equation,

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}} \quad (3)$$

where:

a* and b* = colour values of the vacuum fried product

Rehydration properties calculations

The rehydration properties of the VFBTPW product were determined by weighing a piece of dried product in a weighing balance with 0.01g accuracy (Mettler Toledo, Greifensee, Switzerland) and then putting the piece of dried product in a heat resistant glass bowl with boiling water. A heavier glass bowl was placed on top of the dried product so that it was fully submerged in the hot water. The dried product was left to rehydrate for 3 minutes. At the end of rehydration, the product was taken out of the water and put on three sets of thick tissue paper to dry out all surface moisture. The rehydrated product was weighed in the same weighing balance. The same procedure was repeated for 5 pieces of dried products. The Percentage Gain, Rehydration Rate and Rehydration Ratio of the individual pieces were calculated as follows,

$$\text{Percentage Gain} = \frac{\text{Initial product weight} - \text{Rehydrated weight}}{\text{Initial product weight}} \times 100 \quad (4)$$

$$\text{Rehydration Rate} = \frac{\text{Percentage Gain}}{\text{3 minutes}} \quad (5)$$

$$\text{Rehydration Ratio} = \frac{\text{Rehydrated weight}}{\text{Initial product weight}} \quad (6)$$

Statistical analyses

A two-way analysis of variance (ANOVA) using Minitab 15 (Minitab Inc., State College, Pennsylvania, USA) was carried out on the moisture content, fat content, product yield, colour values (L*, a* and b*) and chroma and integrated force to determine the significance of the results. The Tukey's test was used to locate the difference between the means (*Walpole et al*., 1998).

Results and Discussion

Preliminary experiments on vacuum frying of frozen unmarinated beef slices

The moisture, fat and product yield of VFBTPW unmarinated beef slices processed using 0.5 kg and 2.0 kg frozen sample (4 mm thick) at different frying temperature and time with chamber pressure of 0.7 ± 0.4 kPa and centrifugation of fried samples under the same chamber pressure at 670 rpm for 4 minutes, as well as freeze-dried (FD) unmarinated beef slices at a plate temperature of 60°C chamber pressure of less than 0.1 kPa and for 30 hours are summarised in Table 1. The results show that the use of 0.5 kg in vacuum frying resulted to a product with low moisture content, high fat content and higher product yield even with a shorter frying time. When the amount of sample used in vacuum frying was increased to 4-times (2.0 kg) and using a frying time that was 4-times (60 minutes) the product gave a higher moisture content, lower fat content and product yield. By using a frying temperature of 73°C and frying time of 88 minutes can bring down the product moisture content to 2.0% dry basis and attain a fat content of 30.0% dry basis and product yield of 31.7%.

A VFBTPW unmarinated beef slices can be a ready-to-eat product, or it can be incorporated in instant noodles with beef flavour. Hence, the rehydration properties such as the rehydration rate and rehydration ratio are important properties for the VFBTPW products as a noodle ingredient. Table 2 shows the rehydration rate and rehydration ratio of VFBTPW unmarinated beef slices processed with different frying temperature of and time and chamber pressure of 0.7 ± 0.4 kPa with centrifugation of fried products under the same chamber pressure at 670 rpm for 4 minutes, as well as freeze-dried (FD) unmarinated beef slices at a plate temperature of 60°C chamber pressure of less than 0.1 kPa and for 30 hours. The results show that the use of 0.5 kg frozen sample in vacuum frying resulted

Table 1. Moisture, fat, and product yield of vacuum fried unmarinated beef slices processed using 0.5 kg and 2.0 kg frozen sample (4 mm thick) at different frying temperature of and time and chamber pressure of 0.7 ± 0.4 kPa with centrifugation of fried products under the same chamber pressure at 670 rpm for 4 minutes, as well as freeze-dried (FD) unmarinated beef slices at a plate temperature of 60°C chamber pressure of less than 0.1 kPa and for 30 hours.

Treatment	Amount (kg)	Oil Temperature (°C)	Frying Time (mins)	Moisture Content (% db)	Fat Content	Product Yield
T1	0.5 kg	79±1*	15	1.9a	37.5a	36.4a
T2	2.0 kg	79**	60	2.8b	16.9b	27.0c
T3	2.0 kg	73**	88	2.0a	30.0a	31.7b
FD	0.5 kg	NA	NA	2.4ab	19.4b	12.0d

Legend: * mean of 3 runs; ** – mean of 2 runs; mean of 5 measurements for each run with means with the same letter are not significantly different from each other at 95% confidence level; NA – not applicable

Table 2. Rehydration rate and ratio of vacuum fried unmarinated beef slices processed with different frying temperature of and time with chamber pressure of 0.7 ± 0.4 kPa and centrifugation of fried products under the same chamber pressure at 670 rpm for 4 minutes, as well as freeze-dried (FD) unmarinated beef slices at a plate temperature of 60°C chamber pressure of less than 0.1 kPa and for 30 hours.

Sample	Amount (kg)	Oil Temperature (°C)	Frying Time (mins)	Rehydration rate** (% /min)	Rehydration ratio** (kg rehydrated/ kg dried product)
T1	0.5 kg	79	15	18.7b	16b
T2	2.0 kg	79	60	7.9d	1.2c
T3	2.0 kg	73	88	15.5c	1.5b
FD	0.5 kg	NA	NA	28.5a	1.9a

Legend: **mean of 5 measurements for each run with means with the same letter are not significantly different from each other at 95% confidence level; NA – not applicable

to a product with high rehydration rate and rehydration ratio even with a shorter frying time. When the amount of sample used in vacuum frying was increased to 2.0 kg (4-times) and using a frying time of 60 minutes (4-times) the product gave lower rehydration rate and rehydration ratio. By using a frying temperature of 73°C and frying time of 88 minutes gave a product rehydration rate of 15.5%/min and rehydration ratio of 1.5 kg rehydrated/kg dried product. Hence, in the succeeding experiments the use of 0.5 kg with a frying temperature of 79±1°C for vacuum frying were used.

Effect of frying temperature on the different properties of vacuum fried beef slices

Vacuum frying experiments were carried out using a frying temperature of around 80°C for vacuum frying of frozen unmarinated beef slices at different frying times. The moisture, fat and product yield of VFBTPW unmarinated beef slices processed using 0.5 kg of frozen sample (4 mm thick) with a mean frying temperature of 79±1°C and different frying time and chamber pressure with centrifugation of fried products under the same chamber pressure at 670 rpm for 4 minutes are summarised in Table 3. The results show that frying times of 5 to 10 minutes resulted to higher VFBTPW product moisture content especially with the shortest frying time. The fat contents of the products were not significantly different from each other at all frying times. It was observed that the fat content of the products had high variability. The frying time of 5 minutes gave the highest product yield due its high moisture content. The fat content and product yield of the vacuum fried mussel and cooked prawn products were 27 to 39% dry basis and 24 to 32%, respectively (*Diamante and Yamaguchi*, 2021) which were slightly lower than the vacuum fried unmarinated beef slices. But the moisture content of the vacuum fried mussel and cooked prawn products were 1.3 to 1.9% dry basis (*Diamante and Yamaguchi*, 2021) which compared well with the vacuum fried beef products.

Table 4 shows the rehydration rate and ratio of VFBTPW unmarinated beef slices processed using 0.5 kg of frozen sample (4 mm thick) with a mean frying temperature of 79±1°C and different frying time and chamber pressure with centrifugation of fried products under the same chamber pressure at 670 rpm for 4 minutes. The results suggest that the rehydration rate and rehydration ratio of the vacuum fried products were not affected by frying time despite a decreasing chamber pressure with increasing frying time. *Diamante and Yamaguchi* (2021) reported the rehydration rate of vacuum fried mussel and cooked prawn products were 12 to 18 %/min and the rehydration ratio were 1.36 to 1.54 kg rehydrated/kg dried product which compared well with the vacuum fried unmarinated beef slices in this study.

The L*, a* and b* colour values, chroma and integrated force of VFBTPW unmarinated beef slices processed using 0.5 kg of frozen sample (4 mm thick) with a mean frying temperature of 79±1°C and different frying time and chamber pressure with centrifugation of fried products under the same chamber pressure at 670 rpm for 4 minutes are shown in Table 5. The results show that the degree of lightness (L* colour value) and degree of yellowness (b* colour value) of the vacuum fried products decreased with frying time above 7.5 minutes. In addition, the degree of lightness (L* colour value) and degree of yellowness (b* colour value) of the products were similar for frying time of 10 to 45 minutes. However, the chroma value of the products were not significant-

Table 3. Moisture, fat, and product yield of vacuum fried unmarinated beef slices processed using 0.5 kg frozen sample (4 mm thick) at a mean frying temperature of 79±1°C and different frying time and chamber pressure with centrifugation of fried samples under the corresponding chamber pressure at 670 rpm for 4 minutes.

Treatment/ (Frying Time)	Oil Temperature (°C)	Chamber Pressure (kPa)	Moisture Content** (% db)	Fat Content** (% db)	Product Yield** (%)
T1 (5 mins)	78.1a	1.44b	35.7d	31.7a	42.2b
T2 (7.5 mins)	78.0a	1.17a	11.7c	33.4a	36.6a
T3 (10 mins)	78.0a	0.97a	4.2b	33.2a	35.0a
T4 (15 mins)	79.3a	8.4a	1.9a	37.5a	36.4a
T5 (30 mins)	79.1a	0.62a	1.7a	36.4a	35.2a
T6 (45 mins)	80.0a	0.58a	1.4a	39.6a	36.1a

Legend: **mean of 5 measurements for each run with means with the same letter are not significantly different from each other at 95% confidence level

Table 4. Rehydration rate and ratio of vacuum fried unmarinated beef slices processed using 0.5 kg frozen sample (4 mm thick) at a mean frying temperature of 79±1°C and different frying time and chamber pressure with centrifugation of fried products under the corresponding chamber pressure at 670 rpm for 4 minutes.

Treatment/ (Frying Time)	Oil Temperature (°C)	Chamber Pressure (kPa)	Rehydration rate** (% /min)	Rehydration ratio** (kg rehydrated/ kg dried product)
T1 (5 mins)	78.1	1.44	12.7a	1.4a
T2 (7.5 mins)	78.0	1.17	14.2a	1.4a
T3 (10 mins)	78.0	0.97	16.5a	1.5a
T4 (15 mins)	79.3	0.84	18.7a	1.6a
T5 (30 mins)	79.1	0.62	15.9a	1.5a
T6 (45 mins)	80.0	0.58	16.4a	1.5a

Legend: **mean of 5 measurements for each run with means with the same letter are not significantly different from each other at 95% confidence level

ly different from each other. *Hellmann and Diamante* (2022) reported that the colour values of vacuum fried marinated beef slices at the frying temperatures of 65 to 95°C, frying time of 26 to 66 minutes and centrifuge rotational speed of 20 to 670 rpm) were L* = 41 to 49, a* = 9 to 12 and b* = 14 to 22. The L* and b* colour values of the vacuum fried unmarinated beef slices from this study were different probably due to no marination of the beef slices. The integrated force of the products decreased with frying time above 7.5 minutes. Furthermore, the integrated force of the products was the same for frying time of 10 to 45 minutes of 1.2 to 2.1 kg.sec which were higher than that of vacuum fried marinated beef slices at the optimized vacuum frying conditions (85°C, 52 minutes and 517 rpm) of 0.3 kg.sec (*Hellmann and Diamante*, 2021) indicating that it was crunchier than the vacuum fried unmarinated beef products.

Physicochemical properties of vacuum fried and freeze-dried beef products

Comparison of the physicochemical properties of VFBTPW and freeze-dried unmarinated beef slices using 0.5 kg from Tables 1 and 2, showed that the vacuum fried product had lower moisture content but had higher fat content and product yield compared with the freeze-dried product. The rehydration rate and rehydration ratio of the vacuum fried product were lower than the freeze-dried product.

Effect of vacuum frying on the meat structure of VFBTPW unmarinated beef slices

The scanning electron microscope (SEM) image of the low moisture vacuum fried beef cut longitudinally and transversally to the beef muscle fibres using 0.5 kg and 4 mm thick frozen unmari-

Table 5. L*, a* and b* colour values, chroma and integrated force of vacuum fried unmarinated beef slices processed using 0.5 kg frozen sample (4 mm thick) at a mean frying temperature of 79±1°C and different frying time and chamber pressures ranging from 0.58 to 1.44 kPa with centrifugation of fried products under the corresponding chamber pressure at 670 rpm for 4 minutes.

Treatment	L* value** (no units)	a* value** (no units)	b* value** (no units)	Chroma** (no units)	Integrated Force** (kg. sec)
T1 (5 mins)	46.3b	9.9a	15.9b	18.8a	4.0b
T2 (7.5 mins)	49.1b	11.0a	14.8b	18.5a	3.4b
T3 (10 mins)	40.3a	10.9a	10.8a	15.4a	1.7a
T4 (15 mins)	34.1a	10.1a	7.9a	12.9a	1.2a
T5 (30 mins)	31.4a	9.2a	6.2a	11.8a	2.1a
T6 (45 mins)	30.9a	9.1a	6.1a	11.0a	1.6a

Legend: **mean of 5 measurements for each run with means with the same letter are not significantly different from each other at 95% confidence level

nated beef slices processed with an average oil temperature of 80°C (Figure 2) and the SEM image of the high moisture vacuum fried beef cut longitudinally and transversally to the beef muscle fibre using 0.5 kg and 4 mm thick frozen unmarinated beef slices processed with an average oil temperature of 78°C (Figure 3). The results show that the beef muscle fibres of the low moisture vacuum fried product were looser and more porous compared with the high moisture product which were more compact. The porous structure of the low moisture product resulted from subliming the ice of the frozen beef sample during vacuum frying. The average chamber pressure of the process was 0.58 kPa which was below the triple point of water. Because of the short frying time (5 minutes) and the average chamber pressure of 1.44 kPa which was above the triple point of water, the ice in the high moisture product were not sublimed during the vacuum frying process and so this remained in the product as liquid water thereby facilitating the fusing of the beef muscle fibres at the end of the process. On the other hand, the SEM image of the freeze-dried beef product cut longitudinally and transversally to the beef muscle fibres using 0.5 kg and 4 mm thick frozen unmarinated beef slices processed with a chamber

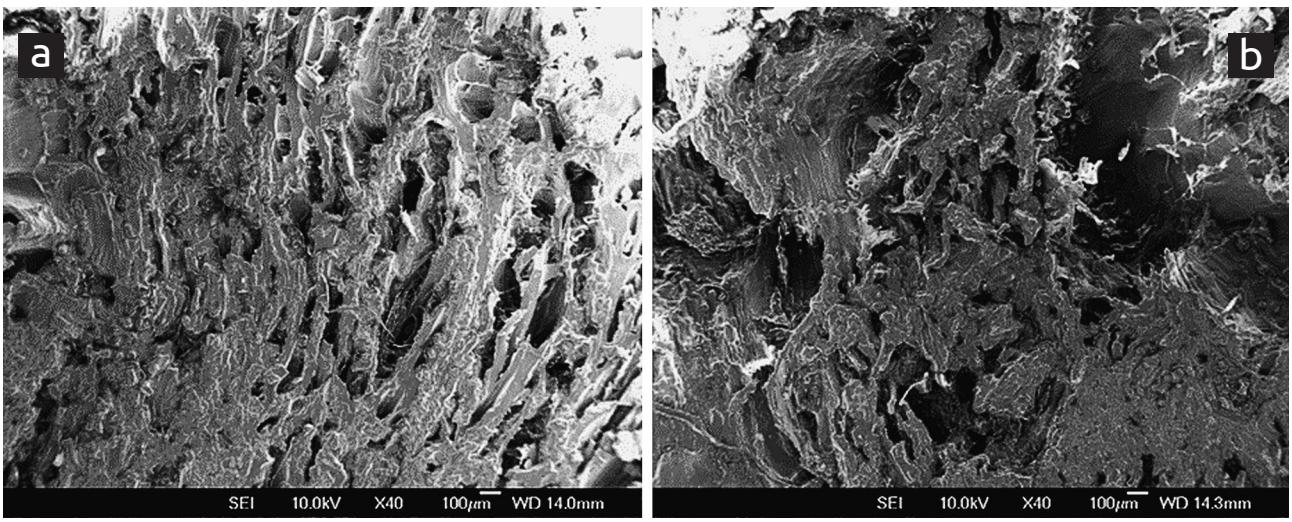

Figure 2. SEM image of low moisture vacuum fried unmarinated beef (MC=1.4% dry basis) cut longitudinally (a) and transversally (b) to the beef muscle fibres using 0.5 kg and 4 mm thick frozen unmarinated beef processed with an average oil temperature of 80°C, an average pressure of 0.58 kPa and frying time of 45 minutes.

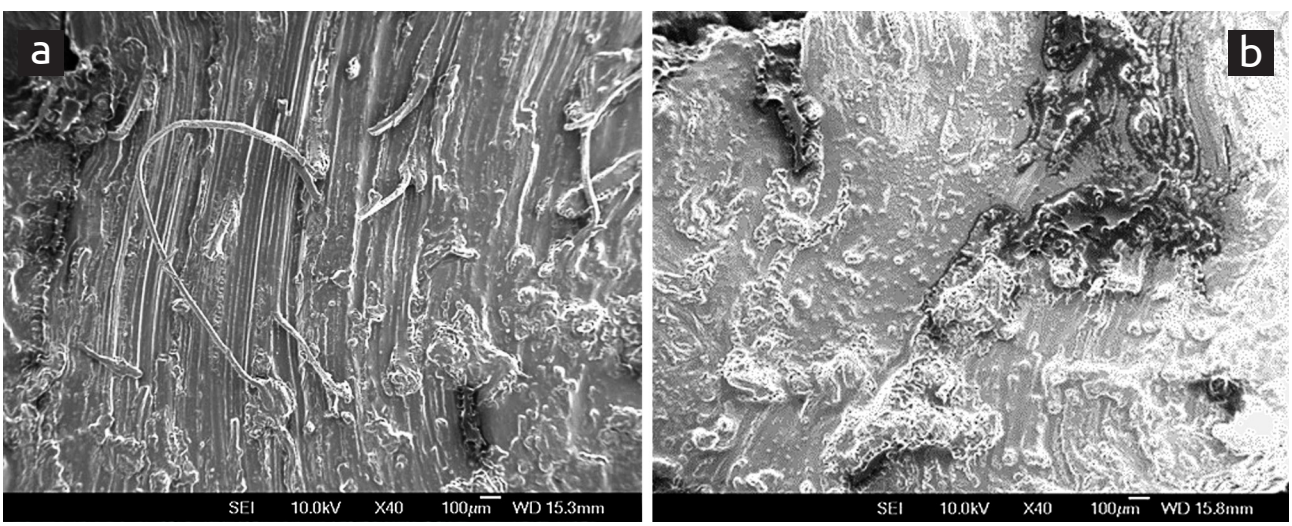

Figure 3. SEM image of high moisture vacuum fried unmarinated beef (MC=35.7% dry basis) cut longitudinally (a) and transversally (b) to the beef muscle fibres using 0.5 kg and 4 mm thick frozen unmarinated beef processed with an average oil temperature of 78°C, an average pressure of 1.44 kPa and frying time of 5 minutes.

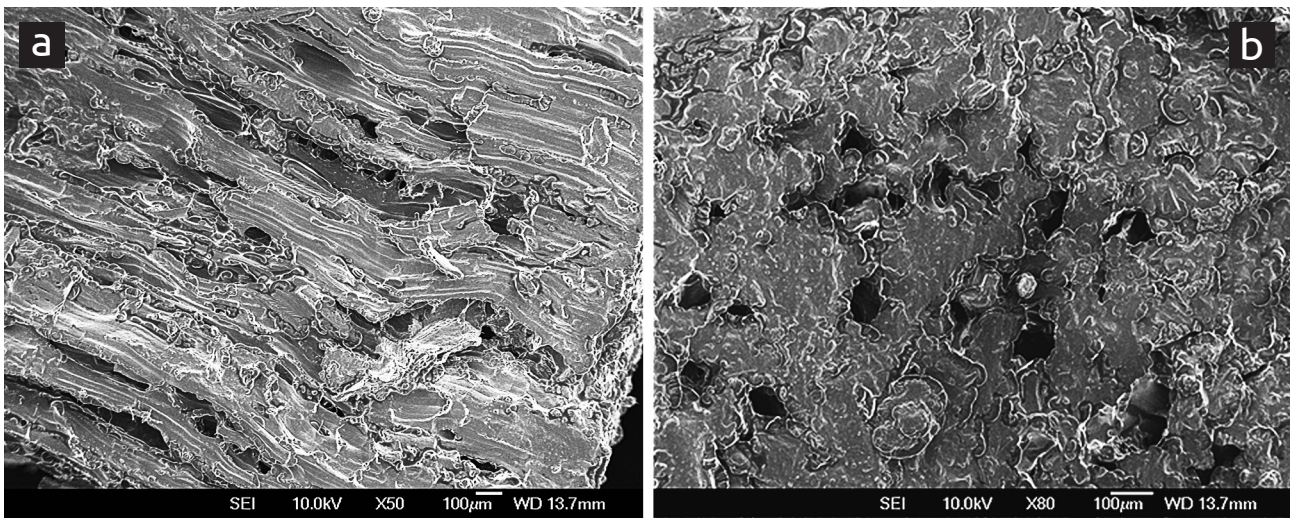

Figure 4. SEM image of freeze-dried unmarinated beef cut longitudinally (a) and transversally (b) to the beef muscle fibres using 0.5 kg and 4 mm thick frozen unmarinated beef processed with a chamber temperature of 60°C and chamber pressure of 0.0.01 kPa for about 30 hours.

temperature of 60°C and chamber pressure of 0.0.01 kPa for about 30 hours (Figure 4). The freeze-dried product was more porous than the low moisture vacuum fried unmarinated beef based on a transversal cut, but the reverse was observed when it is based on a longitudinal cut. *Lapoolkit and Suwannaporn* (2011) reported the SEM image of the longitudinal and transversal structure of freeze-dried pork and *Messina et al.* (2015) of the SEM image of the transversal structure of freeze-dried beef which compared ell with the SEM image of the low moisture vacuum fried unmarinated beef. The freeze-dried pork though had slightly more pores than the vacuum fried beef.

Implications of the results

The results suggest that the vacuum frying below the triple point of water (VFBTPW) of frozen food is a new technology that can be used to produce dried meat and seafood products, especially as an ingredient for instant noodles that will have good rehydration properties closer to freeze-dried products. The VFBTPW dried product had higher fat content which resulted in higher product yield compared with freeze-dried product. High fat content dried beef product in instant noodles is acceptable because some manufacturers add an oil sachet to enhance the flavour. In addition, the dried product from VFBTPW can be produced in a much shorter time (about 15 minutes) compared to freeze-dried products (about 30 hours). Hence, the VFBTPW dried products will be much cheaper compared with the freeze dried product, especially when used in instant noodles.

Conclusion

Using 0.5 kg frozen unmarinated beef slices in vacuum frying below the triple point of water (VFBTPW) at 79°C resulted to a product with low moisture content, high fat content, higher product yield and high rehydration rate and rehydration ratio even with a shorter frying time compared to a 2.0 kg frozen sample. The frying times of 5 to 10 minutes resulted to higher VFBTPW product moisture content especially with the shortest frying time. The fat contents of the VFBTPW products were not significantly different with each other at all frying times. The frying time of 5 minutes gave the highest product yield due its high moisture content. The rehydration rate and rehydration ratio of the VFBTPW products were not affected by frying time despite a decreasing chamber pressure with increasing frying time. The degree of lightness (L* colour value) and degree of yellowness (b* colour value) of the VFBTPW products decreased with frying time above 7.5 minutes. The degree of lightness (L* colour value) and degree of yellowness (b* colour value) of the products were similar for frying times of 10 to 45 minutes. The chroma value of the products were not significantly different from each other.

The VFBTPW product had lower moisture content but had higher fat content and product yield compared with the freeze-dried product. The rehydration rate and rehydration ratio of the VFBTPW product were lower than the freeze-dried product.

The beef muscle fibres of the low moisture VFBTPW product were looser and more porous compared with the high moisture product which were more compact.

Prženje smrznutih nemariniranih komada govedine u vakuumu ispod trostruke tačke vode (VFBTPV)

Lemuel M. Diamante

A p s t r a k t: Istraživanje je sprovedeno: a) kako bi se smrznuti nemarinirani tanki komadi goveđeg mesa pržili u vakuumu ispod trostruke tačke vode (VFBTPV — Vacuum Frying Below the Triple Point of Water) koristeći konstantnu količinu korišćenog uzorka i temperaturu prženja sa različitim vremenima prženja, odredio sadržaj vlage i masti , kao i prinos proizvoda i rehidratacija, svojstva boje i teksture dobijenih proizvoda prženih u vakuumu; b) kako bi se uporedile fizičko-hemijske osobine VFBTPV i proizvoda osušenih zamrzavanjem; i c) kako bi se procenila struktura vakuumski prženih komada govedine pomoću skenirajućeg elektronskog mikroskopa. Prženjem u vakuumu zamrznutih nemariniranih komada goveđeg mesa na 79±1°C, zaključeno je da što je vreme prženja kraće, to je veći sadržaj vlage u vakum prženom proizvodu. Sadržaj masti u proizvodima nije se značajno međusobno razlikovao. Vreme prženja od 5 minuta dalo je najveći prinos proizvoda zbog visokog sadržaja vlage. Vreme prženja nije uticalo na stopu rehidratacije i odnos rehidratacije proizvoda, uprkos smanjenju pritiska u komori sa povećanjem vremena prženja. Vrednosti za boju proizvoda nisu se razlikovale međusobno. Integrisana sila proizvoda smanjila se sa vremenom prženja iznad 7,5 minuta. Proizvod pržen u vakuumu imao je niži sadržaj vlage, ali je imao veći sadržaj masti i prinos proizvoda u poređenju sa liofilizovanim/suvo zamrznutim proizvodom. Brzina/stopa rehidratacije i odnos rehidratacije proizvoda prženog u vakuumu bili su niži nego kod liofilizovanog/suvo zamrznutog proizvoda. Mišićna vlakna goveđeg mesa kod proizvoda sa malom vlagom bila su labavija i poroznija u poređenju sa proizvodom sa visokom vlagom koj je bio kompaktniji. Liofilizovani /suvo zamrznuti proizvod bio je porozniji od nemarinirane govedine pržene u vakuumu sa niskom vlagom na osnovu poprečnog reza, ali obrnuto je uočeno kada se radi o uzdužnom rezu.

Ključne reči: *prženje u vakuumu, komadi goveđeg mesa, fizičko-hemijska, rehidrataciona svojstva.*

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Goat meat consumption patterns and preferences in three provinces of Kabylia region in Algeria compared to other meat species: Results of an online survey

Melisa Lamri[1], Djamel Djenane[1], Mohammed Gagaoua[2]*

A b s t r a c t: This study aimed to investigate, using an online survey, the patterns/frequency of meat consumption, and preferences from several meat types in Kabylia region in Algeria and within three provinces (Tizi-Ouzou, Bejaia, and Bouira). Thus, we specifically examined in this work the consumption of goat meat compared to lamb, beef, horse, camel, and chicken. The attempt is to understand the underlying factors of consumer perception and purchasing behaviour/decisions of goat meat through an exploratory survey on a homogenous gender consumer's population. The survey conducted on 665 respondents revealed that 95.6% of them are consumers of meat and meat products (n = 636) versus 4.4% (n = 29) that never consumed meat. The majority of the respondents never consumed both camel (54.3%, n = 339) and horse meats (42.5%, n = 270). Of those consuming camel meat, only 14 of them eat it always (1.6%), and the others sometimes (35%) or rarely (9.1%). Chicken is the only meat eaten by a significant number of the respondents (n = 534), and 84.0% of them consume it always, followed by beef (56.6%) and lamb (21.2%). Chicken was also found to be the most liked meat compared to other sources, while horse and camel meats were the less appreciated. Goat meat seemed to be intermediate compared to the other species, where it is never consumed by 27.7% of the respondents, and it is mainly consumed sometimes (44.8%, n = 285) or rarely (20%, n = 127) and, on average, appreciated. This study is the first to highlight in the Kabylia region the trend of meat consumption from several species, revealing that the significantly consumed meat is from chicken, followed by beef and lamb. Goat meat is weakly consumed, while camel and horse are never or rarely. Encouraging the consumption of goat meat as an alternative and valuable source of animal proteins can be seen as a sustainable approach.

Keywords: *meat consumption, Algeria, survey, consumer preferences, livestock; online questionnaire.*

Introduction

Meat is considered the main food source of protein and nutrients such as vitamins and minerals, making it an integral part of the human diet (*Multari et al.* 2015; *Ahmad et al*. 2018). On another hand, the consumers' preoccupations with purchasing meat products are multiple, which are mainly related to safety, nutrition, and health (*Bernués et al*. 2003; *Gagaoua & Picard* 2020; *Kantono et al*. 2021; *Gagaoua et al*. 2022). The remarkable worldwide population growth in the past few years led to a significant increase in meat consumption in numerous countries, which also involved a rise in global meat demand and consumption from other species including goat (*Kadim & Sahi* 2018; *Mazhangara et al.* 2019). In fact, goat farming plays an integral part in red meat production and is a tool of importance for rural and national economic development (*Webb & Casey,* 2010; *Chetroiu et al.* 2013; *Pophiwa et al.* 2020). The hardiness of the goat also offers an alternative to red meat that favours the development of food systems adapted to climate change.

Goat meat is consumed in many countries, especially in developing ones, particularly in North Africa and Middle East countries, in Southeast Asia, where it takes an important place, as well as in the Caribbean and other tropical countries (*Rodrigues & Teixeira*, 2010). Goat meat is not only known for being an excellent high-quality protein source but also for its essential nutritional characteristics compared to other red meats such as beef and lamb (*Lee et al*. 2008). Goat meat has been established as lean meat with relatively low-fat content, cholesterol intake, and saturated fatty acids (*Liu et al.* 2013). These nutritional aspects qualify goat meat as a healthy product, especially with the healthy food

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trend, where consumers are becoming more curious and concerned about the nutritional attributes of their food including meat sources (*Resurreccion* 2004; *Mazhangara et al.* 2019). Moreover, goat meat which is leaner compared to other red meats, has favourable sensory and visual appeal (*Webb et al*. 2005). Youth seemed also to be very aware of the different product values that goat meat provides, for instance among South African consumers (*Ngomane et al*. 2022). However, there is a perception among a certain number of consumers that goat meat is tough and too strongly flavoured *(Webb et al. 2005; Webb & Casey*, 2010; *Jacques & Norwood* 2017).

In Algeria, goat breeding is practiced in many areas of the country due to the adaptation capacity to harsh environments and climate changes. Goat meat provides for the local populations and consumers important and stable sources of proteins (essential amino acids) and essential nutrients. The number of estimated goats in Algeria is about 4.9 million in 2018 corresponding to 14% of the world ruminant livestock (*FAOSTAT,* 2018; *Ouchene-Khelifi et al*. 2015). With this very large number, goats occupy then a special place and a significant source of income for about 800,000 small farmers (*Dekhili et al*. 2013). Overall, goat meat is consumed in Algeria as fresh or as traditional meat products (*Gagaoua & Boudechicha*, 2018). Both are considered nutrient-rich products that ensure health and wellness (*McAfee et al.* 2010). Unlike the northern Mediterranean country, which has a more meat-rich diet, the consumption of red meat in Algeria is occasional and generally linked to celebrating traditional or religious events (*Chikhi & Bencharif*, 2016; *Gagaoua & Boudechicha*, 2018). However, to the best of our knowledge, there is a scarcity of studies focusing on the consumption pattern and perceptions of different meat sources (including goat) in Algeria and in the Kabylia region. In this context, we aimed by this first study to investigate the consumption trend of different meat sources in Kabylia within three central provinces: Tizi-Ouzou, Bejaia, and Bouira with a focus on goat meat consumption, compared to lamb, beef, horse, camel, and chicken meat types. Therefore, an online survey was conducted to achieve this lofty goal. We further examine in this paper the consumers' preferences towards the six different meat types as well as an evaluation of the perceptions and willingness to consume and buy goat meat. The ultimate objective of this work is to obtain the first overview of meat consumption patterns, consumers' purchase behaviour and preferences towards the targeted meat types in the Kabylia region.

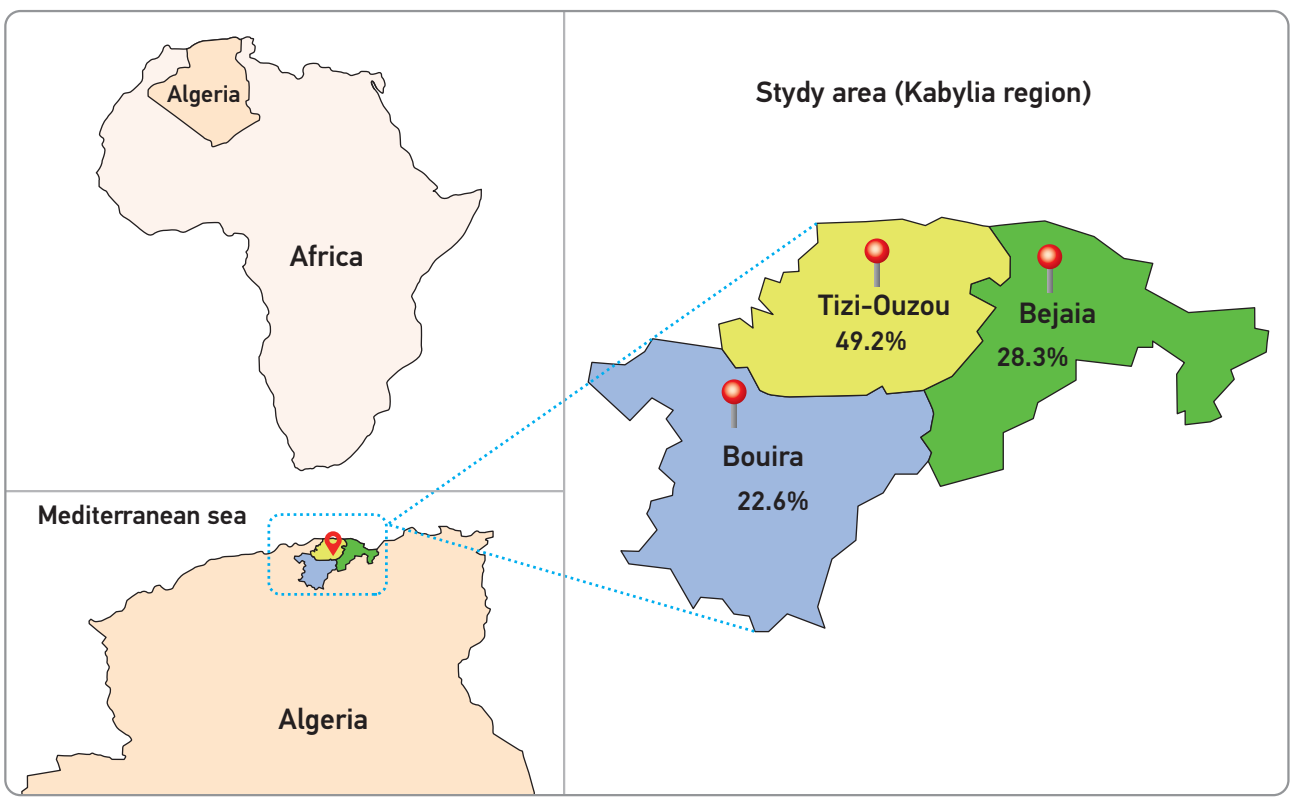

Figure 1. Study area and distribution of the 665 respondents who participated in the online survey from three provinces of the Kabylia region (north of Algeria).

Materials and Methods

Data collection using an online survey

The data of this study were based on a structured online survey at the consumer level, in Kabylia region, related to the consumption of goat meat compared to different other animal meat sources such as lamb, beef, horse, camel, and chicken. The study was conducted online from 31 March – 30 September 2020 using a questionnaire built through the Google forms database that was then shared using online platforms. The survey instruments were adapted from established scales to fit the context of this research that aims a better characterization of overall meat consumption, preferences, and frequencies with a focus on goat meat in Kabylia region, Algeria (Figure 1.). The questionnaire was developed and used in French language.

The data of this online survey were collected by convenience sampling on respondents from Kabylia region in Algeria, grouping three large provinces (Tizi-Ouzou, Bejaia, and Bouira) as illustrated in Figure 1. The survey questionnaire consists of two major sections including consumer experience and meat eating habits. The first section focused on all meat consumers and the second one on goat meat consumers. Among its different items, the first ones enquired the profiles of the respondents and their frequency and preferences of consumption of the six meat sources. We then asked for the i) gender of the respondents, ii) their province, iii) age, iv) employment/occupation, then their v) meat consumption, followed by the vi) frequency (pattern) of meat consumption and vii) preferences among six meat types. Only the participants eating goat meat were allowed to proceed further with the survey questionnaire. Thus, the rest of the questionnaire items were specific to goat consumers; including the i) reasons and frequency of goat meat consumption, ii) how they compare goat meat sensory attributes to other meat sources, iii) consumer experience and eating habits as well as consumer perception and purchasing toward goat meat in comparison to other meat sources. A progress bar was automatically added to stimulate respondents to finish the online survey.

Sample profile and data analyses

From the collected responses, 665 respondents were considered valid and useable. Data quality checks evaluated any outliers from the respondents' response time, thanks to clustering analyses, the respondents who answered to our questionnaire in a static manner were identified and eliminated. The names and emails of the respondents were further scrutinized in each response to ensure that the same individuals were unable to take the survey more than one time. The data analyses were then all conducted in Microsoft Excel 2016 statistical software (Microsoft Corporation, Microsoft Office Excel 2016, USA). For research item questions, we reported the share of consumers in each item as appropriate using percentages. The graphs were elaborated with Microsoft Excel statistical software.

Results and discussion

The evaluation of consumer perception of goat meat has been the subject of numerous studies around the world, but few studies were conducted in Algeria. The main objective of this study was therefore to investigate for the first time the preferences and attitudes of consumers towards goat meat among other meat species in the Kabylia region of Algeria. Thus, this study aimed to identify the relevant consumer motivations towards goat meat, as well as the barriers to its consumption.

Socio-demographics of the meat consumers who participated in this study

Table 1. summarizes the demographic profile of the 665 respondents by describing their gender, distribution in the three provinces, selected age, occupations, and rather eating meat or not. From the total of respondents, 53.8% (n = 358) of them were male whereas 46.2% (n = 307) were female. The majority of the respondents were from Tizi-Ouzou province (n = 327, 49.2%), followed by 188 (28.3%) from Bejaia and 150 (22.6%) from Bouira (Figure 1.). The socio-demographic characteristics of consumers differed in terms of education and age (Table 1.). In terms of age distribution, the majority of the respondents were young, aged between 20– 30 years (63.5%), from which 24.7% were below 30 years. Around 12% were higher than 40 years. A large proportion of the respondents stated their occupations as employee (43.6%) working in different sectors such as teaching, doctors …etc. Within this category a significant part was full-time student (40.0%) followed by professional freelance (9.8%). Finally, a minority of the respondents were unemployed (4.7%) or retired (2.0%)**.** Consumption decisions are heavily influenced by one's degree of education and disposable income (*Khara et al.* 2021) as meat is an expensive commodity in Algeria. The education level of respondents varied from primary school to post-graduate level and majority of them having a minimum undergraduate degree.

Table 1. Description of the socio-demographics of the respondents who participated in the online survey (n = 665) from the Kabylia region.

Variable	Categories	Frequencies	Percentages (%)
Gender	Female	307	46.2
	Male	358	53.8
Province	Bejaia	188	28.3
	Bouira	150	22.6
	Tizi Ouzou	327	49.2
Age	<20	16	2.4
	20-30	406	61.1
	30-40	164	24.7
	40-50	47	7.1
	50-60	22	3.3
	>60	10	1.5
Occupation	Employee	290	43.6
	Full time student	266	40.0
	Freelance (Professional)	65	9.8
	Unemployed	31	4.7
	Retired	13	2.0
Meat consumption	Yes	636	95.6
	No	29	4.4

Participant preferences, attitudes and beliefs towards meat consumption of different species

Meat consumption plays a major role in consumers' daily food intake. Our survey revealed that 4.4% of the respondents (n = 29) never consumed or are not consuming meat and a significant majority of 95.6% (636 responded) are meat eaters (Table 1.), but with divergent frequencies and preferences for the six meat types as discussed below. The trend towards the consumption of meat analogues and substitutes rather than animal proteins in Algeria is not known and cannot yet be considered, or it can be speculated as new. This might reflect the satisfaction of the consumers in eating their traditional meat-based dishes for which preferences are very high (*Gagaoua & Boudechicha,* 2018). The low number (4.4%) of non-meat eaters observed in this study seems to be in agreement with the current worldwide trends/shifts towards new meat alternatives (*Boukid & Gagaoua*, 2022), that are mainly from plant-based food products (*Onwezen et al.* 2021; *Anusha Siddiqui et al.* 2022). A shift/transition to consider meat alternatives in the diet of consumers offers new interest on vegetables/grains and numerous surveys reported meat reducers and meat avoiders (*Holm & Møhl*, 2000; *Possidónio et al.* 2021). The percentage we identified in this survey is comparable to a recent Canadian survey where approximately 5.1% Canadians identified as vegans (*Popoola et al.* 2021). Different attributes and drivers can be involved in such decision-making or the shift to other protein sources. Meanwhile, it is worthy to note that fish and rabbit (and other animal protein sources such as eggs) were not considered in our survey to take any conclusion. Thus, further targeted studies in Algeria including in the Kabylia region are needed to better understand on one hand the origin of animal-proteins sources of the consumers and on the other hand, the main reasons and motivations of non-consumption of meat and meat products.

Based on the above results, the following focuses on the consumption pattern (frequencies) and preferences of the six different types of meat using the data collected from the 636 respondents eating at least one of the six meat types (Figure 2.). This question is important to better analyse the consumer profile of each type of meat to adapt the marketing mix to each

one and identify the motivations and beliefs of meat consumers. The results revealed that the respondents have divergent patterns in meat consumption and preferences towards goat, beef, lamb, chicken, horse and camel meats (Figure 2a.). It is known that patterns in meat consumption are unpredictable and changes were described to occur in the way consumers behave towards food (*Grunert,* 2006). For example, earlier studies reported that the consumption of goat among other meat types is variable and in certain cases households preferred to consume small ruminants' (goat and lamb) meat over beef (*Juma et al.* 2010).

In this study, chicken was found as the main meat eaten by all respondents, mostly always and highly appreciated (Figure 2b.), followed by beef and lamb meats (Figure 2a,b.). The preference towards chicken meat might be due to several factors likely its superior taste, affordability, health attributes, nutritional quality, and convenience of processing. These findings align with the political guidelines in Algeria as, since the beginning of the 1980s, the Algerian Ministry of Agriculture oriented meat consumption to white meat as an alternative to beef and lamb for numerous economic and health reasons. Also, chicken contains low cholesterol and fat with very high omega-3 fatty acids (*Fletcher*, 2002). Furthermore, the high chicken consumption compared to other meat types could be ascribed to the relatively low price (most affordable type of meat available in the market) with typically convenient portions, hence making chicken as the most economical meat if the number of dishes cooked with meat is usually high. In agreement to our findings, *Tomasevic et al.* (2021) reported for Eastern European consumers that only 2.6 % avoid consumption of chicken meat, while the majority (51.7%) and more than half of them eat it on a fortnightly basis. Similarly, in India the contribution of meat from poultry was found very high (50%)

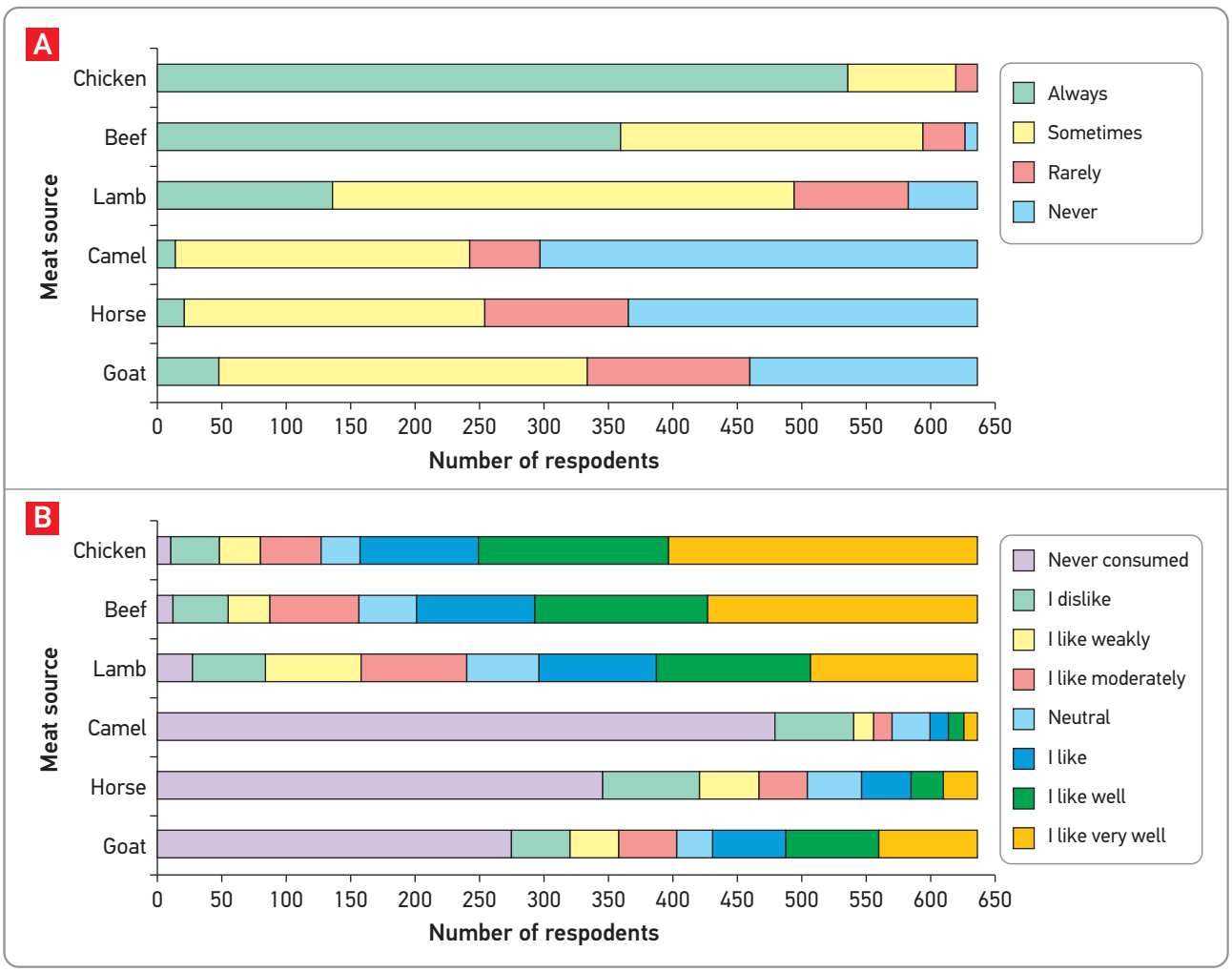

Figure 2. Frequency of consumption (**A**) and preferences (**B**) of goat meat compared to the meat sources listed in the online survey likely camel, lamb, beef, horse and chicken from the three provinces (Tizi-Ouzou, Béjaia and Bouira) in Kabylia region.

followed by buffalo (19%), goat (14%), sheep (8%), pig (5%) and cattle (4%) (*Mohan et al.* 2022). Among Canadian consumers, the study by *Popoola et al.* (2021) reported that the most frequently consumed meat was poultry, followed by beef and pork, while only a small proportion of participants consumed lamb frequently. Inversely to these studies including our survey, Australian consumers were described to allocate 44% of the meat expenditure on beef, 24% on pork, 20% on chicken, 12% on lamb, and very little on mutton (*Wong et al*. 2015). A Spanish consumers study reported that beef and turkey meats were associated to the consumers' food-related lifestyle (*Escriba-Perez et al*. 2017).

Horse and camel meats were found as being not well appreciated or eaten by the consumers from Kabylia region (Figure 2b.), hence representing the lowest proportions (Figure 2a). This result may be explained by the meat-eating habits of the consumers of this region towards those meats that are not produced locally or because they are not dominating the main dishes of this region. The limited availability of horse and camel meats may have contributed to lower familiarity scores as the per capita consumption of other meats in Algeria and the disparity that might exist for camel meat availability and consumption between the North and South of country (camel is more dominant in the South) with different tradition, cultures, lifestyles and habits. In fact, culture, traditions, and taboos all play an important role in determining how much or which type of meat can be eaten in a society (*Bernués et al.* 2012; *della Malva et al.* 2022), especially in rural areas such as Kabylia. Food neophobia (reluctance to try or avoidance of new food) and food variety seeking (tendency to seek variety in food choice) (*Pliner & Hobden*, 1992) impact behaviour towards unfamiliar meat products that can be the case of horse and camel meats. However, it is important to mention that research on Algerian consumers' perception of horse and camel meat is limited and, to the best of our knowledge, none of the few available studies has focused on understanding consumers' perception of these meats. On another hand, consumers have perceptions about a food, which influence their decision to accept or reject it. Consumers' tendency to avoid unfamiliar meat products can be attributed to a distaste for their sensory attributes, fear of the negative consequences of their consumption, a sense of repulsion for the source of the food, and the mental classification of the food as inappropriate *(Derinalp Çanakçı & Birdir*, 2020). This was recently described in a survey among Canadian consumers for which horse meat was unfamiliar to 80% of the participants (*Popoola et al.* 2021). In fact, the horse was perceived as a companion animal and the dominant perception of its meat was then judged unacceptable for eating. According to *Belaunzaran et al.* (2015), the consumption of horse meat has been mainly interrupted throughout history due to three major reasons related to religion, social and/or culture.

Finally, goat meat seemed to be intermediate compared to the other meat types (species), where it is never consumed by 27.7% of the respondents, and it is mostly consumed sometimes (44.8%, n = 285) or rarely (20%, n = 127) and on average, it is well appreciated. These data allow an initial concept of the behaviour of consumers concerning goat meat consumption. Compared to the other species namely chicken, beef and lamb, less scientific investment has been made towards improving the productivity of goats (*Dhanda et al.* 2003). This maybe one major reason that relegated goats to low economic value, hence driving the preference of consumers for other meat types. Compared to other studies, our findings are in line to European consumers of goat meat consumptions that were significantly lower than for other types of meat likely chicken and beef (*Mandolesi et al.* 2020). On another hand, it is worthy to mention that in Africa including in Algeria, the demand for goat meat consumption is very much linked to household income and the market price of this meat (*Dubeuf et al.* 2004; *Juma et al.* 2010; *Teixeira et al.* 2020).

Goat meat consumption and consumer purchase behaviour

Based on the 636 meat consumers, only 362 respondents (56.9%) declared consuming goat meat (Table 2.). Thus, the rest of our survey focused on goat meat consumers only. Surprisingly, goat meat consumption was found to be very low in Kabylia region with about 45% of respondents consuming it only once a year and 44.2% consuming it monthly or seasonally (combined), and only less than 10% declared consuming it once every two weeks or weekly (Table 2.). Our results are globally in line with the goat meat consumption rate of Turkish households based on several surveys (*Kosum et al.* 2019). Available research suggests also that the demand for goat meat is influenced by consumers' age, gender, household sized, and marital status (*Nelson et al*. 1999; *McLean-Meyinsse*, 2003). The familiarity to goat products would be another important reason of low goat meat consumptions. Accordingly, the perception of goat meat quality amongst American consumers was found to differ

Table 2. Characteristics, perception and behaviour of goat meat consumption by the respondents who eat meat (n = 636) from the Kabylia region.

Variable	Categories	Frequencies	Percentages (%)
Goat meat consumers	Yes	362	56.9
	No	274	43.1
Frequency of goat meat consumption	Once per week	21	5.8
	Once per 2 weeks	18	5.0
	Once per month	60	16.6
	Once per season	100	27.6
	Once a year	163	45.0
Raisons of goat meat consumption	No specific raison	274	43.1
	Price	47	13.0
	Taste	188	51.9
	Nutritional values	230	63.5
	Safety	114	31.5
	Others[1]	34	9.4
Which of these sensory attributes do you judge different in cooked goat meat comparable to other species?	Colour	64	17.7
	Taste	294	81.2
	Texture (tenderness)	207	57.2
	Flavour	112	30.9
Reasons of goat meat consumption	Traditional and religious events	180	49.7
	Restaurant	111	30.7
	Cooking at home	7	1.9
	No specific raison	189	52.2
How do you judge the frequency of goat meat consumption?	Low	143	39.5
	Medium	169	46.7
	High	45	12.4
	Very high	5	1.4
Reasons for the weak goat meat consumption	Strong taste	89	24.6
	High price	98	27.1
	Availability	183	50.6
	Culinary habits	186	51.4
	Ignorance of its nutritional values	198	54.7
How do you judge the price of goat meat?	Low	19	5.2
	Acceptable	180	49.7
	High	163	45

Legend: [1] The main other reasons were for curiosity, the only meat available, familial traditions.

based on product familiarity, with consumers that grew up eating goat meat holding positive perceptions and neophobia being experienced by those that were unfamiliar (*Ekanem et al.* 2013). These percentages further highlight that goat meat is underutilised, which can be the consequence of the low societal awareness on the beneficial nutritional value of this meat as previously evidenced (*Marandure et al.* 2020). In support of this, *Melody and Amit Kumar* (2021) confirmed that the nutrient content of goat meat is undervalued by many consumers and suggested that educating consumers about this added value should be emphasized in marketing communication to encourage them to increase their frequency of consumption. In agreement to this and from the respondents consuming goat meat, our survey reported that the main reasons of purchase/consumption are for its nutritional values (63.5%), followed by taste (51.9%) and other reasons (43.1%): such as the curiosity, the only meat available and for familial traditions. The study carried out by *Ekanem et al.* (2013), reported a percentage of 56% of the respondents considered the nutritional value of goat meat when buying it. Moreover, the study reported that 60% of the participants are willing to buy more goat meat if additional information on its nutritional value was made available. Another study confirmed the motivation of consumers to pay a premium for goat meat for which they had a guarantee of its nutritional and food safety (*Ibrahim et al.* 2018). Based on these aspects, we can suppose that the major reasons for poor goat meat familiarity and consumption are related to marketing, lack of organized production, and consumption pattern. Thus, raising awareness of the constructive and beneficial effects of goat meat through direct or indirect means can be considered the first step toward improving the supply of such a valuable animal protein source.

In agreement to earlier studies (*Webb et al.* 2005), respondents declared that the most significant differences of goat meat compared from other types of cooked meat were related to the sensory attributes: taste (81.2%), tenderness (57.2%), flavour (30.9%) and weakly in terms of colour (17.7%). In comparison to lamb meat, an earlier study reported that goat meat was tougher with high connective tissue amounts (*Schönfeldt et al.* 1993). However, it is important to note that such differences are depending on the animal type, breed, age at slaughter and production system *(Gagaoua et al.,* 2016*; Pophiwa et al.* 2020*; Teixeira et al.* 2020*; Gagaoua et al.,* 2022). A total of 49.7% of the respondents declared that they mostly consume goat meat during religious and socio-cultural events (Table 2.) such as family celebrations, or religious feasts of the sacrifice "*Aid Al Adha*", birth of a child, circumcisions and for welcoming visitors. This is in agreement to the habits and practices related to the consumption of meat and traditional meat products in several African countries including Algeria (*Gagaoua & Boudechicha* 2018; *Marius et al.*

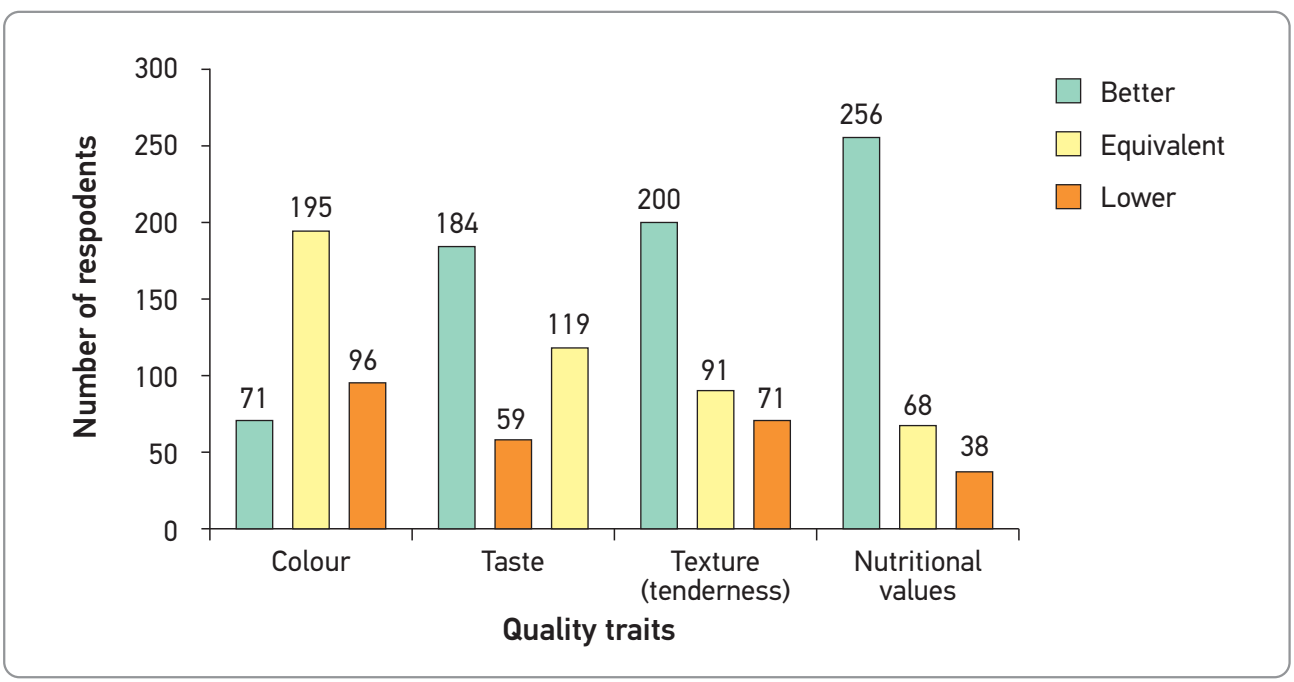

Figure 3. Comparison of the evaluation and appreciation of goat meat sensory and nutritional attributes from the surveyed respondents eating goat meat (n = 362) to beef meat.

2020). Further, this is maybe because Algerian people like to eat and share food with family and eating goat meat at this event could enhance the relationships and enjoy better the celebrations. Overall, the respondents judged low to medium the consumption of goat meat, explaining this trend by several reasons, likely culinary habits (51.4%), its non-availability (50.6%), high price and the fact that most consumers are not aware of its nutritional value importance.

Evaluation of goat meat quality by the respondents and consumers purchase behaviour

The determinants of goat meat purchase, consumption, and meat quality attributes evaluation are multiple and the analysis of the consumer perceptions is critical for understanding and forecasting consumer behaviour (*Grunert et al.* 2004). Therefore, for a better understanding on how respondents evaluate goat meat in relation to certain intrinsic qualities of meat (nutritional and sensory attributes) compared to other types of meat, we focused on beef as an example (Figure 3.). It appears that the majority of the respondents rate the colour of goat meat as equivalent to beef, but better in terms of tenderness and taste, and as expected significantly better in terms of nutritional attributes related to goat (*Resurreccion,* 2004; *Liu et al.* 2013; *Mazhangara et al.* 2019). Nevertheless, a number of consumers consider goat meat to being inferior in colour, texture and taste compared to beef (Figure 3.). A general belief that goat meat is inferior to beef sensory qualities was reported in earlier studies (*Babiker et al.* 1990). In another study, goat meat was reported to be equivalent in flavour but less tender and overall less palatable than beef when samples of comparable maturity and fatness were compared (*Smith et al.* 1974). Consumers judge that a better satisfaction of their needs by adding goat meat to their diets for its nutritional value and the lowest fat content, hence making it a healthy choice compared to other meat sources (*Mandolesi et al.* 2020). The health aspect is a common reason for changing consumption habits and seemed in this study of significant role to consumers from Kabylia region. Overall, it is known that consumers tend to view meat as a healthy and important part of the diet to provide them with needed nutrients such as proteins and vitamins (*Verbeke et al.* 2010).

The decisions to purchase meat by consumers are influenced by meat consumption properties and quality attributes (*Font-i-Furnols & Guerrero*, 2014). The purchase criteria described in this survey by the respondents for goat meat were in the following order: freshness and tenderness in the first place, followed

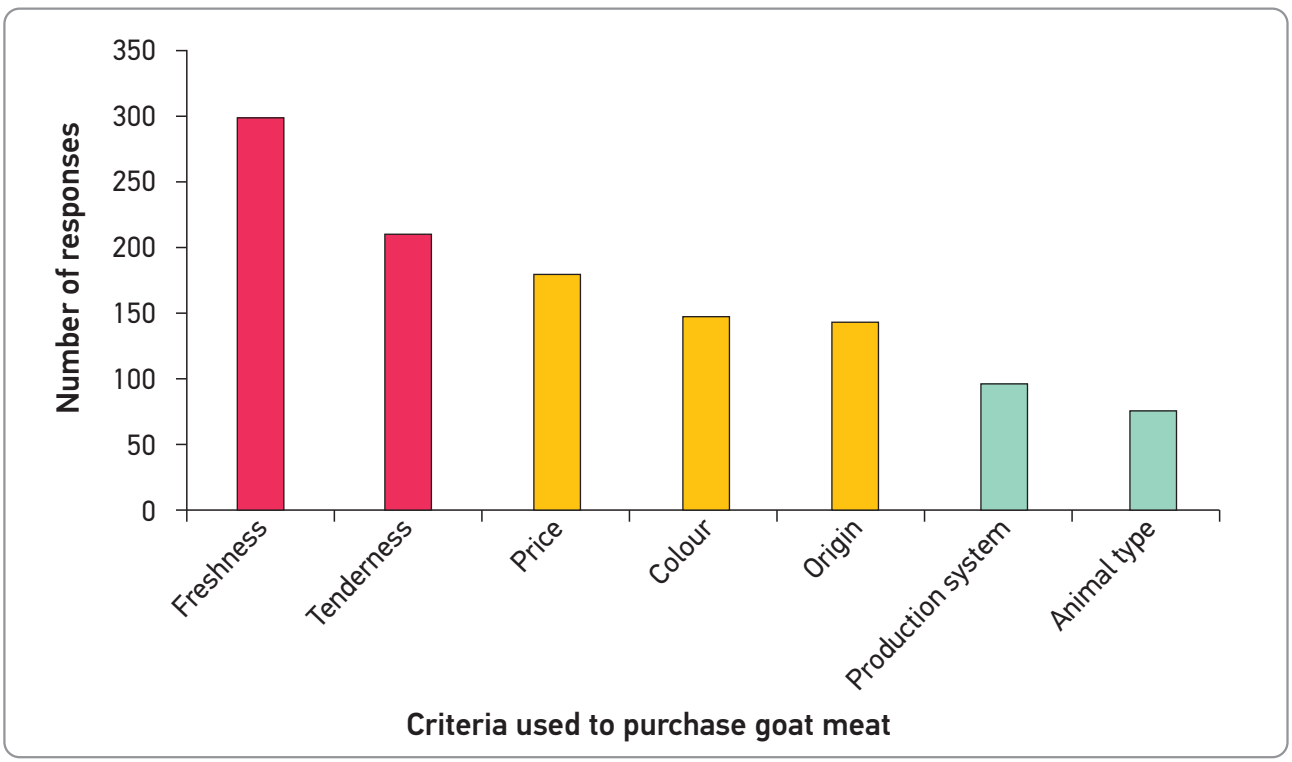

Figure 4. The main criteria used by the surveyed respondents to purchase goat meat. The criteria were ranked based on the number of responses, knowing that the respondents were given the liberty to score more than one parameter.

by price, colour and origin, and finally the production system and information on the animal type (Figure 4.). According to a recent study, Chinese consumers consider freshness not only as one of the most crucial factors in buying red meat, but also as a primary safety criterion, hence allowing to evaluate its quality and safety *(Kantono et al.* 2021). Consumers also relate freshness (product credibility or 'credence') to colour, which indicates deterioration and freshness loss, hence ranking colour as an essential driver of meat purchases (*Mancini & Hunt* 2005; *Gracia & de-Magistris*, 2013). Among Indian consumers, freshness of meat would be decided mainly by tenderness and colour (*Mohan et al.* 2022). Respondents also revealed in our survey that tenderness is another major cue influencing their purchase decision of goat meat. In fact, tenderness is the leading indicator of meat quality and the main factor worldwide described to influence meat product processing and consumer acceptance (*Gagaoua et al.* 2019; *Gagaoua et al.* 2021). Regardless of all sensory and nutritional attributes, price remains a critical parameter and was ranked by respondents in third place with a significant number (45%) rating prices as very high and not affordable and very few as low (Table 2.). Indeed, price is known as a key factor to consumers for purchasing meat including that from small ruminants (*Ward et al.* 1995; *Hoffman et al.* 2005). Finally, the comparison of the major intrinsic sensory quality traits (colour, tenderness, taste and flavour) of goat meat to other meat types in terms of their importance is given in Figure 5. The respondents seemed to compare similar/equivalent the quality attributes of goat meat to those of lamb. However, colour was the only trait identified by the consumers to be similar to that of beef. This can be related to the type of muscle, mostly characterized as red.

Conclusions

This study is the first to highlight in Kabylia region and within its three provinces (Tizi-Ouzou, Bejaia, and Bouira) the trend of meat consumption from several species, revealing that the main consumed meat is chicken followed by beef and lamb. Goat meat, which is the focus of our study, is consumed to a small extent, while horse and camel meats are never or rarely consumed. Overall, it was found that the purchase and/or consumption of meat is done where it is produced, which is the case in our study area. Consumers' perception and purchase behaviour of goat meat in Kabylia region was then investigated in a sub-population of the survey. Further studies are needed to confirm our findings and to explore the antecedents of these attitudes in larger samples and on special populations looking for special attributes. Encouraging the consumption of goat meat as an alternative and valuable source of animal proteins can be seen as a sustainable approach. In fact, goats can contribute to sustainable and productive use of water resources if their efficiency is

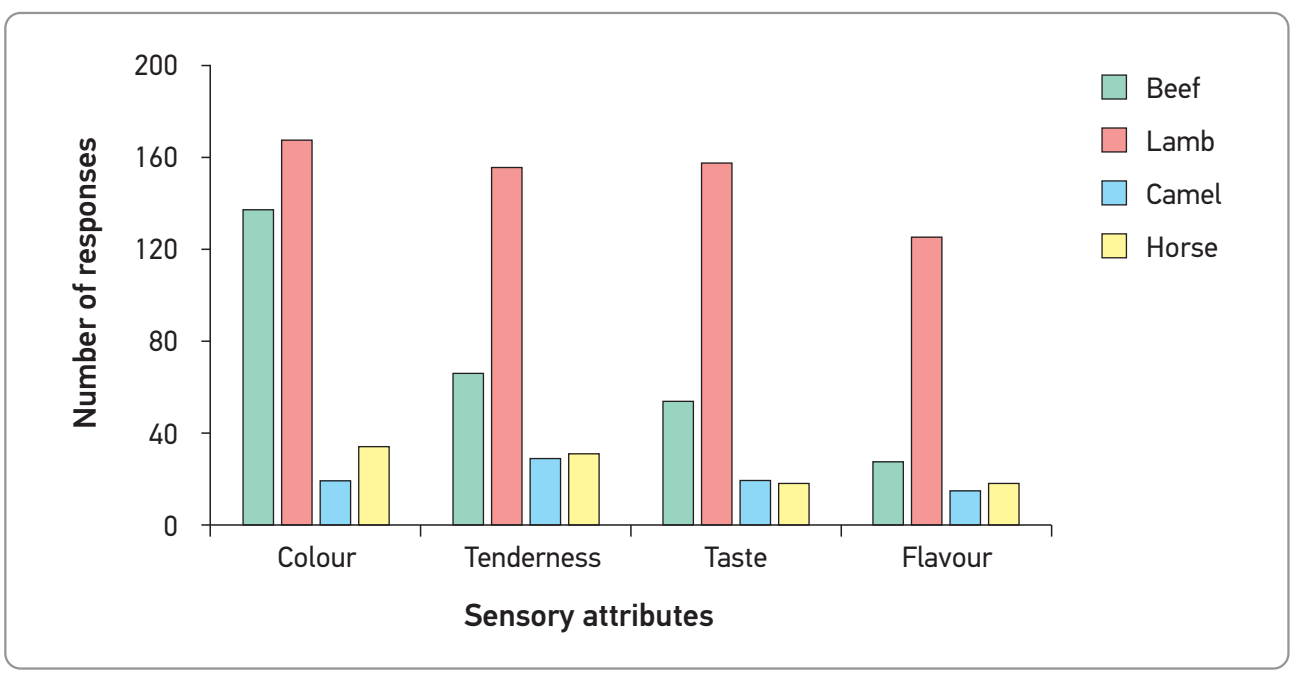

Figure 5. Comparison of the major intrinsic sensory quality traits of goat meat to red meat species in terms of their importance.

improved by better adapted research and more efficient extension service. Therefore, the Algerian goat industry has great potential to grow in the market. Additionally, goat production entails lower methane emissions compared to other domestic ruminants, therefore this could contribute to the mitigation of climate change in red meat production. However, few strategies are needed to increase the consumption of goat meat. For example, a better communication on the benefits related to the healthiness of goat meat and the provision of more detailed information on its characteristics would be very helpful.

Obrasci potrošnje kozjeg mesa i preference u tri provincije regiona Kabilija u Alžiru, u poređenju sa drugim vrstama mesa: rezultati onlajn ankete

Melisa Lamri, Djamel Djenane, Mohammed Gagaoua

A p s t r a k t: Ova studija je imala za cilj da, koristeći onlajn anketu, istraži obrasce/učestalost konzumacije mesa i preference nekoliko vrsta mesa u regionu Kabilija u Alžiru, i unutar tri provincije (Tizi-Ouzou, Bejaia i Bouira). U ovom radu je posebno ispitana potrošnja kozjeg mesa u odnosu na jagnjeće, govođe, konjsko meso, kao i kamilje meso i piletinu. Korišćenjem istraživačke ankete na homogenoj populaciji potrošača po polu, pokušali smo da objasnimo/razumemo osnovne faktore percepcije potrošača i kupovnog ponašanja/odluka pri kupovini kozjeg mesa. Istraživanje sprovedeno na 665 ispitanika pokazalo je da su 95,6% ispitanika potrošači mesa i mesnih prerađevina (n = 636), a da 4,4% (n = 29) nikada nisu konzumirali meso. Većina ispitanika nikada nije konzumirala meso kamile (54,3%, n = 339), kao ni konjsko meso (42,5%, n = 270). Od onih koji konzumiraju kamilje meso, samo 14 ga stalno konzumira (1,6%), a ostali ponekad (35%) ili retko (9,1%). Piletina je jedino meso koje jede značajan broj ispitanika (n = 534), od kojih 84,0% ga stalno konzumira, zatim govođe (56,6%) i jagnjeće (21,2%). Piletina je takođe bila najomiljenije meso u poređenju sa drugim vrstama, dok su konjsko i kamilje meso manje cenjeno. Kozje meso je bilo srednje, u odnosu na ostale vrste, 27,7% ispitanika ga nikada ne konzumira, i uglavnom se konzumira ponekad (44,8%, n = 285) ili retko (20%, n = 127) i, prosečno je cenjeno. Ova studija je prva koja je u regionu Kabilija istakla trend potrošnje mesa nekoliko vrsta, otkrivajući da se značajno konzumira piletina, a zatim govođe i jagnjeće meso. Kozje meso se slabo konzumira, a kamilje i konjsko meso, nikad ili retko. Podsticanje konzumiranja kozjeg mesa kao alternativnog i vrednog izvora životinjskih proteina može se posmatrati kao održiv pristup.

Ključne reči: *potrošnja mesa, Alžir, anketa, preference potrošača, stoka, online upitnik.*

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Review paper

A review of hyperspectral imaging in the quality evaluation of meat, fish, poultry and their products

Charan Adithya S.[1*]

A b s t r a c t: Meat and meat products are rich sources of nutrition in the daily diet. Quality and safety assessments of foods, including meats, are essential due to their perishability and vulnerability. The need to analyse food products in real time has stimulated the invention of non-destructive measuring systems. Hyperspectral imaging (HSI) combined with various statistical analysis methods such as multiple linear regression (MLR), least squares-support vector machine (LS-SVM), or partial least squares regression (PLSR), was created as a rapid, non-destructive, non-intrusive and chemical-free process to determine important quality aspects and chemo metrics of foods. The HSI system is used to collect spectral and spatial data. This review discusses the recent developments and application of HSI for detecting quality and safety attributes of tenderness, colour, pH, moisture content, marbling, fat, microbial level and adulteration in meat, fish and poultry meat and products. Overall, HSI technology has tremendous potential to classify different parameters in meat and its products.

Keywords: *hyperspectral imaging, classification, meat, quality assessment, safety detection.*

Introduction

Meat has always played a significant role in human diets all over the world (*Jiang et al.*, 2020a). Humans require meat and meat products in order to acquire some basic vitamins, amino acids, proteins, and other useful components (*Jiang et al.*, 2020b). Pork, beef, lamb, chicken, tuna and other muscle foods are perishable and susceptible to alterations. Microbial growth, colour characteristics, tenderness, marbling, fat content, moisture content (MC) and pH affect certain important quality parameters during the post-mortem storage (*Cheng et al.*, 2017). Furthermore, unscrupulous merchants sell adulterated meat products in which cheaper meat, animal offal, meat unfit for human consumption, and non-meat synthetic chemical materials are added for profiteering purposes. Authenticity testing to detect adulteration in meat and meat products is increasingly vital as trade globalises (*Zhao et al.*, 2019). Consumers and producers equally are concerned about the safety of their meat.

Traditional detection approaches have been introduced, including chromatography, immunological procedures, electrophoretic separation of proteins and techniques focused on DNA, as well as manual sorting. These procedures, on the other hand, are time consuming, damaging, demand complicated laboratory analyses and produce many chemicals, generating toxic waste and polluting the environment (*Zhao et al.*, 2019, *Cheng et al.*, 2017). Hyperspectral imaging (HSI) is a comparatively recent advancement that allows for real-time measurement. This approach incorporates conventional optical imaging and spectroscopy into a single device that at the same time can obtain both spectral and spatial data for an element. On account of its spectral signature, spectroscopy detects or evaluates the analytical signal, and imaging converts the acquired data as distribution maps for spatial visualisation. Following that, HIS can be applied to variety of areas. The meat industry has been paying special attention to HSI techniques. Tenderness, colour, water holding capacity, drip loss, springiness, chewiness, chemical composition, microbial spoilage, authenticity, freshness, and identification of adulteration in meat, fish, and poultry are some of the applications. A variety of studies on HSI for measuring meat quality and safety have been published. However, this review addresses the application of HSI for the assessment of both quality and safety parameters of meat.

Hyperspectral Imaging (HSI) System

HSI has been researched for more than two decades and is one of the most commonly used advanced food investigation methods. HSI's food identification ability has been shown in a number of publications, including for poultry and meat products, fruits

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and vegetables, cereals and others (*Ma et al.*, 2019). It is a non-destructive food quality and safety testing platform that uses accelerated inspection. Every pixel in the image produced comprises the spectrum of that particular location, i.e., the light-absorbing and/or scattering properties in the spatial field, which can be used to describe the pixel composition. The entire meat chain uses or will use HSI approaches at different levels (*Achata et al*., 2020).

Components of HSI

The major components of HSI are a camera with a charge-coupled device (CCD)/CMOS detector, objective lens, light source, transporter stage, computer with image acquisition and data processing software, motor and power supply. A regular zoom lens, an extremely specific and sensitive spectrograph and a charge-coupled device or complementary metal-oxide semiconductor camera complete the imaging unit, which is a key component for constructing spatial and spectral knowledge of food specimens. The spectrograph's job is to scatter the captured light into a continuous "electromagnetic spectrum". Most HSI spectrographs include optical instruments like prisms, diffraction gratings and automatically regulated liquid crystal tuneable filters or acousto-optic tuneable filters to accomplish this goal. In HSI systems, the light source is critical because it acts as an optical probe in detecting the chemical components and physical structure of the target foods. In hyperspectral reflectance and transmittance imaging systems, a halogen lamp is frequently used to illuminate the target area with a wider spectral range in the visible-near infrared region (VNIR) region.

Principle and Fundamentals of Hyperspectral Imaging

The HSI approach integrates classical optical spectroscopy and computer vision into a single system that simultaneously generates spectral and spatial information about the specimens being tested. The classical spectroscopic equipment produces a single spectrum I (λ), where an imaging system typically produces an image in two dimensional (2-D) data I. As a result, a 3-D hypercube I , λ) is formed. It could be described as a distinct spatial image I for each wavelength (λ) or as a spectrum I (λ) for each single pixel.

By converting incident photons into electrons, the area is detected using a CCD that can control and quantify the intensity of the light received. The hyperspectral images are acquired and calibrated using a computer control system, which also controls the exposure duration, motor speed, combining mode and wavelength range. Scanning of point, line and region are also terms that describe HIS acquisition techniques. Reflecting, transmitting and interacting properties of the image-sensing models are used to distinguish the light source and the optical detector settings.

Since HIS is described as fast, non-destructive, non-intrusive, environmentally safe and a non-chemical tool, it can be used for effectively evaluating food quality in laboratories and research settings, and it has a lot of promise for replacing conventional analytical techniques in on-line industrial applications. In the hypercube structure, the derived spatial and spectral data must be statistically processed as thousands of spectra (to give the spectral signature) scattered across the calculated region (the spatial signature).

Chemo metric analysis is extremely useful for analysing hypercube data. Chemometrics has the potential to minimise the difficulty in acquiring large data sets, to generate classifying and predicting models and to improve the precision and strength of spectral data analysis models. To limit and correct potential interferences associated with scattering, baseline drift, path-length variance and overlapping bands, spectral pre-treatment methods such as multiplicative scatter correction (MSC), standard normal variate (SNV), smoothing, baseline removal and first as well as second derivatives are used. Regression coefficient analysis (RC), principal component analysis (PCA), successive projections algorithm (SPA), uninformative variable elimination (UVE) and genetic algorithms (GA) are common techniques for selecting the highly educative regions of spectra/optimum wavelengths to simplify the modelling and model construction. Partial least squares regression (PLSR), multiple linear regression (MLR), least squares-support vector machine (LS-SVM) and artificial neural network (ANN) are some of the most commonly used modelling approaches for quantitative analysis. The resulting system is evaluated using numerous statistical parameters that include: calibration (C), cross-validation (CV), and prediction (P) determination coefficients; the corresponding root mean square errors calculated by calibration (RMSEC), cross-validation (RMSECV) or prediction (RMSEP), and; the overall indication factor that is the residual predictive deviation (RPD). In general, a good model should have higher C, CV, P, and RPD values and lower RMSEC, RMSECV, and RMSEP values, while there should be slight discrepancy between them (*Cheng et al.,* 2017).

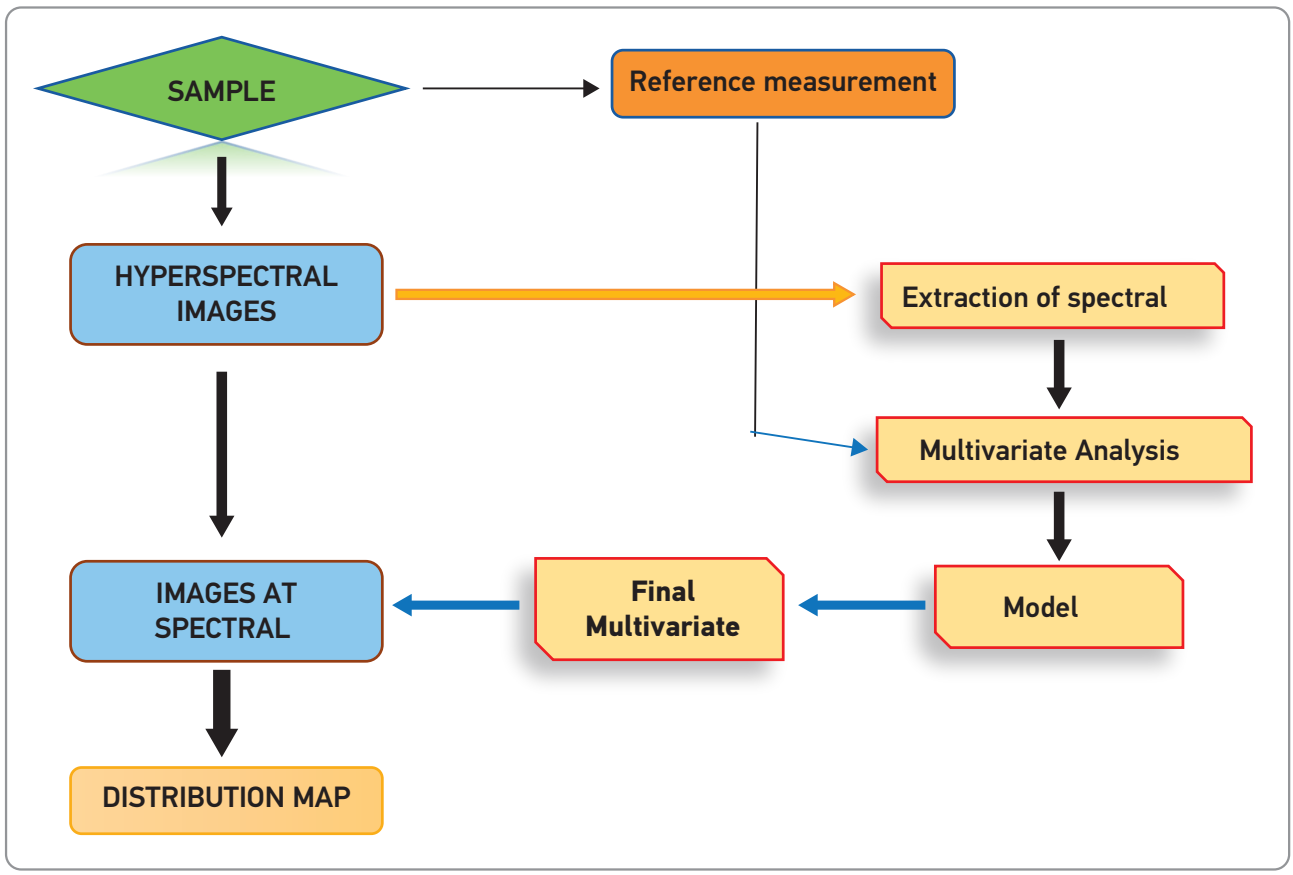

Figure1. Data acquisition using hyperspectral imaging with the multivariate analysis model.

Quality Evaluation

The quality of meat and meat products, which is influenced by their tenderness, colour, pH, MC, fat, marbling, microbial level and adulteration, was evaluated using the HSI systems presented in Table 1. Various statistical methods that were used for detection are also shown in Table 1.

Table 1. Assessment of meat quality and safety traits using hyperspectral imaging

Tested meat specimen	Parameter	Model	Spectral Range (nm)	Accuracy Values	Reference
Beef	Tenderness	HSI-NIR, PLSR	900–1700 nm	cv – 0.83, RMSECV – 40.75 N	(*ElMasry et al.*, 2012)
Fresh Boiler Breast Fillets	Tenderness	HSI - PLS-DA	400–1000 nm	Rp – 0.84	(*Jiang et al.*, 2018)
Beef	Tenderness	VNIR- HSI	400–1000 nm	SSF – 205.8 to 254.8 N Efficiency – 94.40%	(*Naganathan et al.*, 2008)
Beef	Tenderness	HSI - NIR, MLR	900–1700 nm	R – 0.89	(*Saadatian et al.*, 2015)
Beef	Tenderness	HSI - WBS	496–1036 nm	R – 0.67	(*Cluff et al.*, 2008)
Hanging Beef Carcasses	Tenderness	HSI	400–1000 nm	SSF – 18.9% TO 81.1%, Efficiency – 87.60%	(*Naganathan et al.*, 2015)
Salmon Fillets (Raw Farmed)	Tenderness	VNIR - HSI, PLSR & LS-SVM	400–1720 nm	Rp – 0.949, RMSEP – 1.089, RPD – 2.339	(*He et al.*, 2014)

Tested meat specimen	Parameter	Model	Spectral Range (nm)	Accuracy Values	Reference
Chicken breast fillets	Colour (L*)	HSI, PLSR	400–1000 nm	L* - Rp − 0.85, RMSEP − 40.75 N	(*Yang et al*., 2021)
Salmon Fillet	Colour (L*a*b*)	LW-NIR - HSI	900–1700 nm @ 256 bands	L* => Rp − 0.864 RMSEP − 2.424 a* => Rp − 0.736 RMSEP − 1.454 b*=>Rp − 0.798 RMSEP − 2.060	(*Wu et al*., 2012)
Beef, Lamb, Pork	Colour (L*a*b*)	HSI - MLR	400–1000 nm	L* => p − 0.94 RMSEP − 1.89 a* => p − 0.91 RMSEP − 1.40 b* => p − 0.83 RMSEP − 1.37	*(Kamruzzaman et al*., 2016)
Beef	Colour (L*a*b*)	HSI-NIR, PLSR	900–1700 nm	L* => cv – 0.88 RMSECV – 1.21 a* => *not satisfactory b * => cv – 0.81 RMSCV – 0.58	(*ElMasry et al*., 2012)
Beef	Colour (L*a*b*)	HSI, SG-RC-MLR	400–1000 nm	L* => p – 0.858 RMSEP – 0.808 a* => p – 0.890 RMSEP – 0.735 b* => p – 0.8161 RMSEP – 0.521	(*Liu et al*., 2018)
Turkey Ham	Colour (L*a*b*)	HSI-NIR, PLSR	900–1700 nm	L* => cv – 0.18 RMSECV – 1.66 a* => cv – 0.74 RMSECV – 0.35 b* => cv – 0.49 RMSECV – 0.89	(*Iqbal et al*., 2013)
Chicken breast fillets	pH	HSI-VNIR, PLSR	400–1000 nm @473 bands	Rp – 0.854 RMSEP – 0.13	(*Yang et al*., 2021)
Beef	pH	HSI-NIR, PLSR	900–1700 nm	cv – 0.73 RMSEP – 0.06	(*ElMasry et al*., 2012)
Chicken	pH	HSI-VNIR, PLSR	400–1000 nm	– 0.80 to 0.84 RMSE – 0.16 to 0.18	(*Kaswati et al*., 2020)
Beef	pH	HSI - SVM	400–1000 nm	99% accuracy pH – 5.8	(*Crichton et al*., 2017)
Salted Pork	pH	HSI, PLSR	400–1000 nm	p – 0.794 RMSEP – 0.086	(*Liu et al*., 2014)
Turkey Ham	pH	NIR - HSI, PLSR	900–1700 nm	cv – 0.81 RMSECV – 0.02	(*Iqbal et al*., 2013)
Beef	Moisture Content	HSI, SG-SPA-LS-SVM	400–1000 nm	p – 0.869 RMSEP – 1.304	(*Liu et al*., 2018)
Ground Beef	Moisture Content	NIR-HSI, PLS	880–1720 nm	p – 0.82 RMSEP – 1.77% (w/w)	(*Zhao et al*., 2017)
Lamb meat	Moisture Content	NIR-HSI, PLSR	900 –1700 nm	p – 0.88 RPD – 2.63	(*Kamruzzaman et al*., 2012)

Tested meat specimen	Parameter	Model	Spectral Range (nm)	Accuracy Values	Reference
Turkey Ham	Moisture Content	NIR-HSI, PLSR	900 –1700 nm	cv – 0.88 RMSECV – 2.51	*(Iqbal et al.*, 2013)
Pork	Moisture Content	HSI, PLSR	400–1000 nm	p – 0.94 RMSEP – 0.7682	(*Ma et al.*, 2017)
Cooked Beef	Moisture Content	HSI, BP-ANN, PLSR	400–1000 nm @ 774 bands	p – 0.977 RMSEP – 0.915	(*Yang et al.*, 2017)
Salmon Fish	Moisture Content	HSI, PLSR & LS-SVM	400–1753 nm	Rp – 0.815 to 0.970 RMSEP – 0.312% to 1.147%	(*Wu and Sun,* 2013a)
Beef	Microbial Growth - TVC	VNIR- HSI, PLSR	957–1664 nm	p – 0.86 RMSEP – 0.89 log CFU/g	(*Achata et al.*, 2020)
Chicken	Microbial Growth - *Pseudomonas spp. & Enterobacteriaceae*	NIR- HSI, MSC-PLS	900–1700 nm	Rp – 0.954 RMSEP – 0.396 log10 CFU/g	(*Jiang et al.*, 2021)
Spiced Beef	Microbial Growth - Total Viable Count	HSI, N-PLS	400–1000 nm @ 774bands	p – 0.934 RMSEP – 0.755	(*Yang et al.*, 2018)
Pork Meat	Microbial Growth - Total Viable Count	HSI	430–960 nm	p – 0.8308 RMSECV – 0.243 log CFU/g	(*Huang et al.*, 2013)
Chicken Meat Surface	Bacterial Contamination - Total Viable Count	HSI - TBFI	400–1000 nm	– 0.6833	(Ye et al., 2016)
Grass Carp Fish Flesh	Microbial Growth - *E. coli*	HSI - PLSR & MLR	400–1000 nm	p – 0.870 RMSEP – 0.274 log CFU/g	(*Cheng and Sun,* 2015)
Porcine meat (pork)	Microbial Growth - TVC, PPC	HSI - NIR	900–1700 nm @ 256 bands	– 0.82 to 0.85	(*Barbin et al.*, 2013)
Salmon Flesh	Microbial Growth - Total Viable Count	TS-HSI-VNIR, PLSR	400–1700 nm	p – 0.985 RMSEP – 0.280	(*Wu and Sun*, 2013b)
Pork Meat	Microbial Growth - *E. coli*	HSI - Gompertz function	400–1100 nm	Rcv – 0.939 RMSECV – 0.6369	(*Tao and Peng*, 2014)
Beef & Chicken	Adulteration of beef with chicken	HSI, GD-RC	380–1000 nm, with 950bands	Rp – 0.9831 RMSEP – 0.0319	(*Zhao et al.,* 2020)
Beef	Adulteration of beef with spoiled beef	VNIR - HSI, methods - PLSR, SVM	496–1000 nm, 250 bands	p – 0.95 RMSEP – 5.67%	(*Zhao et al.*, 2019)
Beef	Adulteration of beef with duck meat	VNIR - HSI, methods - PLSR, PCR	400–1000 nm	p – 0.96 RMSEP – 6.58%	(*Jiang et al.*, 2019)
Beef & Pork	Adulteration of plant and animal based in beef & pork	HSI, PLSR	400–1000 nm	R – 0.69 RPD – 1.41 to 2.82	(*Rady and Adedeji,* 2020)

Tested meat specimen	Parameter	Model	Spectral Range (nm)	Accuracy Values	Reference
Chicken	Adulteration of chicken with carrageenan	VNIR - HSI, PLSR	400–1000 nm	p – 0.85 RMSEP – 0.93	(*Zhang et al.,* 2019)
Pork Minced	Adulteration of minced pork with minced pork jowl meat	HSI, RC-PLSR	400–1000 nm	p – 0.9063 RMSEP – 13.93%	(*Jiang et al.,* 2020a)
Minced Beef	Adulteration of minced beef with pork & duck meat	NIR - HSI, DA / PLS	980–1800 nm	Rp – 91.62 to 95.8% RMSEP – 9.27 to 10.3	(*Leng et al*., 2020)
Lamb, Beef, Pork	Adulteration of red meat	HSI, SVM/CNN	548–1701 nm	94.40% accuracy	(*Al-Sarayreh et al.*, 2018)
Prawn	Adulteration of prawn with gelatin	HSI, LS-SVM	441–1030 nm	p – 0.962 RMSEP – 0.339	(*Wu et al*., 2013)
Minced Beef	Adulteration level of minced beef with horse meat	VNIR - HSI, PLSR	400–1000 nm	p – 0.98 RMSEP – 2.20%	(*Kamruzzman et al.* 2015)
Pork Minced	Adulteration pork minced with fats of leaf lard	HSI, PLSR	400–1000 nm	p – 0.98 RMSEP – 4.87%	(*Jiang et al.,* 2020b)
Beef	Marbling	HSI - PLSR	400–1000 nm	Rp – 0.95 RMSEP – 0.3BMS	(*Aredo et al*., 2017)
Pork	Marbling	HSI - NIR	900–1700 nm	Rp – 0.90 RMSEP – 0.52	(*Huang et al*., 2014)
Pork	Marbling	HSI	430–1000 nm	3.0 to 5.0 %	(*Qiao et al.*, 2007)
Beef	Marbling	HSI	400–1100 nm	cv – 0.92 RMSEP – 0.45	(*Li et al*., 2011)
Beef	Marbling	HSI	400–1000 nm	– 0.91	(*Lohumi et al.*, 2016)
Beef	Marbling	HSI	400–1000 nm	Error – 0.08% Level of prediction – 0.99%	(*Velásquez et al.*, 2017)
Ground Beef	Fat	NIR-HSI, PLS	880–1720 nm	p – 0.90 RMSEP – 1.72 to 1.83% (w/w)	(*Zhao et al.*, 2017)
Lamb meat	Fat	NIR-HSI, PLSR	900–1700 nm	p – 0.88 RPD – 3.20	(*Kamruzzaman et al.*, 2012)
Pork	Fat	HSI - PLSR	900–1700 nm	– C14:0 to C18:2 RMSECV – 0.087 to 0.304 mg/g	(*Kucha et al*., 2020)
Pork	Fat	NIR-HSI	900–1700 nm	Rp – 0.83	(*Huang et al*., 2017)
Salmon fillets	Fat	NIR-HSI, LV-SVM	900–1700 nm	Rp – 0.9685 RMSEP – 1.1750	(*Zhang et al*., 2020)
Lamb	Fat	HSI	954–1677 nm	– 0.59 RMSE – 2.34 mm	(*Rahman et al*., 2018)

Tenderness

Tenderness is an essential trait of meat consistency, characterised by chewing ease. It has been commonly used as a consumer-perceived proxy for the eating consistency of beef (*Jiang et al.,* 2018). Consumer approval of meat is based on tenderness, so it is vital for the meat industry to deliver high-quality, safe-to-eat, tender meat (*Saadatian et al.*, 2015). Flaws in meat quality, particularly in tenderness, have resulted in lower consumer loyalty and, as a result, lower market share. According to recent reports, about 15–20% of meats offered to consumers are not tender (*Cluff et al.*, 2008). In the meat industry, meat tenderness is currently determined mostly by the use of shear force equipment or sensory evaluation. These techniques, on the other hand, are time-consuming, destructive, and incompatible with the rapid-paced manufacturing and processing environments used in meat plants (*Tao and Peng*, 2014). *Cluff et al*. (2008) combined HSI with Warner-Bratzler shear force (WBSF) to collect tenderness reference values. The established model predicted WBSF scores (R = 0.67). However, the applied model showed limitations in predicting tenderness in beef. *ElMasry et al*. (2012) combined HSI operating in near the infrared region (NIR) with a PLSR model, which resulted in good prediction in the 900–1700 nm range (c – 0.91, RMSEC – 29.42 N, cv – 0.83, RMSECV – 40.75 N). More research is required to improve the model's prediction, accuracy and reliability. *He et al*. (2014) demonstrated tenderness evaluation in fresh farmed salmon fillet with HSI operating in VNIR at 400–1700 nm combined with PLSR and LS-SVM models, which resulted in the strongest performance among the systems examined (Rp – 0.905, RMSEP – 1.089, RPD – 2.339). The results indicated that combining HSI with LS-SVM showed better performance for predicting tenderness in salmon fillets. *Jiang et al*. (2018) used HSI combined with a PLS-DA model in the spectral range 400–100 nm for fresh chicken, and showed the model strongly predicted tenderness (Rp – 0.84, RC – 0.94). Similarly, pork meat tenderness analysed using HSI combined with MLR model showed reasonably good prediction (Rcv – 0.949, RC – 0.995, SEC – 2.796, SECV – 5.702).

Colour

In the meat industry and meat science study, colour is a significant element that is widely seen as a quality index. Consumers identify colour loss mainly as an indicator of lack of freshness and wholesomeness, so colour has been identified as a crucial meat quality attribute that affects the purchasing decision (*Kamruzzaman et al.*, 2016). Meat colour is also affected by the amount of protein pigments and myoglobin in the muscle. The quality and proportion of bound myoglobin establishes lightness (L*), redness/greenness (a*) and yellowness/blueness (b*) values (*Liu et al*., 2018). L* values are used to categorise pork into three groups, i.e. dark, firm, and dry (DFD), normal (NORM), and pale, soft, and exudative (PSE) (*Yang et al*., 2021). Conventional methods, such as using a colorimeter to assess lightness (L*), a* and b*, usually involve interaction with meat surfaces, which could contribute to contamination (*Liu et al*., 2018). As a result, developing a fast and non-destructive system for assessing meat quality is of great importance. *Kamruzzaman et al*. (2016) examined a HSI system at 400–1000 nm with the MLR model for red meat colour; the prediction results were: L* – (p – 0.94, RMESP – 1.89, RPD – 4.12); a* – (p – 0.91, RMSEP – 1.40, RPD – 3.79) and; b* – (p – 0.833, RMSEP – 1.37, RPD – 2.29), which proved good performance for predicting the red meat colour. A HSI system operating in the NIR region at 901–1710 nm combined with a PLSR model was used to determine the colour information of meat (*ElMasry et al*., 2012). The model showed good predicting results for L*– (cv – 0.88, RMSEP – 1.21) and b* – (cv – 0.81, RMSEP – 0.58). However, a* values were not satisfactory because the fell in a narrow range.

pH

pH is one of the most important consistency characteristics of beef. After being slaughtered, the acidity of meat increases (*Kaswati et al.*, 2020). pH is an important technical factor that influences microbial development. It also has a major effect on meat colour, flavour, water holding capacity, water activity and shelf life. During salting, protein precipitation and solubilisation cause the pH of meat products to change. In salted and dry cured beef, pH is linked to water holding capacity and loss of water. pH can also differentiate pork into three categories, i.e. DFD, NORM and PSE (*Yang et al*., 2021). A portable pH meter or a surface electrode are widely used to measure pH, but they are destructive and unstable methods, unsuitable for large-scale industrial applications. A HSI that operated in the VNIR region at 400–1000 nm was used to determine the pH of chicken meat. A fully cross-validated PLSR model was used (*Yang et al.,* 2021), and measures (Rp – 0.854, RMSEP – 0.13) showed the

resulting model had good prediction rates. A similar model (VNIR-HSI, PLSR) was used (*Kaswati et al.*, 2020) for pH prediction in chicken meat. The system yielded close results on fresh (– 0.80, RMSE – 0.16) and spoiled (– 0.84, RMSE – 0.18) chicken. Another HSI system in the NIR region, at 900–1700 nm in combination with PLSR model resulted in strong prediction of pH in beef compared to other models (c – 0.83, RMSEC – 0.05, cv – 0.73, RMSECV – 0.16) (*ElMasry et al*., 2012). Parallel results were obtained with HSI system in the NIR region in combination with a PLSR model for turkey and ham at 900–1700 nm (c – 0.88, RMSEC – 0.02, cv – 0.81, RMSECV – 0.02) (*Iqbal et al*., 2013). The overall pH present in the meat and meat products was predicted to be from pH 5.3 to 6.2.

Moisture Content (MC)

Since water is a vital element of meat and meat products, MC is one of the most essential properties that determines the quality and safety of meats. Changes in MC have a significant impact on microbial growth and meat quality traits (such as flavour, juiciness and appearance), processed meat storage time and consumer purchasing desires. MC is usually measured using a number of conventional techniques, including drying using a hot air oven, microwave drying, freeze drying and infrared moisture analysis (*Yang et al.*, 2017). However, because of their time-consuming and complicated processes, general moisture analysis approaches are not suitable for evaluating a large number of samples. HSI technique was used to determine the MC in cooled meat samples (*Liu et al.*, 2018) at 400–1000 nm using a SPA-LS-SVM model, but results were not encouraging (p – 0.869, RMSEP – 1.304, RPD – 2.724). However, better results were obtained in another study using HSI in combination with BP-ANN and PLSR to model cooked meat at 400–1000 nm (p – 0.977, RMSEP – 0.915) (*Yang et al.*, 2017). These results were superior to those of other prediction models. Moisture content in salmon fish was better predicted by combining HSI with PLSR and LS-SVM models at 400–1753 nm (p – 0.872 to 0.934, RMSEP – 0.312% to 1.147%, RPD – 1.082 to 4.034) (*Wu and Sun*, 2013a). Similarly, MC in other red meats (pork, lamb) was detected using HSI in NIR region at 400–1700 nm with a PLSR model (p – 0.88, 0.942, RMSEP – 0.7682, 1.4736) (*Kamruzzaman et al.*, 2012, *Ma et al.*, 2017). The overall prediction of MC in meat and meat products showed good results using HSI system.

Microbial Level

During storage, the wet, nutrient-rich fresh meat surface facilitates the growth of wide variety of spoilage bacteria. As a result, the total viable count (TVC) of bacteria is a valuable indicatior of meat's microbial control. When the TVC in meat exceeds a certain level, the bacteria tend to be pathogenic. However, since meat has adequate moisture and nutrients required for microbial growth and reproduction, particularly for the dominant spoilage microorganisms, chilled meat can harbour and support growth of *Pseudomonas* and *Enterobacteriaceae* at 0–4°C (*Jiang et al.*, 2021). Cross contamination of meat carcasses with *Escherichia coli*, *Salmonella* and other bacteria can occur during the processing steps like bleeding, scalding, feather removal, cleaning, chilling, and secondary processing (*Cheng and Sun*, 2015). To predict bacterial spoilage in meat, numerous chemical, physical and microbiological techniques were suggested. The majority of these techniques, on the other hand, take a lot of time, are destructive, involve complicated laboratory processes and require repetitive sample preparation. As a result, the HSI approach to rapidly and precisely diagnose microbial spoilage in meat is widely used. *Achata et al*. (2020) studied TVC in beef using HSI in the VNIR region at 957–1664 nm using PLSR model. The results were not ideal (p – 0.86, RMSEP – 0.89 log CFU/g, RPD – 2.27). Using the same system (*Yang et al*., 2018) but with different modelling strategies, N-PLS at 400–1000 nm, yielded better prediction results (p – 0.934, RMSEP – 0.755) for TVC in beef. Similarly, *Wu and Sun* (2013b) predicted TVC in salmon fish, using HSI in the VNIR region at 400–1700 nm with PLSR modelling technique, and showed this system had better performance (p – 0.985, RMSEP – 0.280, RPD – 5.127). *Cheng and Sun* (2015) used the same HIS system to predict whether there was *E. coli* contamination in fish using the PLSR and MLR technique at 400–1000 nm, (p – 0.870, RMSEP – 0.274 log CFU/g, RPD – 5.22). Similarly, *Jiang et al.* (2021) investigated the growth of *Pseudomonas* and *Enterobacteriaceae* in chicken under cold storage with HSI system operating in the NIR region at 9000–1700 nm in combination with MSC-PLS model, and achieved good prediction results (p – 0.954, RMSEP – 0.396 log CFU/g, RPD – 3.33).

Adulteration

Adulteration and authenticity identification in meat and their products is becoming highly relevant as trade globalises (*Zhao et al.*, 2019). Meat adulteration has direct impacts on consumer interests and can pose

many health risks. The horsemeat scandal in Europe several years back, for example, exposing meat adulteration process around the world, resulted in a major public confidence calamity (*Leng et al.*, 2020). Meat composition products, such as hamburgers, meatballs, patties, salami and sausages, often use minced or finely chopped meat as a key component. Partial or complete substitution of cheaper meat or addition of proteins from animal or vegetable origins to minced meat and similar ingredients can be tempting to dishonest meat chain actors. Compared with several other spectroscopic studies for detecting adulteration in meat and meat products, HSI was the best rapid, non-destructive analytical technique to detect the level of adulteration. *Kamruzzman et al*. (2015) determined the adulteration level of minced beef adulterated with horse meat using HSI in the VNIR region at 400–1000 nm with a PLSR model, which, among the systems examined, yielded the best performance in prediction rates (p – 0.98, RMSEP – 2.20%). Using the same system with the GD-RC model at 380–1000 nm predicted beef adulterated with chicken meat (R – 0.9831, RMSEP – 0.0319) (*Zhao et al.*, 2020). *Jiang et al*. (2020a) and *Jiang et al.* (2020b) experimented to detect the adulteration of minced pork with two different adulterants, namely minced pork jowl meat and leaf lard fats. A HSI system with PLSR modelling strategy was established at 400–1000 nm which showed prediction results for minced pork jowl meat adulterant (p – 0.9063, RMSEP – 13.93%, RPD – 2.30, LOD – 6.50%) and leaf lard adulterant (p – 0.98, RMSEP – 4.87%, RPD – 6.57, LOD – 6.08%). In addition, HSI was considered for the detection of adulteration in prawns after the animals ingested gelatine that had been extracted from mammal animal skins and bones using LS-SVM model at 441–1734 nm range (*Wu et al.*, 2013). The resultant prediction indicators were p – 0.962, RMSEP – 0.339, RPD – 5.128.

Marbling

Marbling is characterised by the volume and spatial distribution of visible fat that occurs as thin layers in the muscle, whereby the entire tissue resembles marble. It is considered to be a major meat trait that affects the acceptability of meat and their products. Fat lines that are evenly spread around the surface of the beef cause marbling that is commonly associated with higher meat quality. The quantitative and spatial distribution of fat lines in meat and meat products that contain pork and beef, in which marbling defines and distinguishes the commodity, lead to variations in eating consistency (*Velásquez et al.*, 2017). Marbling is a critical criterion for determining the consistency of beef. It is linked to the tenderness and flavour of beef. In general, beef with a lot of marbling has a tender feel (*Li et al.*, 2011). Marbling detection is labour-intensive and difficult to visually grade, which makes it hard for a human observer to correctly determine the scores for marbling. Because of such drawbacks, the traditional approach is not suited for a fast-paced on-line operation (*Huang et al.*, 2014). A HSI system that operated in the NIR region was established to detect marbling in meat products. *Aredo et al.* (2017) combined the HSI system with a PLSR model at 400–1000 nm to measure marbling in beef; the system proved to be the most efficient method among those examined and resulted in Rp – 0.95, RMSEP – 0.3 BMS, Rc – 0.98, RMESC – 0.2 BMS. Another study using the same system by *Huang et al*. (2014) showed the marbling in pork meat at 900–1700 nm spectral range with results of Rv – 0.90, RMSEV – 0.52, Rc – 0.91, RMSEC – 0.34. This established the good performance of the HIS system in detecting the level of pork meat marbling.

Fat

Intramuscular fat (IMF) content in meat is described as the total amount of dispersed spots of fat within edible muscle. It reflects the amount of fat in meat, and has a considerable effect on meat cooking quality, consumer satisfaction and consumer health. Although higher IMF levels are associated with greater market acceptance, consumer preferences differ by geographic location (*Huang et al.*, 2017). The content and structure of the IMF have a significant impact on other consistency attributes including juiciness, tenderness and flavour. The IMF is released during mastication that activates the salivary glands, resulting in juiciness. Fat improves muscle tenderness by weakening the muscle's elastic strength and preventing cross-linking between connective tissue and muscle fibre proteins, allowing the muscle to be split open easily in the mouth with less friction. Because of their contact with Maillard reaction products to liberate volatile compounds during the cooking of beef, fatty acids affect meat taste *(Kucha et al.*, 2020). *Zhao et al.* (2017) studied fat content in beef using a HSI system in the NIR region 880–1720 nm with PLSR, and computed the following results: p – 0.90, RMSEP – 1.72% to 1.83% w/w. Another study was carried out using the same system (*Kamruzzaman et al.*, 2012) for determining the fat content in lamb meat at spectral range 900–1700 nm gave the prediction statistics

of p – 0.88, RMSEP – 0.35%, RPD – 3.20. The results indicated HIS would be much better for detecting fat percentage in lamb meat than the other chemometric analysis methods. Similarly, other studies were conducted for pork (*Huang et al.*, 2017) and fish (*Zhang et al.*, 2020) in the spectral range 900–1700 nm showed reasonably good prediction statistics of Rp – 0.83 for pork and Rp – 0.9685 for fish.

Future Trends and Challenges

Despite the above benefits, HSI has several restrictions in meat industry applications. One such concern is the speed of HSI, which is a major downside. It requires a very long time for handling, displaying and processing the data. As a result, the HSI systems' speeds must be increased in order to speed up the collection and examination of spectral data. The cost of HIS is another drawback to its widespread application. HSI systems are considerably more expensive than multispectral imaging systems. For the outcome in real time applications, a multispectral imaging device of chosen wavelengths is an alternate promising solution. HIS has been researched by several groups in order to determine the most powerful wavelengths for constructing on-line multispectral imaging instruments. Since HSI is used to develop dedicated multispectral vision systems, it is important to think about wavelength range in all HIS techniques. The agricultural industry would benefit greatly if the food processing industry could incorporate spectral imaging technologies in real-time modes. However, a major significant drawback of HSI is that it is not a direct tool, and so its implementation involves systematic calibration and model transition procedures. As a result, moving these off-line lab applications to an on-line manufacturing environment will take more time and resources.

Conclusion

The quality and safety evaluation of meat and meat products that is achieved by rapid, objective, and non-destructive calculation and prediction of technical parameters and various classifications is crucial. HIS incorporates the complete benefits of spectroscopy and computer vision, which are the two traditional techniques used. HIS systems offer both spatial and spectral information; as a result, this technology provides new sensing capabilities that improve beef, poultry, and fish examination. In this review, the application of HSI to detect quality and safety attributes of tenderness, colour, pH, moisture content, microbial level, adulteration level, marbling and fat percentage in meat and meat products was presented. Various chemometric parameters can be predicted with HIS systems in different spectral ranges and predicted results are then analysed statistically (by tools like PLSR, MLR, LS-SVM). The results show that spectral data could be used to replace laborious and time-consuming standard analytical methods, offering a simple and non-destructive testing tool for the meat industry. However, there is still potential for progress in the production of low-cost multispectral imaging systems for particular applications. The important wavelengths specified in this review can be used to build HIS systems for specific applications.

Hiperspektralno snimanje u proceni kvaliteta mesa, ribe, živine i njihovih proizvoda

Charan Adithya S.

A p s t r a k t: Meso i proizvodi od mesa su bogati izvori hranljivih sastojaka u svakodnevnoj ishrani. Procena kvaliteta i bezbednosti hrane, uključujući mesa, su od suštinskog značaja zbog njihove kvarljivosti i osetljivosti. Potreba za analizom prehrambenih proizvoda u realnom vremenu podstakla je pronalazak nedestruktivnih mernih sistema. Hiperspektralno snimanje (HSI), u kombinaciji sa različitim metodama statističke analize, kao što su višestruka linearna regresija (MLR — Multiple Linear Regression), metoda potpornih vektora koja koristi tehniku najmanjih kvadrata (LS-SVM — Least Squares-Support Vector Machine) ili delimična regresija najmanjih kvadrata (PLSR — Partial Least Squares Regression), kreirano je kao brzi, nedestruktivni, neintruzivni proces bez hemikalija za određivanje važnih aspekata kvaliteta i hemometrike hrane. HSI sistem se koristi za prikupljanje spektralnih i prostornih podataka. Ovaj revijalni rad daje uvid u nedavni razvoj i primenu HSI sistema za otkrivanje kvalitetnih i bezbednosnih odlika kao što su mekoća, boja, pH, sadržaj vlage, mramoriranost, masnoća, sadržaj mikroba i falsifikovanja mesa, ribe i živinskog mesa i njihovih proizvoda. Sve u svemu, HSI tehnologija ima ogroman potencijal da klasifikuje različite parametre mesa i njegovih proizvoda.

Ključne reči: *hiperspektralno snimanje, klasifikacija, meso, procena kvaliteta, detekcija bezbednosti.*

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Common pheasant as a biomonitoring tool for environmental cadmium levels in Serbia

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A b s t r a c t: Contamination of food by heavy metals is a concerning problem in developing countries. Cadmium is one of the toxic elements that is considered as a marker for environmental contamination. The avian ecosystem is suitable for biomonitoring purposes, especially in cases where stationary sources of pollution are present. Pheasant samples (n = 327) were collected during four hunting seasons within the framework of the Serbian National Residue Monitoring Program, from 2018 to 2021. The level of cadmium in the samples was measured using inductively coupled plasma mass spectrometry (ICP-MS). The average cadmium level in analysed liver and leg muscle samples was 0.306 mg kg^{-1} and 0.009 mg kg^{-1} respectively. Cadmium levels ranged between 0.005–4.206 mg kg^{-1} in liver and < 0.001–0.235 in leg muscle. The cadmium level in pheasants in Serbia has slightly increased numerically (not statistically) over the past four years, so the level should continue to be carefully monitored.

Keywords: *cadmium, biomonitoring, common pheasant, ICP-MS.*

Introduction

Cadmium is one of the heavy metals marked as an environmental contaminant. It is a non-essential element for plants, animals and humans. Sources of cadmium in the environment are industrial activity (by far the largest), followed by its natural occurrence (*EFSA, 2012*).

Cadmium is typically a metal of the 20th century. It is mainly used in battery production and for the manufacture of special alloys. It can be released into the environment by burning fossil fuels and waste, or via heavy industry emissions, fertilizer production and agriculture processes (*Bernard, 2008*).

Released cadmium remains on site for decades. It enters the food chain by uptake from plants. Animals and humans are exposed via food, water and air (*Govind and Madhuri, 2014*). After absorption in the small intestine, most of the ingested cadmium is accumulated in the liver and kidneys, where it is bound to the transport protein, metallothionein (*VKM, 2015*). Liver is the principal organ for cadmium metabolism.

If it is accumulated in high amounts in animals, cadmium is responsible for disruptions of essential element metabolism, and damage and dysfunctions of internal organs. The toxicity of cadmium depends on the general state of the animal, exposure time, ingested concentrations, sex, age etc. (*Swiergosz and Kowalska, 2000*). Stationary sources of pollution present in the biotopes of non-migratory wild a nimals (e.g. birds) are considered suitable for biomonitoring purposes. Birds selected for such research need to fulfil several conditions related to easy detection and capture, abundance, well known biology of the species etc. (*Dzugan et al. 2012*).

Common pheasant (*Phasianus colchicus*) is colourful, medium-sized bird, well adapted and abundant in the biotope of Serbia, which makes it a good choice for heavy metal biomonitoring of the Serbian environment. It can be found near rivers, close to crop fields, or at the edges of forests. Considering that it is also a game bird, common pheasant is an adequate model for biomonitoring of heavy metals (*CABI, 2015*).

Pheasant meat is considered a delicacy, and it is also rich in proteins, essential amino acids, minerals and vitamins, with a good fatty acid profile. Wild pheasants, as a rule, have higher levels of toxic metals than do farmed animals. Levels of contamination principally depend on the nutrition profile of the animals (*Lazarus et al., 2014*).

Table 1 shows a brief overview of research on the origin and distribution of cadmium in liver and muscle of pheasants and birds that share habitats and

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lifestyles with them. The influence of nutrition on farms and in the natural environment as well as from the bird habitat itself was taken into consideration for this study.

The aim of this study was to determine the concentration of cadmium from environmental origin in edible tissue (liver and leg muscle) of common pheasant.

Table 1. Level of cadmium in liver and muscle of different bird species

Animal	Sample	Range (mg kg^{-1})	Mean (mg kg^{-1})	Technique	Source
Common pheasant (*Phasianus colchicus*)	Liver	0.026–2.008[a]	0.721[a]	AAS	Dzugan et al. (2012)
Common pheasant (*Phasianus colchicus*) Common pheasant (*Phasianus colchicus*)	Leg muscle[w] Leg muscle[f]	/ /	0.012[b] 0.016[b]	ICP-OES	Flis et al. (2020)
Common pheasant (*Phasianus colchicus*) Mallard (*Anas platyrhynchos*)	Leg muscle Leg muscle	0.0194–0.1084[a] 0.0035–0.2110[a]	0.0336[a] 0.0289[a]	GFAAS	Gasparik et al. (2010)
Common pheasant (*Phasianus colchicus*)	Liver Muscle	/ /	0.033[a] 0.003[a]	FAAS	Celechovska et al. (2008)
Common Pochard (*Aythya ferina*) Mallard (*Anas platyrhynchos*)	Liver Male Female Liver Male Female	0.016–0.280[a] 0.001–0.115[a] 0.108–0.800[a] 0.083–0.432[a]	0.123 0.044 0.418 0.249	FAAS	*Florijancic et al. (2009)*
Pigeon Jay Black coot	Liver Muscle	/ / / / / /	< LOD[a] 0.09[a] 0.07[a] < LOD[a] < LOD[a] < LOD[a]	ICP-MS	*Medunic et al. (2018)*
Pigeon	Liver Urban Rural	/ /	0.52[b] 0.44[b]	FAAS	Miliaimi et al. (2016)
Mallard (*Anas platyrhynchos*)	Liver	0.25–1.3[b]	0.65	ICP-AES	Mateo and Guitart (2003)
Eurasian Woodcocks (*Scolopax rusticola*)	Liver	/	4.39[b]	AAS	Kim and Oh (2013)
House sparrow (*Passer domesticus*)	Liver Rural Urban	/ /	0.009[b] 0.016[b]	ICP MS	Kekkonen et al. (2012)
Mallard (*Anas platyrhynchos*)	Liver	0.66–2.03[b]	/	GFAAS	Aloupi et al. (2017)
Common pheasant (*Phasianus colchicus*)	Liver Muscle	0.014–1.162[a] < LOD–0.049[a]	0,262[a] 0,006[a]	ICP MS	*Nikolic et al.* (2017)

Legend: [a] – wet weight, [b] – dry weight, [w] – wild, [f] – farm

Materials a nd methods

Cadmium levels were measured in liver and leg muscle of common pheasants in the period of four hunting seasons within the framework of the Serbian National Residue Monitoring Program (from 2018 to 2021). The total number of samples analysed was 327.

Samples were stored at −18°C. Frozen samples were thawed at 4°C one day before the analysis and subsequently homogenized. Approximately 0.3 g of each sample tissue was accurately weighed (± 0.001 g) and transferred into a Teflon vessel of a microwave digestion system with 5 mL nitric acid (67% trace metal grade, Fisher Scientific, Bishop, UK) and 1.5 mL of hydrogen peroxide (30% analytical grade, Sigma-Aldrich, St. Louis, MA, USA) for microwave digestion. The microwave (Start D, Milestone, Sorisole, Italy) used a three-step program (5 min from room temperature to 180°C, 10 min hold at 180°C, 20 min cooling and ventilation). After cooling, the digested sample solutions were quantitatively transferred into volumetric flasks and diluted to 100 mL with deionized water obtained from a water purification system (Purelab DV35, ELGA, Buckinghamshire, UK).

Inductively coupled plasma mass spectrometry (ICP-MS), (iCap Qc, Thermo Scientific, Bremen, Germany), equipped with a collision cell and operating in the kinetic energy discrimination (KED) mode, was used to determine the ^{111}Cd isotope. A five-point calibration curve (including zero) was constructed for the quantitative analysis. Multielement internal standard (^{6}Li, ^{45}Sc, 10 ng mL^{-1}; ^{71}Ga, ^{89}Y and ^{209}Bi, 2 ng mL^{-1}) was introduced inline by an additional line through the peristaltic pump. Measured levels were corrected for the response factors of internal standards. The quality of the analytical process was verified by analysing of the certified reference material NIST SRM 1577c (Gaithersburg, MD, USA). Reference material was prepared in the same way as samples using microwave digestion. Replicate analyses were in the ranges of certified values.

Statistical analysis

Statistical analysis of experimental data was performed using Minitab® 17.1.0 Statistical Software. One-way analysis of variance (ANOVA) and Tukey's test were used for comparison of cadmium levels between muscle tissue and liver within different years.

Results and Discussion

Tables 2 and 3 show the measured cadmium levels in liver and leg muscle of common pheasant.

National legislation does not prescribe maximum levels (MLs) for cadmium in pheasant tissue. Therefore, we used MLs for cadmium in poultry tissue (liver, muscle) for compliance assessment; 0.50 mg kg^{-1} for liver and 0.050 mg kg^{-1} for muscle (*Official Gazette of RS, 2014*).

Table 2. Cadmium levels in liver of common pheasant from Serbia

Year	Number of samples	Mass fraction mg kg^{-1}			Non-compliant*
		Median	Range	Mean ± SD	
2018	89	0.203	0.025–4.206	0.354±0.511	17
2019	71	0.179	0.016–1.237	0.247±0.228	11
2020	92	0.226	0.005–1.324	0.306±0.274	18
2021	75	0.197	0.009–1.396	0.303±0.296	6.7

Legend:* Percentage of samples exceeding the permitted cadmium values defined for poultry by national legislation, which for liver is 0.5 mg kg^{-1}.

Table 3. Cadmium levels in leg muscle of common pheasant from Serbia

Year	Number of samples	Mass fraction mg kg^{-1}			Non-compliant*
		Median	Range	Mean±SD	
2018	89	0.005	< LOD–0.146	0.009±0.018	3.4
2019	71	0.006	0.006–0.036	0.006±0.007	/
2020	92	0.005	< LOD–0.235	0.011±0.026	/
2021	75	0.006	0.001–0.048	0.011±0.012	/

Legend:* Percentage of samples exceeding the permitted cadmium values defined for poultry by national legislation, which for muscle is 0.05 mg kg^{-1}.

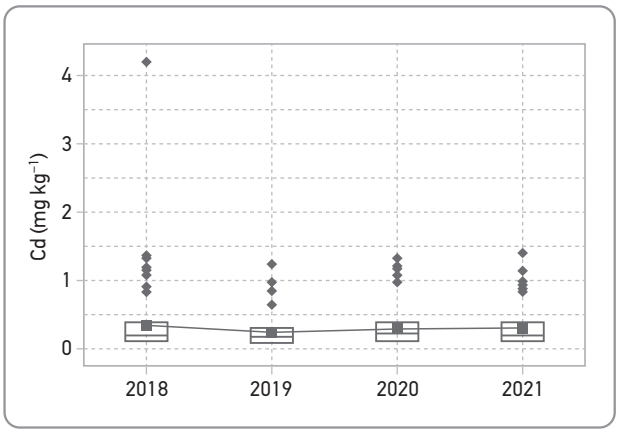

Figure 1. Cadmium levels (mg kg^{-1}) in pheasant liver samples

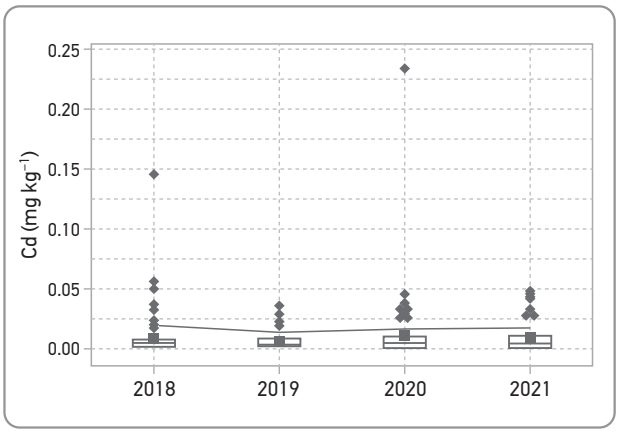

Figure 2. Cadmium levels (mg kg^{-1}) in pheasant leg muscle samples

For the entire observed period (2018–2021), levels of cadmium in liver were within the range of 0.005–4.206 mg kg^{-1}. The highest cadmium level in liver was determined in 2018 (4.206 mg kg^{-1}) (Figure 1). Comparing cadmium levels in liver for the four years, there was no statistically significant difference at a confidence level of 95%. The percentage of samples that were non-compliant with the ML for cadmium in liver was highest in 2020 (18.5%), and decreased in the following order: 2018>2019>2021 (Table 2).

The highest mean cadmium level in leg muscle was measured in 2020 (0.235 mg kg^{-1}) (Figure 2). Only 3.4% of all leg muscle samples exceeded the ML. At a confidence level of 95%, there was no statistically significant difference in leg muscle cadmium levels, comparing all four years. The limit of detection (LoD) for cadmium was 0.001 mg kg^{-1}.

As expected, comparing the results between liver and leg muscle, there was a statistically significant difference. *Nikolic et al.* (2017) reported a level of 0.262 mg kg^{-1}, but for the period from 2018 to 2021 (the current study), the mean cadmium level was 0.306 mg kg^{-1}. Therefore, the mean cadmium level in the liver of pheasants in Serbia was slightly higher in the period from 2018 to 2021 than in previous years (2013–2016). The mean cadmium level in the leg muscle of pheasants for the period 2018–2021 was 0.009 mg kg^{-1}, which was also higher than in 2013–2016 (0.006 mg kg^{-1}). *Dzugan et al.* (2012) reported a higher mean cadmium level in pheasant liver (Table 1) than was found in our study. The cadmium level in liver reported by *Celechovska et al.* (2008) (Czech Republic) was lower than the level in pheasant caught in Serbia.

Flis et al. (2020) reported that leg muscle samples from wild pheasant contained 0.012 mg kg^{-1} of cadmium, while farmed pheasant had 0.016 mg kg^{-1}, which means that the animals on the farms consumed feed with a higher cadmium content than in the food of wild birds. Both tested groups had higher cadmium levels in muscle than did birds in our findings in Serbia. Unlike our results, *Gasparik et al.* (2010) found 0.0336 mg kg^{-1} of cadmium in leg muscle of pheasants from Slovakia, which was a significantly higher level than our findings.

Conclusion

This study reports a slight increasing trend (numerical but not statistical) of cadmium content in the liver and muscles of pheasants, from 2014 onwards. Although such increase is not alarming, further research is recommended for the purposes of monitoring cadmium levels in the environment. Based on these findings, it is apparent that continuous biomonitoring of heavy metals is necessary in industrial areas since it is a useful indicator of the state of the environment. Firstly, this is because pheasant is used in human nutrition, and secondly, the data are useful to monitor concentrations of bioavailable cadmium that enters the food chain. Further research could be expanded to analysis of soil, air and water from pheasants' habitats.

Fazan kao sredstvo za biomonitoring nivoa kadmijuma u životnoj sredini u Srbiji

Nikola Borjan, Zoran Petrović, Stefan Simunović, Dragica Nikolić Perović, Brankica Lakicević, Danijela Vranić, Saša Janković

A p s t r a k t: Hrana kontaminirana teškim metalima je problem koji je sve češći kod zemalja u razvoju. Jedan od teških metala označen kao zagađivač životne sredine je kadmijum. Ptice predstavljaju dobar izbor za biomonitoring, posebno kod područja gde je prisutan stacionarni izvor zagađenja. Uzorci fazana su prikupljeni tokom četiri lovne sezone u Srbiji u okviru programa Nacionalnog praćenja rezidua od 2018. do 2021. godine. Ukupan broj uzoraka je iznosio 327. Količina kadmijuma u uzorcima je određena primenom indukovano spregnute plazme sa masenim detektorom (eng. Inductively coupled plasma mass spectrometry — ICP-MS). Prosečna vrednost kadmijuma u analiziranim uzorcima jetre i mišića nogu je 0.306 mg kg^{-1} i 0.009 mg kg^{-1}. Opseg nivoa kadmijuma je bio 0.005–4.206 mg kg^{-1} za jetru i < 0,001–0.235 za mišić nogu. Nivo kadmijuma kod fazanu u Srbiji je neznatno povećan brojčano (ne statistički) u protekle četiri godine, pa nivo kadmijuma treba i dalje pažljivo pratiti.

Ključne reči: *kadmijum, biomonitoring, fazan, ICP-MS.*

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Original scientific paper

Comparison of fatty acid content of cows milk consuming different grass diets

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A b s t r a c t: The aim of this study was to evaluate effects of three dairy cow groups consuming different grass diets (Diet A comprising of 20% grass, Diet B comprising of 50% grass and 100% grazed grass-G) on cow milk proximate and fatty acid (FA) composition. The first principal component (PC1) accounted for 55.1%, and the second (PC2) accounted for 19.5% of the variance. The score values for PC1 and PC2 of the FAs show that milk fat from grass (MF G) was characterized by high C6:0, C8:0 and C14:0 contents. Milk from Diet A (MF A) was characterized by a higher content of C16:0. Milk from Diet B (MF B) was characterized by higher contents of C18:1n-9 and C18:2n-6 than milk from Diet A. The most favorable FA composition was in milk from Diet B, comprising 50% grass. The least favorable FA composition was in milk from Diet A, comprising 20% grass and in milk from 100% grazed grass. However, more testing is needed to bring a conclusion which food for dairy cows is the best.

Keywords: *chemical composition, feed composition, milk fatty acids, principal component analysis.*

Introduction

Diets consumed by lactating dairy cows are low in fat content, generally containing only about 4–5% lipid (*Lock and Baumann, 2004*). Butyric (C4:0) to myristic acids (C14:0) are generated through *de novo* synthesis in the mammary gland, while varying amounts of palmitic acid (C16:0) are derived from *de novo* synthesis and from the uptake of circulating lipids (*Grummer* 1991*; Sejrsen et al.,* 2007*; Neville and Picciano,* 1997). The main isomer present in milk is the *trans* monounsaturated fatty acid (MUFA), vaccenic acid (18:1trans-11) (*Chillard et al*., 2007). In the mammary gland, the fatty acids (FAs) undergo desaturation by biohydrogenation of linoleic acid from the rumen to rumenic acid (RA, CLA cis-9, trans-11), which finally converts C18:1 trans-11 to stearic acid (C18:0) (*Harfoot and Hazlewood*, 1997). Conjugated linoleic acid (CLA) is common in milk, and is a mixture of positional and geometric isomers of linoleic acid (C18:2n-6) with conjugated double bonds (*Bauman and Lock*, 2006). The high natural levels in ruminant depot fat originate partly from bacteria in the rumen (*Harfoot and Hazlewood*, 1997). The anticarcinogenic, antidiabetogenic, anti-atherogenic and immunomodulatory effects of CLA have been clearly established (*Banni et al.,* 2003; *Belury,* 2002; *Ip et al*., 2003; *Lee et al*., 2004; *Pariza et al*., 1996). The predominant source of CLA in human diets is ruminant-derived food products, with dairy products contributing CLAs in various isomers but predominantly as rumenic acid. Although CLA occurs in small amounts in vegetable oils, the meat and milk of ruminants contain particularly high concentrations, varying between 0.5% and 2% of total lipids (*Bauman and Griinari*, 2003; *Jenkins et al*., 2008; *Parodi*, 2003). CLA is a component of milk fat, and hence, research has concentrated on increasing the CLA content per unit of fat. Processing has little effect on CLA, so the content in food products is related to the CLA concentration in the starting fat (*Parodi*, 2003). These are the reasons for the intense interest in the distribution, synthesis, and concentration of CLA in foods that is believed to be health-promoting for consumers. Linolenic acid (C18:3n-3) is derived principally from forage crops, being a major component of the oilseeds and concentrates that are fed to dairy cows (*Lock and Baumann*, 2004). *Gaspardo et al.* (2010) found unsaturated FAs and long-chain C18 FAs can be used as efficient markers for the discrimination of milk based on country of origin. This is in agreement with the findings of other authors who pointed out that the variation of FA compositions in milk can be related to the

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origin of the animals and breed (*Poulsen et al*., 2012; *Palladino et al*., 2010). The aim of this study was to evaluate effects of three cow grass-based diets on cow milk proximate and fatty acid composition.

Material and Methods

Compliance with ethical standards

The experimental use of animals and procedures for their management was performed in compliance with the Animal Welfare Law, Serbia, and approved by the Ethics Committee, Institute of Meat Hygiene and Technology, Belgrade.

Dairy cow feeding and milking

A total of 21 lactating Holstein-Friesian dairy cows were divided into three groups and then each group was assigned to one of three dietary treatments. Animal groups were fed one of three experimental diets (Diet A comprising of 20% grass, Diet B comprising of 50% grass, both of which were mixed diets, and grazed grass G). Cows were milked twice daily and individual milk yields were recorded at each milking using the afimilk (Kibbutz Afikim, Israel) system. Cows were fed at least 35 days before each sampling.

Milk and feed analysis

Milk samples were cooled and transported to the laboratory for analysis of fat and protein contents. The fat content was measured according to the Gerber butyrometric method (ISO 488:2008), the protein content was measured using a fully automated Kjedahl analyser (Kjeltec 8400, Foss, Hillerød, Denmark)

Feed samples were analyzed for moisture (*ISO* 6496:1999), crude protein, total fat (*ISO* 6492:1999) crude ash (*ISO* 5984:2002) and fibre content (*ISO* 6865:2000). The protein content was measured using a fully automated Kjedahl analyser (Kjeltec 8400, Foss, Hillerød, Denmark). Nitrogen-free extractives (NFE) as a measure of the soluble carbohydrates in the feed, such as percentage of starch and sugar, were calculated.

FA analysis by capillary gas chromatography

The FA composition was determined by capillary gas chromatograph previously using accelerated solvent extraction (ASE), (ASE 200, Dionex, Sunnyvale, CA, USA) with petroleum ether and isopropanol mixture (60:40, v/v) at 100°C over three static cycles of 1 min under nitrogen at 12 MPa. The solvent from the collected extracts was removed under a stream of nitrogen (Dionex Solvent evaporator 500, Dionex, Sunnyvale, CA, USA) at 50°C until dry. The fatty acid methyl esters (FAMEs) were prepared by the method of base catalyzed methylation of FAs with sodium methoxide in methanol according to the method proposed by *Christie et al.* (2001). FAMEs were determined by gas-liquid chromatography (Shimadzu 2010, Kyoto, Japan) with with flame ionization detector (FID) on HP-88 column (length 100 m, i.d. 0.25 mm, film thickness 0.20 μm). Injector and detector temperature were 250°C and 280°C, respectively. Nitrogen was used as the carrier gas at flow rate of 1.87 mL min^{-1}. The injector split ratio was set at 1:50. The injected volume was 1 μL. Detector gases: hydrogen 40 mL min^{-1}, synthetic air 400 mL min^{-1}, make-up gas (nitrogen) 30 mL min^{-1}. Temperature program for column: 50°C, hold 1 min; at a rate of 13°C min^{-1} to 175°C, hold 15 min; at a rate of 4°C min^{-1} to 215°C, hold 10 min; at a rate of 2°C min^{-1} to 230°C, hold 5 min. Total analysis time was 61.5 min. The chromatographic peaks in the samples were identified by comparing FAME peaks with peaks in FAME mix standard (Supelco 37 Supelco, Bellefonte, PA) and to which a mixture of 5 mg ml^{-1} CLA was added (mixture of methyl cis 9,11- and trans-10,12-octadecadienoic acid, O5632, Sigma Aldrich). Each milk sample was analyzed in triplicate.

Statistical analysis

All chemical analyses were performed in three replicates and the results were statistically analyzed. One factor analysis of variance (ANOVA) was used to compare grouped data. Tukey-Kramer test was used to test the significance of differences between the observed means. All statistical analyses as well as principal component analysis (PCA) were conducted using JMP 10 software (SAS Institute Inc.USA).

Results and Disccusion

Milk production and diets composition

The chemical composition of the milks is given in Table 1.

There was no significant difference in weight of cows fed different diets. There was a significant difference in the protein content of the milks, the highest being in milks from Diets A and B and the lowest in milk from grazing ($P < 0.05$). There were

Table 1. The effect of dietary treatment on dairy cow and milk performance

	MF (A) (n = 6)	MF (B) (n = 6)	MF (G) (n = 9)	P- value
Milk yield, kg day^{-1}	22	28	25	NS
Weight, kg cow^{-1}	597±8^{NS}	560±8^{NS}	550±4^{NS}	NS
Protein, %	3.41±0.01^{A}	3.21±0.02^{AB}	2.90±0.01^{B}	**
Fat, %	3.60±0.01^{NS}	4.18±0.03^{NS}	3.75±0.01^{NS}	NS

Legend: Values are mean ± SEM, n – number of samples. P-value – level of significance; NS – not significant, ** Means within a row with different superscripts differ significantly (P < 0.01); MF (A) – milk from diet A; MF (B) – milk from diet B; MF (G) – milk from grazing

no significant differences observed in milk fat content (P > 0.05). However, significant different for protein content and fat content were observed in study of *Palmar et al*. (2020).

Chemical and FA composition of the diets are given in Table 2.

Diet A and Diet B contained similar contents of crude proteins, total fat and crude ash but differed in moisture, crude fibre and in nitrogen-free extractives; the latter were highest in Diet A. Silage accounted for 50% of Diet A and 20% of Diet B. Also, the FA composition of Diets A and B differed. Diet B contained higher levels of saturated FAs (SFAs), including palmitic acid (C16:0) and stearic acid (C18:0), than Diet A. Higher levels of monounsaturated FAs (MUFAs) occurred in Diet A, among which oleic acid (C18:1n-9) was also higher than in Diet B. Diet A contained higher levels of polyunsaturated FAs (PUFAs), of which linoleic acid (C18:2n-6) was higher than in Diet B, but linolenic

Table 2. Chemical and fatty acid composition in diets (%)

Proximate composition	Diet A	Diet B	Diet G
Crude proteins	8.10	9.49	3.86
Moisture	42.07	35.99	80.72
Crude total fat	1.66	1.42	0.77
Crude ash	4.61	5.19	1.95
Crude fibre	7.61	22.39	2.65
NFE	35.96	25.52	10.05
Silage	50	20	0
Concentrate	30	30	0
Grass	20	50	100
Fatty acid composition			
C16:0	18.02	23.32	28.05
C18:0	2.61	4.99	6.45
C18:1n-9	25.67	20.18	13.68
C18:2n-6	47.36	37.92	13.34
C18:3n-3	4.02	10.51	32.38
SFA	21.62	31.10	36.54
MUFA	25.93	20.47	17.24
PUFA	51.38	48.43	46.17

Legend: NFE – nitrogen-free extractives; SFA – saturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids

acid (C18:3n-3) was higher in Diet B than in Diet A. Grass was full of moisture, nitrogen-free extractives and linolenic acid.

Milk fatty acid composition

Milk FA composition is presented in Table 3.

SFAs were the most abundant FA class, being statistically highest in milk from Diet A and milk from grazing and the lowest in milk from Diet B. MUFAs were the next most abundant FA class, being statistically highest in milk from Diet B and the lowest in milk from Diet A and milk from grazing. PUFAs were statistically highest in milk from Diet B followed by milk from grazing and were the lowest in milk from Diet A ($P < 0.05$). Among the SFAs, palmitic acid was present in the greatest amounts, and was statistically highest in milk from Diet A and statistically lowest in milk from Diet B ($P < 0.05$). Among the MUFAs, oleic acid was statistically highest in milk from Diet B followed by milk from grazing and was the lowest in milk from Diet A ($P < 0.05$). Among the PUFAs, linoleic acid was statistically highest in milk from Diet B, followed by milk from grazing and was the lowest in milk from Diet A ($P < 0.05$). The profile of *c*9*t*11-CLA isomers

Table 3. Effects of dietary treatments on milk fatty acid profiles (% of total FA).

FAs	MF (A) (n = 6)	MF (B) (n = 6)	MF (G) (n = 9)	P- value
C4:0	2.44 ± 0.02^{B}	2.47 ± 0.02^{B}	3.96 ± 0.02^{A}	**
C6:0	1.87 ± 0.01^{B}	1.60 ± 0.02^{C}	2.34 ± 0.02^{A}	***
C8:0	1.15 ± 0.01^{B}	0.97 ± 0.01^{B}	1.33 ± 0.02^{A}	**
C10:0	2.76 ± 0.04^{AB}	2.26 ± 0.05^{B}	3.17 ± 0.06^{A}	**
C12:0	3.31±0.06	2.48±0.07	3.52±0.09	NS
C14:0	13.52 ± 0.08^{A}	9.67 ± 0.10^{B}	12.90 ± 0.12^{A}	**
C16:0	42.01 ± 0.23^{A}	29.67 ± 0.22^{C}	34.30 ± 0.30^{B}	***
C16:1	1.44 ± 0.02^{A}	1.64 ± 0.04^{A}	0.89 ± 0.01^{B}	**
C17:0	0.53 ± 0.01^{B}	0.67 ± 0.01^{A}	0.55 ± 0.01^{B}	**
C18:0	8.39 ± 0.12^{B}	10.95 ± 0.20^{AB}	11.02 ± 0.25^{A}	**
C18:1 trans-11	1.49±0.05	2.46±0.15	1.46±0.08	NS
C18:1n-9	19.81 ± 0.28^{B}	33.58 ± 0.02^{A}	20.39 ± 0.27^{B}	**
C18:2n-6	1.40 ± 0.01^{C}	2.42 ± 0.02^{A}	1.88 ± 0.03^{B}	***
C20:0+C18:3n-6	0.23±0.01	0.25±0.01	0.28±0.01	NS
c9,t11 CLA	0.15 ± 0.01^{AB}	0.10 ± 0.01^{B}	0.17 ± 0.01^{A}	**
C20:4n-6	0.10 ± 0.01^{B}	0.16 ± 0.01^{AB}	0.16 ± 0.01^{A}	**
SFA	77.10 ± 0.29^{A}	61.90 ± 0.09^{B}	74.75 ± 0.33^{A}	**
MUFA	21.25 ± 0.26^{B}	35.23 ± 0.04^{A}	21.28 ± 0.27^{B}	**
PUFA	1.65 ± 0.05^{C}	2.67 ± 0.02^{A}	2.21 ± 0.03^{B}	***
SCFA	8.26 ± 0.05^{B}	7.30 ± 0.05^{B}	10.88 ± 0.10^{A}	**
MCFA	61.87 ± 0.37^{A}	45.20 ± 0.24^{C}	53.82 ± 0.49^{B}	***
LCFA	31.09 ± 0.46^{B}	49.41 ± 0.16^{A}	34.75 ± 0.56^{B}	**
VLCFA	0.51±0.02	0.58±0.01	0.62±0.01	NS

Legend: Values represent mean ± SEM, n – number of samples; P-value –level of significance; NS- not significant, ** Means within a row with different superscripts differ significantly ($P < 0.01$); *** Means within a row with different superscripts differ significantly ($P < 0.001$); SFA – saturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids, SCFA – short-chain fatty acids (< C11:0); MCFA – medium-chain fatty acids (C12:0-C17:0); LCFA – long-chain fatty acids (C18-C19); VLCFA – very long-chain fatty acids (> C19:0); MF (A) – milk from diet A; MF (B) – milk from diet B; MF (G) – milk from grazing.

in the milks was statistically highest in milk from grazing, followed by milk from Diet A and was the lowest in milk from Diet B ($P < 0.05$) (Table 3). The same profile was obtained in study of *Trbović et al.* (2017). The characteristic FA profile of milk from the grazing dairy cows was predominantly C16:0, C18:0 and C18:1n-9. The FAs of milk from Diet A were high in C16:0, and the FAs of milk from grazing and Diet B and C18:1n-9 were high in milk from Diet B.

With our grass-based diets, the short-chain FAs (SCFAs) composed 7-11% of the cow milk FAs across all dietary groups. Conversely, if lipid dietary supplements are rich in medium-chain FAs (MCFAs), this could account for the different MCFA content of 45% in Diet B milk and 62% in Diet A milk; in fact, this is likely a consequence of the C16:0 content (29.67% to 42.01% in milks from Diet B and A, respectively). Long-chain FAs (LCFAs) composed 31–49% of cow milk FAs and, in contrast to MCFA, were the lowest in milk from Diet A, followed by milk from grazing, but were the highest in milk from Diet B. Very long-chain FAs (VLCFA) were very similar in the three milk groups and did not differ statistically. In contrast to short SCFA, very little VLCFA is synthesized *de novo* by ruminants and therefore most VLCFA must be ingested in the feed if these moieties are to be present in the milk (*Elgersma et al.*, 2006; *Chilliard et al.*, 2007). LCFA in milk originate almost exclusively from the

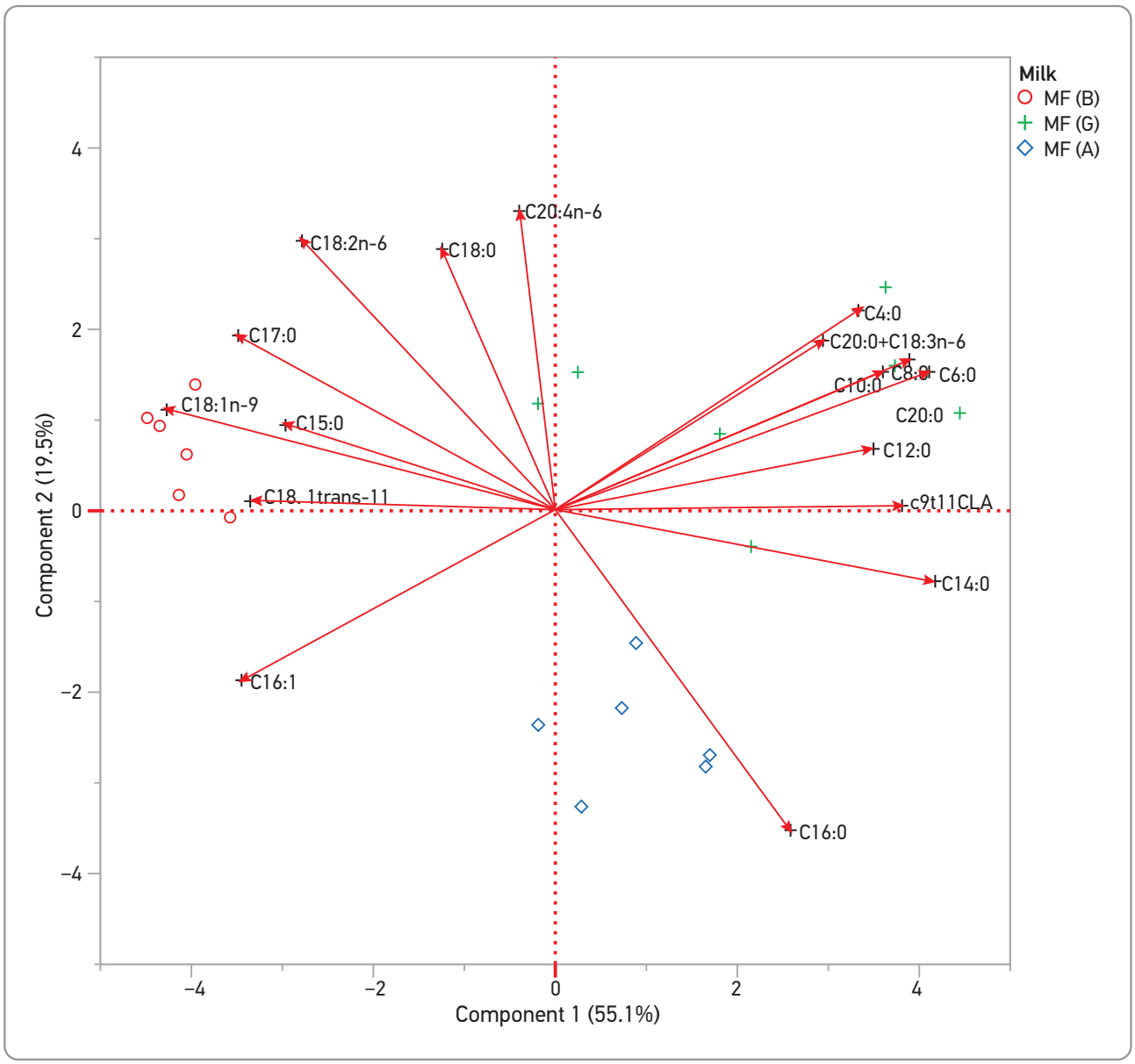

Figure 1. Principal component analysis among milk fatty acids (FA) (% of total fatty acids) in milk from 3 different diets

feed, but can be considerably modified in the rumen. Within the rumen, isomerization and hydrogenation depend on the FA content in the feed, but they also relate to the amounts of feed-derived starch and fiber that reach the rumen. According to *Chillard et al.* (2007), the potential to decrease MCFA in milk *via* cow diet is considerable, as occured in our study. For example, in milk from the grazed grass diet, MCFA composed 54% of the cow milk FAs, in milk from Diet A, MCFA accounted for a higher percentage of milk FAs, (62%) and in milk from Diet B, the amount of MCFA was lower (45%). This was due to the different cow diets. In contrast, our three cow diets had no effect on concentrations of SCFA in cow milk fat, as was observed by *Chillard et al.* (2007). The enzyme Δ9-desaturase catalyzes the introduction of a cis-double bond mainly favoring the conversions of C16:0 into C16:1 and C18:0 into C18:1 n-9 (*Ntambi and Miyzaki*, 2004; *Bauman et al*., 2006; *Jenkins et al*., 2008), as obtained in our study (Table 3). According to *Poulsen et al*. (2012), the results obtained in the current study show that grass induces higher C6:0 to C14:0 levels in milk which could be related to reduced *de novo* synthesis of FA. C18:3n-3 probably was derived from grass, which accounted for 50% of Diet B and 100% of the grazing diet.

PCA performed on the FAs (expressed as a percentage of the total FA) in the 21 milk samples provided better insight into the data structure (Figure 1). The analysis resulted in a two-principal-component model that explained 74.6% of the total variance. The first principal component (PC1) accounted for 55.1%, and the second (PC2) accounted for 19.5% of the variance. The score values for the first two principal components (PC1 and PC2) of the FAs expressed as percentages of the total FAs show that milk fat from grass (MF G) was characterized by high C6:0, C8:0 and C14:0 contents. Milk from Diet A (MF A) was characterized by a higher content of C16:0. Milk from Diet B (MF B) was characterized by higher contents of C18:1n-9 and C18:2n-6 than milk from Diet A.

Conclusion

In this study, we examined the proximate and FA composition in Holstein-Friesian dairy cows fed on three dietary treatments. There was a significant difference in the protein content of the milks, the highest being in milks from Diets A and B and the lowest in milk from grazing. There were no significant differences observed in milk fat content. Diet B and Diet A contained similar contents of proteins, total fat and crude ash but differed in moisture content, crude fibre content and in nitrogen-free extractives; the latter were highest in Diet A. The most favorable FA composition was in milk from Diet B, comprising 50% grass, 30% concentrate and 20% silage. The least favorable FA composition was in milk from Diet A, comprising 20% grass, 30% concentrate and 50% silage and in milk from 100% grazed grass. The different feeding regimens resulted in dietary responses in the dairy cows that significantly affected the milk fat composition. However, more testing is needed to bring a conclusion which food for dairy cows is the best.

Poređenje sadržaja masnih kiselina u kravljem mleku u zavisnosti od načina ishrane životinja

Nikola Ašanin, Dejana Trbović, Jelena Ćirić, Milan Ž. Baltić, Vesna Đorđević, Nenad Parunović, Snežana Bulajić

A p s t r a k t: Cilj ispitivanja ovog rada je bio da se procene efekti tri različita načina ishrane mlečnih krava (ishrana A- od 20% trave, ishrana B - 50% trave i 100% ishrana na ispaši-G) na masnokiselinski sastav kravljeg mleka. Prva glavna komponenta (PC1) čini 55,1%, a druga (PC2) 19,5% varijanse. Vrednosti skora za PC1 i PC2 FA pokazuju da se mlečna mast (MF G) karakteriše visokim sadržajem C6:0, C8:0 i C14:0. Mleko krava koje su bile u A grupi (MF A) karakteriše veći sadržaj C16:0. Mleko krava iz B grupe (MF B) karakteriše veći sadržaj C18:1n-9 i C18:2n-6 u odnosu na mleko krava hranjenih u grupi A. Najpovoljniji masnokiselinski sastav bio je u mleku krava iz grupe B, sa 50% trave. Najnepovoljniji masnokiselinski sastav bio je u mleku krava iz grupe A, i u mleku krava hranjenih 100% na ispaši. Međutim, potrebno je veći broj istraživanja da bi se doneo zaključak koja je ishrana mlečnih krava najbolja.

Ključne reči: *hemijski sastav, sastav hrane za životinje, masne kiseline mleka, analiza glavnih komponenti.*

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Original Scientific Paper

Are egg classes enough, or do we need an egg quality index?

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A b s t r a c t: This research on eggs from one of the largest producers on the Serbian market shows variations in the most important internal and external quality characteristics in relation to freshness (expressed in Haugh Units (HUs)) and weight class (S, M, L, XL). In parallel, sensory evaluation was conducted (for the two most common culinary methods of preparation) in order to determine whether consumers notice differences in quality when consuming scrambled eggs and how panellists perceive boiled eggs. Knowing that HUs are a scientific-based quality dimension, as opposed to weight classes that are consumer-based and associated with size of eggs, the authors have introduced a new total quality index elevating the perspective of HUs.

Keywords: *egg quality, total quality index, egg classes.*

Introduction

The perception of quality through the table egg supply chain has changed along with the rapid growth of production and has followed modern trends in the development of this industry. Research by the European Consumers' Association indicates that table eggs are increasingly recognized as a quality product, highlighting the most important parameter as safety, followed by eggs' freshness, nutritional value and sensory characteristics. Shell quality, albumen consistency and egg yolk colour are the most frequently evaluated attributes from the consumer's point of view (*Hernandez*, 2004).

From the market aspect, the most important characteristics are egg freshness, egg weight (size) and functional quality of the shell. Consumer preferences according to the colour of the shell and the size of the eggs differ according to the type of market. Research conducted in the last ten years indicates that most Europeans prefer a larger egg size, brown shell colour and dark orange yolk colour (*Bertechini*, 2017). This is partly related to the lack of understanding of quality assessment, due to consumer belief that a bigger egg is also of better quality (*Jacob et al.*, 2011).

In order to respond to market demands and ensure that consumers buy high quality eggs, criteria have been established for quality identification, evaluation and classification. Standardization of products according to physical and qualitative characteristics of economic importance for placing eggs on the European market is defined by Council Regulation (EC) No. 1308/2013 (*EC*, 2013) and Commission Regulation (EC) no. 589/2008 (*EC*, 2008). These provisions are also applied in Serbia, and include two egg quality classes: fresh class A eggs, with egg weight sub-categories (S, M, L, XL), and class B eggs (which are used for further industrial processing) (*Serbian Regulation*, 2019).

The mechanical characteristics of eggs are important from the transportation point of view and handling along the entire supply chain, while the geometric characteristics are important for the manner and type of packaging. Also, the quality of the shell is in direct correlation with the size, i.e., the weight of the eggs (S, M, L, XL), which significantly reflects on the sales revenue. It is well known that the colour and thickness of the shell decrease during the production cycle, while at the same time the egg gains weight (*Duman et al*., 2016). Natural variations in the colour of the shell of eggs produced from the same line hybrid are associated with the age of the laying hen and the change in egg size (*Samiullah et al*., 2015).

For consumers, the quality of the egg shell is primarily related to its structure, colour and appearance (*Koelkebeck*, 2010). Consumers prefer a dark shell color because of the belief that such eggs have

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a better texture, internal appearance and taste (*Berkhoff et al*., 2020). However, although the dark brown colour of the shell has a direct impact on the external quality perception of eggs, it does not correlate with the internal quality in terms of nutritional value, taste and cooking characteristics (*Jacob et al.*, 2011).

Of the internal characteristics of the overall quality, the most important is the freshness of the eggs, i.e., the quality of the yolk and egg white. A good quality egg has a round, firm yolk, and has a smaller diameter when spilled due to its dense viscous egg white that covers a small area (*Zaheer,* 2015). Variability in egg freshness leads to complex changes in protein structure, which are primarily reflected in changes in pH, vitelline membrane, fatty acid composition and oxidative processes (*Hisasaga et al*., 2020). The consequences are changes in the diameter of the yolk, which takes on a flat appearance due to the absorption of water from proteins and results in diluted egg whites that cover a large area when spilled (*Tamiru et al.,* 2019). Freshness can be measured by various methods, but it is most often estimated (as a standard measure of quality) in Haugh units (HU) by the ratio of the thickness of the thick egg white to the weight of the egg (*Liu et al.,* 2016). In addition to the above, oxidative processes can also affect changes in the sensory characteristics of quality, primarily in the taste and smell of egg yolks (*Hisasaga et al*., 2020).

A recent survey of quality perceptions along the entire table egg supply chain in Serbia highlighted the shape and size of eggs (i.e., weight groups/ weight classifications) as very important characteristics for all stakeholders (*Mitrović et al.,* 2021). In addition to the above, sellers and consumers singled out the age of eggs (i.e., their freshness) and shell characteristics as very important quality parameters (*Mitrović et al.,* 2021). For these reasons, this study aimed to examine the variation of selected internal quality characteristics (height and colour of egg whites, yolk colour and yolk proportion in the spilled surface) in relation to freshness (expressed in HU) from one of the largest manufacturers on the market. Also, as pointed out by consumers and in relation to the established classification, the most important external characteristics of the shell (colour, thickness and deformation) and geometric characteristics of eggs (shape index) were studied. Sensory evaluation was also conducted in order to determine whether consumers notice the stated differences in quality when consuming boiled and scrambled eggs.

Materials and Methods

Instrumental analysis of egg quality

The mass of 100 eggs was measured on an analytical balance, OHAUS Adventurer Model AR2140, USA. Shell deformation was tested with a Brookfield CT3 Texture Analyser, with the following parameters: peak load (N), shell deformation (mm), final load (N). Shell thickness (mm) was determined using digital Vernier calliper INSIZE 1113 (0–150mm/0–6). Egg albumen (mm) was measured with a micrometre B C Ames Co, Waltham, Massachusetts, USA. Eggs were analysed on the tenth day from the day of laying.

Haugh units

After determining the external characteristics of the shell and the mass, the eggs (100) were broken on flat plastic surfaces and the height of the egg white was determined. The Haugh unit (HU) was calculated based on the established equation (*Hisasaga et al*., 2020):

$$HU = 100 \log (H + 7.57 - 1.7 \times M^{0.37}) \quad (1)$$

HU – Haugh Unit; H – height of the albumen (mm); M – egg mass (g);

After measurement, the eggs were classified into three groups by freshness as follows: group C (HU = 20–40), group B (HU = 40–60), group A (HU = 60–80).

Computer Visual System (CVS)

Determining the colour of the shell, egg white, yolk, the proportion of yolk in the spilled surface and determining the egg shape index was performed by computer visual method according to *Tomasević et al*. (2019). Color was measured in three-dimensional (CIELAB) space, as the distance of the coordinates of two colors (Δ). The difference in lightness (L*), red (a*) and yellow (b*) were calculated and presented as total color differences (ΔE). Color parameters (L*a*b*) are expressed as an average of seven random measurements for each sample (100 eggs) (*Tomasević et al.*, 2019).

The total colour differences between the identified groups of eggs (in relation to the quality determined by HU for albumen and egg yolk and in relation to the defined weight groups S, M, L and XL for

egg shell) were calculated using the following equation (*Milovanović et al*., 2021):

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (2)$$

$$\Delta L^* = L_1 - L_0 \quad (3)$$

$$\Delta a^* = a_1 - a_0 \quad (4)$$

$$\Delta b^* = b_1 - b_0 \quad (5)$$

The criterion for determining colour differences was defined as follows: ΔE = 0–0.5 not perceptible differences, ΔE = 0.5–1.5 slightly perceptible differences, ΔE = 1.5–3 perceptible differences, ΔE = 3–6 very perceptible differences (*Milovanović et al*., 2021). Recent research shows that untrained evaluators, i.e. consumers, can detect color differences (ΔE) of approximately 1 (*Altmann et al.,* 2022).

The egg shape index (SI) was determined using the following equation (*Nedomová and Buchar*, 2014):

$$SI = \frac{B}{L} \quad (6)$$

B = egg width (mm)

L = egg length (mm)

The criteria for determining the characteristics of the egg shape were defined as follows: SI <72 sharp shape, SI = 72–76 standard shape, SI > 76 round shape.

Knowing the dimensions of the egg provides an opportunity to determine the following geometric characteristics (*Nedomová and Buchar*, 2014):

$$\text{Geometric diameter } D_g = (LB^2)^{1/3}\,(\text{mm}) \quad (7)$$

$$\text{Sphericity } \Phi = \frac{Dg}{L} \quad (8)$$

$$\text{Egg volume } V = (0.6057 - 0.0018B)LB^2\,(\text{mm}^3) \quad (9)$$

$$\text{Egg surface } S = (3.155 - 0.013L + 0.0115B)LB\,(\text{mm}^2) \quad (10)$$

Sensory testing of egg quality

The sensory panel consisted of 12 experienced and trained evaluators of food of animal origin. The panelists were trained in two sessions of two hours, in order to check the detection of target sensory characteristics and knowledge of the methodology (*Đekic et al.*, 2021).

Descriptive method

Evaluation of hard-boiled eggs — 48 eggs (laid on the same day from the same producer) were boiled for 8 minutes in boiling water. After cooking, the eggs were cooled to 40°C and prepared for testing without the addition of salt. The eggs were peeled, cut in half and placed on white cardboard trays previously marked with three-digit codes (*Parpinello et al*., 2006).

Sensory evaluation of hard-boiled eggs was performed by a descriptive method by 12 trained panellists, in two sessions in two repetitions. The examination was performed during two days in the laboratory space for sensory analysis at the Faculty of Agriculture, University of Belgrade. Panellists evaluated the intensity of the following attributes using a linear scale of 15 cm with two anchors at each side: 1) visual appearance (shape of boiled egg; 0 = irregular ovoid shape to 15 = ideally ovoid shape), 2) smell (smell of whole egg, 0 = no smell to 15 = intense smell), 3) taste (characteristic taste of whole egg; 0 = no taste of egg to 15 = intense taste of egg), 4) hardness of egg yolk (0 = soft to 15 = hard) 5) hardness of egg white (0 = soft to 15 = hard) 6) stickiness of egg yolk (gum stickiness intensity; 0 to 15) (*Hayat et al*., 2010; *Sasaki et al*., 2019).

Discriminatory test

Evaluation of scrambled eggs — 48 eggs laid on the same day from the same producer were homogenized with a blender. After homogenization, eggs were cooked in a heated Teflon pan for 2 minutes with constant stirring, without the addition of salt or oil. Then, 30 g of prepared scrambled eggs were placed on white cardboard trays previously marked with three-digit codes (*Parpinello et al*., 2006).

Sensory evaluation of scrambled eggs was performed by testing the differences in the triangle in accordance with the procedures of ISO 4120 (*ISO*, 2021) and ISO 16820 (*ISO*, 2019). The panellists performed sensory evaluation in two consecutive sessions in two repetitions. Sensory evaluation was conducted in a dedicated laboratory space for sensory testing, with breaks between sessions of 10 minutes.

Panellists were presented with two different types of scrambled eggs to determine the existence of perceptible differences between the eggs with different HUs. For that purpose, 32 triads of eggs were used, using a sequential method of applying the triangle test (*Ilić et al*, 2021)

Quality Index Method (Quality Index)

Having in mind that egg classes distinguish eggs based on size while HUs differentiate them based on size and albumen, we employed a total quality index technique to see how the selected quality characteristics correlated with HUs using additional quality characteristics.

In order to calculate a unique quality index comprising different quality characteristics, the egg quality results were evaluated in line with research by *Režek Jambrak et al*. (2018), *Đekic et al*. (2018) and *Đekic et al*. (2017), using the rule "the lower the value, the better the quality", for two additional criteria — total colour difference for egg yolk colour and egg white colour, equation 11:

$$QI = \frac{X_i}{X_{max}} \quad (11)$$

QI – quality index of a selected quality characteristic; x_i – measured value in the subset of values; x_{max} – maximal value in the subset of values.

The total quality index (TQI) was calculated as recommend by *Finotti et al*. (2007):

$$TQI = \sqrt{\sum_{j=1}^{N}(QI_j)^2} \quad (12)$$

For understanding the TQI, rule of the thumb is 'the lower the TQI value, the better the quality'.

Statistical data processing

Statistical processing of the obtained data was performed in SPSS Statistics 20.0 using ANOVA one-factor analysis of variance. Differences between groups were found at the level of statistical significance of 0.05.

Statistical processing of sensory test data for the triangle test was performed in accordance with the requirements of ISO 16820 (*ISO*, 2019), setting criteria as follow: $p_d = 0.25$, $\alpha = \beta = 0.05$.

Results and Discussion

Egg quality characteristics

The results of colour characterization tests in relation to egg freshness expressed by HUs are presented in Table 1. The average determined differences in yolk and egg white colours between the identified quality groups were in ranges that were not statistically significant ($p>0.05$), even though consumers were able to observe those differences in egg shell and yolk hues (ΔE) in eggs from different freshness categories (*Altmann et al.*, 2022). Similar effects were found for the determined differences in shell, in relation to different egg classes (S, M, L, XL), which are shown in Table 2.

All shell quality measurements varied in relation to egg weight. Shell thickness increased with egg weight from S to L class, while shells of class

Table 1. Characterization of colour: egg yolks and egg whites in relation to egg freshness quality groups (Haugh Units (HU))

Parameter CVS (n=7)	Egg yolk colour (n=100)			Egg white colour (n=100)		
	C (HU=20–40) (n=36)	B (HU=40–60) (n=33)	A (HU=60–80) (n=31)	C (HU=20–40) (n=36)	B (HU=40–60) (n=33)	A (HU=60–80) (n=31)
L*	69.73 ± 2.30	70.23 ± 0.22	71.10 ± 0.20	91.62 ± 0.19	91.03 ± 0.10	91.27 ± 0.11
	49.63 ± 0.22	47.08 ± 0.17	46.44 ± 0.48	−0.33 ± 0.13	−0.35 ± 0.09	−0.35 ± 0.14
	78.38 ± 0.53	78.60 ± 0.65	77.72 ± 0.51	8.22 ± 0.20	9.97 ± 0.30	10.25 ± 0.29
Colour						
P	P > 0.05			P > 0.05		

Parameter	Egg yolk colour		Egg white colour	
ΔE	C-A comparison	B-A comparison	C-A comparison	B-A comparison
	5.06 ± 0.39	1.03 ± 0.67	2.06 ± 0.12	0.37 ± 0.05
Evaluation	Very perceptible	Perceptible	Perceptible	Not perceptible

Table 2. Characterization of colour: eggshells in relation to egg weight classes (S, M, L, XL)

Parameter CVS (n=7)	Egg shell colour (n=100)			
	S (n=25)	M (n=25)	L (n=25)	XL (n=25)
L*	59.69 ± 1.39	60.90 ± 2.21	60.29 ± 1.99	62.11 ± 2.01
	33.54 ± 0.29	32.45 ± 0.33	33.03 ± 0.20	32.74 ± 0.58
	37.17 ± 0.44	35.93 ± 0.66	36.91 ± 0.60	36.66 ± 0.97
Colour				
P	P > 0.05			

Parameter	Egg shell colour			
ΔE	S-M	M-L	L-XL	S-XL
	4.17 ± 2.04	1.67 ± 1.29	3.47 ± 1.86	6.76 ± 2.60
Evaluation	Very perceptible	Perceptible	Very perceptible	Very perceptible

XL eggs were no thicker than those of class L eggs (Table 3). The results for shell deformation to the breaking point differed only for class S eggs, while for classes M, L and XL, they were relatively constant.

The comparisons of egg weight in relation to egg white height and HU value coincided with the research of other authors (*Kralik et al., 2017*). Dense egg white height and HU value were negatively correlated with egg weight, which can be seen in Table 4.

Table 3. Characterization of egg shell in relation to egg weight classes (S, M, L, XL)

Egg class (n=100)	Shell thickness (mm)	Peak Load (N)	Shell deformation (mm)	Final Load (N)
S	0.47 ± 0.11	49.32 ± 11.87	0.37 ± 0.12	13.63 ± 5.00
M	0.53 ± 0.07	51.00 ± 8.45	0.30 ± 0.06	13.24 ± 4.61
L	0.57 ± 0.12	44.63 ± 15.87	0.34 ± 0.14	14.30 ± 5.75
XL	0.55 ± 0.11	46.05 ± 9.17	0.32 ± 0.12	11.54 ± 4.05
P	P > 0.05			

Table 4. Characterization of shape and basic parameters of egg quality in in relation to egg freshness quality groups (Haugh Units (HU))

Quality groups in relation to HU (n=100)	Egg mass (g)	Egg albumen (mm)	Egg yolk in the spilled surface (%)	L (mm)	B (mm)	SI (%)	D_g (mm)	Φ (%)	S (mm²)	V (mm³)
I (HU=20–40)	67.74 ± 6.29	2.48 ± 0.40	22.53 ± 6.10	61.34 ± 4.32	47.82 ± 1.91	78.21 ± 4.51	51.94 ± 2.32	84.86 ± 3.26	8532.95 ± 731.79	73166.38 ± 8839.63
II (HU=40–60)	47.60 ± 3.24	2.50 ± 0.33	22.59 ± 2.06	53.81 ± 1.97	42.81 ± 1.23	79.67 ± 4.01	46.19 ± 1.01	85.92 ± 2.85	6790.16 ± 283.92	52168.64 ± 3214.19
III (HU=60–80)	62.06 ± 8.31	4.70 ± 0.61	23.26 ± 5.11	57.76 ± 3.41	46.33 ± 2.75	80.27 ± 3.66	49.85 ± 2.77	86.35 ± 2.62	7874.03 ± 827.54	65171.91 ± 1024.83
P	P > 0.05									

Sensory evaluation

The triangle test did not reveal significant sensory differences in smell and taste that could be observed between eggs with an HU value up to 70 and those with an HU value over 70 (Figure 1). The HU is considered a standard measure of internal quality and indicates oxidative processes during egg storage, which further affect sensory characteristics (*Hisasaga,* 2020). Regardless of the above, the panellists did not find differences ($p>0.05$) in the sensory properties of scrambled egg made from eggs of different freshness.

Comparisons of descriptive sensory characteristics of boiled eggs from different classes (XL-L/S-M) are shown in Figure 2. The average score for the intensity of smell and taste of eggs from group I (XL-L) tended to be higher (i.e., better) compared to eggs

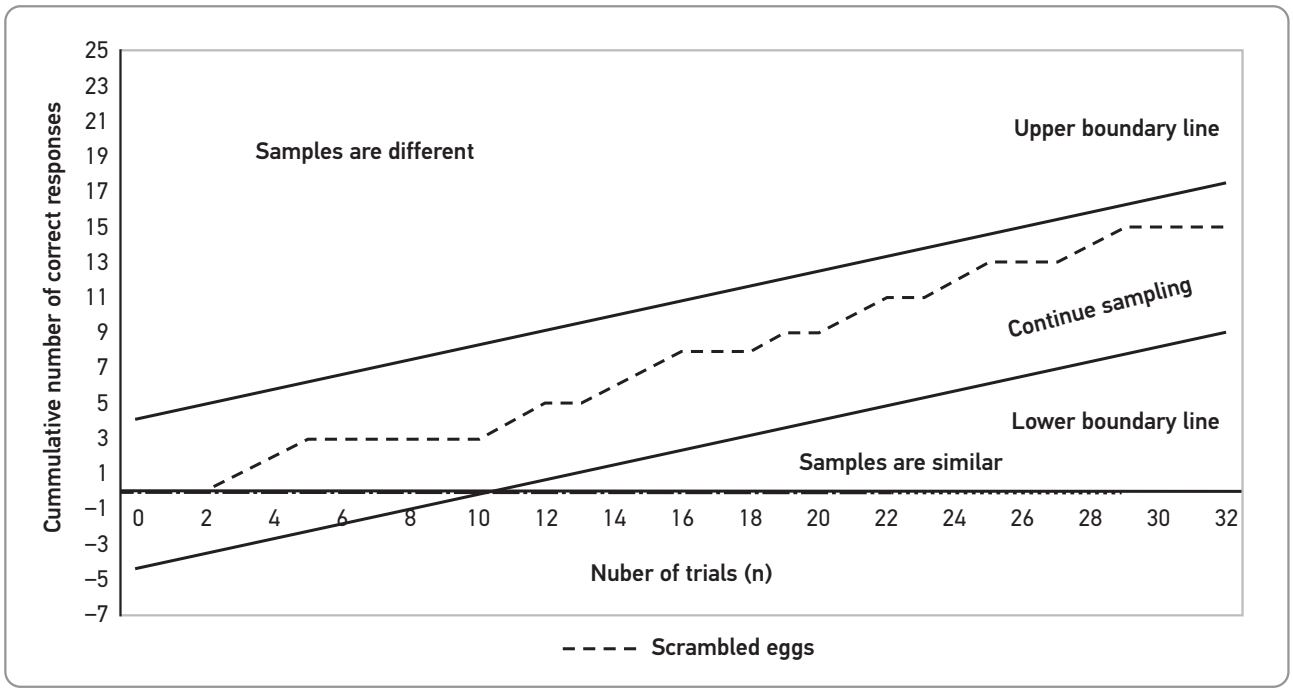

Figure 1. Discriminant triangle test — Differences between scrambled egg groups divided by Haugh Units

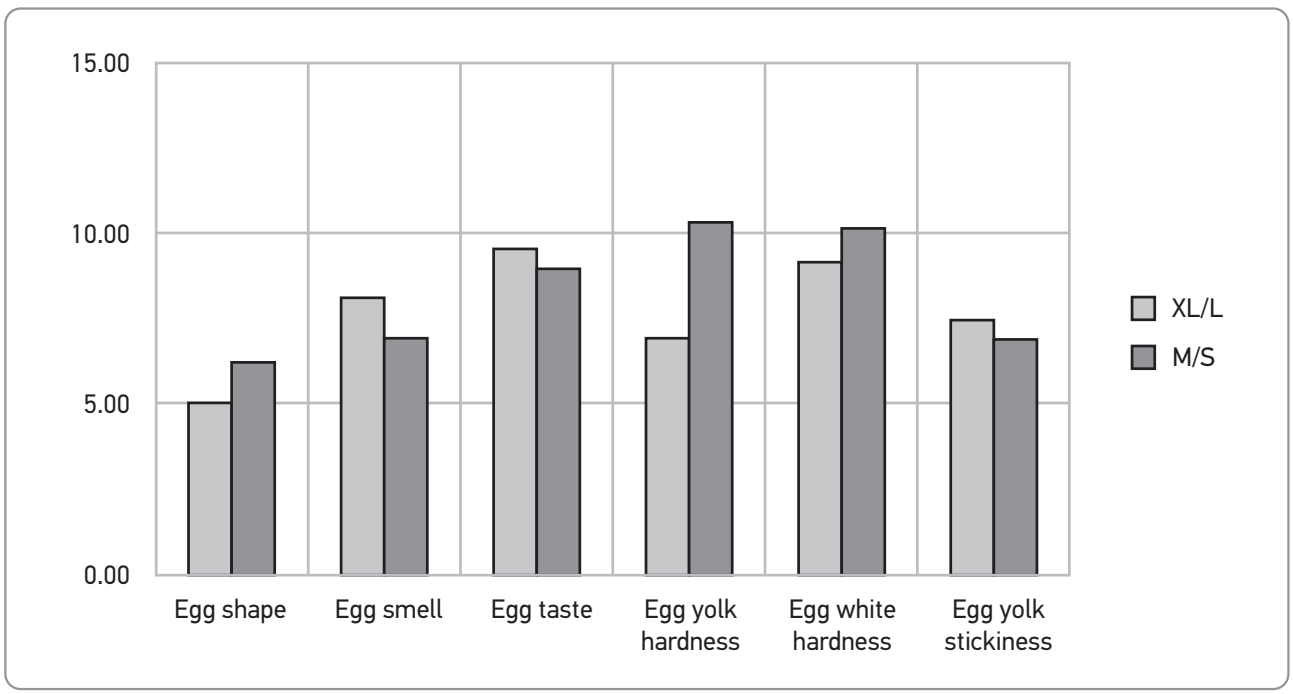

Figure 2. Descriptive characteristics between boiled eggs of different quality classes

from group II. However, the eggs from the second group received a better grade for the visual appearance of the cross-section, and for the hardness of the egg white and yolk. Also, the stickiness of the yolk to the palate was lower in group II eggs (M-S). The results showed there were no statistically significant differences ($p>0.05$) between the compared sensory characteristics in terms of cross-sectional appearance, smell, taste, egg white hardness, or hardness and stickiness of the yolk within the selected egg groups.

Total quality index

Bearing in mind that the higher the HU, the better the quality, authors compared two classes of eggs (HU 20–40; HU 40–60) with the eggs scoring HU above 60, using total quality index where the rule of thumb is "the lower the overall score, the better the overall quality". The introduction of two additional parameters — ΔE egg yolk and ΔE egg white — within the formula shows that TQI of HU 20–40 scored worst (1.732), followed by TQI of eggs with HU 40–60 (0.469). As expected, best score of TQI was for eggs of highest HU value (TQI = 0.111).

Conclusion

As expected, external quality characteristics associated with weight classes do not show any quality pattern as these classes are only perceived by consumers (the bigger the egg the better the quality) with no scientific background.

Opposed to this, the research results indicate that there are differences in colour (egg yolk and egg white) between eggs of different freshness (HU) that the consumers were able to observe. In parallel, the calculation of the total quality index shows that the combination of selected characteristics can give a new dimension in the assessment of egg quality. Opposed to this, the sensory panel did not detect any perceivable differences between these quality groups. Future research should focus on deploying the total quality index using HU and instrumental quality characteristics as a baseline for developing a new quality perspective.

Da li su klase jaja dovoljne, ili nam je potreban indeks kvaliteta jaja?

Marija Mitrović, Igor Tomašević, Ilija Đekić

A p s t a r k t: Ovo istraživanje ukazuje na varijacije u najvažnijim unutrašnjim i spoljašnjim karakteristikama kvaliteta jaja jednog od najvećih proizvođača na srpskom tržištu u odnosu na svežinu (izraženu Hogovim jedinicama (HJ)) i težinske klase (S, M, L, XL). Paralelno, sprovedena je i senzorna evaluacija (za dva najčešća kulinarska načina pripreme) kako bi se utvrdilo da li potrošači primećuju razlike u kvalitetu prilikom konzumiranja kajgane i kako panelisti percipiraju kuvana jaja. S obzirom da je HJ naučno zasnovana dimenzija kvaliteta, za razliku od težinskih klasa koje su zasnovane na potrošnji povezanoj sa veličinom jaja, autori su uveli novi indeks ukupnog kvaliteta koji daje novu perspektivu HJ.

Ključne reči: *kvalitet jaja, indeks ukupnog kvaliteta, klase jaja.*

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