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Qualitative changes occurring during the storage of an innovative beef roulade for senior consumers

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Summary

This study was conducted to assess the nutritional value, textural, sensory, and microbiological characteristics of innovative beef roulade stuffed with groats and vegetables during their storage (21 days). The innovative roulades contained protein 7 %, salt 0.8 %, fat 3.0 %, sugar 0.8 %, and fibre 1.5 %. The storage of the innovative roulade caused increase in the shear force from 23.1 N (1st day) to 25.9 N (21st day). However, on the 21st day of storage, the shear force value of the innovative roulade was more than 2.5 times lower than that of the traditional roulade. The general acceptability, consistency, and taste of the model roulade were rated higher than those of the commercial roulade ($p > 0.05$). On the 21st day of storage, the product was analysed microbiologically and proved to be a low microbiological hazard. The total count of mesophilic microorganisms was $< 4.0 \times 10^1$ CFU·g^{-1}; the count of mesophilic lactic acid bacteria was $< 4.0 \times 10^1$ CFU·g^{-1}; the count of *Listeria monocytogenes* was $< 1.0 \times 10^1$ CFU·g^{-1}; was no *Salmonella* spp. in 25 g. The texture and nutritional value of the model roulade were adapted to the needs of elderly consumers and received high ratings from them for sensory acceptability.

Keywords

innovative beef roulade; elderly consumers; physicochemical properties; texture; microbiological analysis; sensory evaluation

According to the European Union's policy on the quality and promotion of food products, one of its priorities is to cultivate local traditions and customs. The EU member states have regulations promoting food produced with traditional methods and from local ingredients. Elderly people fit well into this trend as they are a large group of consumers of such products. As they have well-established dietary preferences [1], they are more likely to stick to their traditional dietary habits and products. The regular consumption of meat and dairy products is an example of such an approach to the daily diet.

The beef roulade is a traditional Polish meat dish. The Organisation for Economic Co-operation and Development (OECD) and the Food and Agriculture Organisation (FAO) published a report [2] in which they predicted that in high-income countries, where meat consumption per capita is high, the demand for meat would stabilise or decrease slightly due to the ageing of the population and the fact that consumers search for a greater variety of protein sources. In the last decade, global beef consumption has been about 6 kg per capita. According to the report, by 2032, global beef consumption will have increased by 10 %.

Meat and meat products are highly nutritious foods with a rich sociocultural and culinary tradition. They are a good source of high-quality protein, minerals and trace elements (e.g. haem iron, zinc, selenium), vitamins (e.g. B vitamins), long-chain fatty acids (e.g. eicosapentaenoic acid and docosahexaenoic acid), and bioactive compounds

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(e.g. choline, carnitine, carnosine, and anserine) [3]. Due to the fact that meat is characterised by high protein digestibility as well as micronutrient density and bioavailability, regular consumption of even moderate amounts of meat contributes to dietary 'robustness'. It reduces the risk of micronutrient deficiencies and the need for supplementation, especially at critical life stages [4].

Meat and meat products belong to the group of foods where texture is the dominant qualitative trait. However, elderly people often have chewing or swallowing difficulties caused by age-related changes in the anatomy and physiology of their bodies. Typically, these problems are the result of a progressive loss of sensory perception and appetite and decreased salivation (xerostomia). Other common changes exacerbating these difficulties are the decline in skeletal muscle mass (sarcopenia), the decreased bone mass and strength caused by osteoporosis, and gastrointestinal alterations. In consequence of these changes, elderly people may avoid dishes that are difficult to consume. This may lead to deficiencies of some nutrients and malnutrition [5]. Therefore, it is necessary to carefully consider every possibility of reducing the hardness of a meat product for elderly people, who have dental problems and impaired ability to chew and swallow. The texture of a meat product can be softened with some well-established methods such as thermal treatment, meat comminution, or high-pressure treatment. Other methods include pureeing, mincing, and softening. However, some of these methods may make the finished product unappetising and lacking sensory appeal. Consequently, they may be discouraging to consumers and reduce their food intake [6].

Thermal treatment is an important step in the conversion of inedible (raw) to edible meat, and it may affect the eating and sensory quality of meat, especially its texture. Thermal treatment causes the denaturation and dissociation of myofibrillar proteins, transversal and longitudinal shrinkage of meat fibres, aggregation and gel formation of sarcoplasmic proteins, and solubilisation of collagen in the connective tissue [7]. Texturing, i.e. modifying the rheological properties of food by comminution, is also often used in the meat industry. This process gives new, desirable rheological properties to food. It causes significant damage to the original structure of meat and thus increases its susceptibility to gelatinisation [8]. It is recommended that foods for consumers suffering from dysphagia should be comminuted into small and tender particles (e.g. < 1.5 mm). The bolus should be moist, cohesive, and slippery to be smoothly swallowed [6].

Both dieticians and food producers are searching for methods to improve the nutritional value and modify or impart new functional properties to meat products. In response to the growing need to increase the share of beneficial substances for the human body in food products, their composition is reformulated. This method is used to reduce the content of ingredients responsible for the occurrence of diet-related non-communicable diseases, e.g. saturated and trans fatty acids, salt, and sugar [7]. However, reformulated food products must be acceptable to consumers. It seems important to select the right raw meat components as well as the additives of vegetables, spices, and herbs (cumin, juniper, sweet paprika, allspice, nutmeg, thyme, ginger, marjoram) in order to achieve the desirable taste and smell that satisfy the consumer. These ingredients not only enhance the taste and aroma of the product but also increase appetite, stimulate the secretion of digestive juices, and improve peristalsis. However, excessive reformulation may modify important properties of meat products, such as yield, texture parameters, colour, microbiological stability, and sensory properties [7, 8].

In view of the fact that beef is nutritious, tastes very good, and has a specific structure of muscle fibres determining its hardness, the authors of this study made an attempt to develop a beef roulade for elderly people with mastication problems, which they could easily and safely consume. At the same time, it was important to develop a model product enriched with vegetables (and thus with fibre) but with a reduced content of fat, salt, and sugar. Apart from that, our goal was to develop a product without stabilisers, flavour enhancers, colourants, or acidity regulators. Our model beef roulade could be an alternative to the traditional beef roulade made from meat with intact tissue structure, but with the texture, sensory, and nutritional parameters adapted to the needs of elderly people.

MATERIALS AND METHODS

Raw material and production technology

The object of our study was a beef roulade stuffed with groats in vegetable sauce. Following the design assumptions, the model ready-meal product was industrially produced according to the current quality standards. The raw materials were: uncured beef (bottom side, demembraned), vegetables (celery, leek, parsnip), starch additives (couscous and barley groats), salt, and spices.

There were two variants of the finished

product, which differed in the technique of raw meat processing. At the initial stage of the technological process, raw meat for the beef roulade was prepared. Half of the raw meat was used for the production of roulades with an intact tissue structure – a commercial product (Poland). The vegetable filling of the commercial roulade consisted of smoked bacon and pickled cucumber. In the second variant, in order to obtain a model product, the raw beef and carrots were initially minced in a grinder, through a sieve with a mesh diameter of 5 mm. Next, they were additionally minced in a bowl chopper, where water, rapeseed oil, and salt were added. At the same time, the beef roulade filling was prepared. It consisted of selected proportions of couscous, barley groats, vegetables, and spices. Following the recipe, the correct proportions of the meat filling and vegetable filling were used to automatically form the beef roulade through co-extrusion in a specialised device. The vegetable sauce consisted of potatoes, carrots, celeries, leeks, and parsnips. After pre-grinding, the vegetables were stewed with spices in a boiling pan. Then, they were ground in a continuous cutter in order to obtain a homogeneous mass. The model and commercial products were packaged in a thermostable polystyrene tray to ensure the oxidative stability of the product. After the tray had been automatically closed with a barrier film, the product was heated at 95 °C for 50 min to ensure its microbiological safety within the assumed shelf life. The manufacturer keeps the detailed composition of the ingredients and parameters of the technological process secret.

Basic chemical composition

The content of the following components in the beef roulades was analysed: protein [9], fat, sugars and sodium chloride [10], saturated fatty acids [11], and dietary fibre [12].

The total carbohydrate content was calculated according to the formula:

$$X_1 = 100 - (W + F + P + A) \quad (1)$$

where X_1 is total carbohydrates, W is water, F is fat, P is protein and A is ash. All parameters are expressed in percent.

Product energy value

The energy value of the products was calculated with the conversion factors specified in Annex XIV of the Regulation (EU) No. 1169/2011 [13] (carbohydrate 17 $kJ \cdot g^{-1}$ or 4 $kcal \cdot g^{-1}$; protein 17 $kJ \cdot g^{-1}$ or 4 $kcal \cdot g^{-1}$; fat 37 $kJ \cdot g^{-1}$ or 9 $kcal \cdot g^{-1}$; fibre 8 $kJ \cdot g^{-1}$ or 2 $kcal \cdot g^{-1}$).

Textural properties

The texture of the tested samples was instrumentally assessed with a TA-XT2i Texture Analyser (Stable Micro Systems, Godalming, United Kingdom). A shear test was carried out to determine the maximum shear force value (expressed in newtons) and shear work (expressed as newton·seconds). A type blade set HDP/BS Warner-Bratzler blade (Godalming, United Kingdom) was used for this purpose. The following settings of the texture analyser were used: test speed 1.5 $mm \cdot s^{-1}$; distance 70 mm; trigger force 20 g; data were acquisition rate 200 measurement points per second. The whole roulades (diameter – about 50 mm) were subjected to the shear test. For the texture tests, the samples were heated to about 55 °C (± 2 °C).

Sensory analysis

The sensory attractiveness of the products was evaluated by consumers according to the following hedonic scale: I love it – 9 points; I like it very much – 8 points; I mostly like it – 7 points; I quite like it – 6 points; I neither like nor dislike it – 5 points; I don't like it a little – 4 points; I mostly don't like it – 3 points; I really don't like it – 2 points; I hate it – 1 point. Both the overall acceptability of the product and the acceptability of individual characteristics (appearance, colour, aroma, taste, consistency, overall acceptance) were evaluated. The products were evaluated by a group of 15 consumers (7 men and 8 women) who had not received any sensory training. The consumers' age was a criterion for the selection of members of the group. The average age of the evaluators was 67 years. The products were heated for the evaluation of their sensory characteristics.

Microbiological analysis

The following methods were used for the microbiological analysis of the model beef roulade: the total count of aerobic mesophilic microorganisms [14], the presence of *Salmonella* spp. [15], the presence of *Listeria monocytogenes* [16], and the count of mesophilic lactic acid [17].

Statistical analysis

The Statistica 13.1 software (StatSoft, Tulsa, Oklahoma, USA) was used for statistical analyses. Differences were considered significant at $p < 0.05$. The distribution of variables was examined with the Shapiro-Wilk test. Multivariate analysis of variance (ANOVA) was used to assess the effect of the storage time and sample type on changes in the texture characteristics of the samples. Tukey's test was used for pairwise comparisons of means for significant factors. Principal component analysis (PCA) was used to visualise the data and detect interdependencies between variables.

RESULTS AND DISCUSSION

Basic composition and nutritional value

The content of basic ingredients and the nutritional values of the innovative beef roulade and the commercial product are shown in Tab. 1. It is important to note several significant differences between the products. The energy value of the commercial roulade was 486 kJ (116 kcal) and was higher than that of the innovative roulade. It is most likely that this effect resulted from the fact that the fat content in the developed product (3.0 %) was twice lower than in the traditional roulade (6.0 %). It is also significant that the amount of saturated fatty acids in the innovative roulade was twice lower than in the commercial product. The higher content of carbohydrates (7.5 %) and the presence of fibre (1.5 %) in the innovative roulade resulted from the high content of couscous, barley groats, and vegetables. However, the high content of plant ingredients may have reduced the protein level in the roulade to 7.0 %. It is important, not only for elderly consumers, to reduce the consumption of salt and simple sugars. Although the amount of salt and sugar (per 100 g of product) in the innovative roulade was respectively 0.9 g and 0.8 g lower than in the traditional product, no undesirable changes in the sensory properties of the product were observed. The elimination of smoked bacon and pickled cucumber from the vegetable filling formulation likely contributed to a reduction in the sodium and fat content of the model product.

The recipe and technology of production of the innovative beef roulades are consistent with general nutritional recommendations for elderly consumers [18]. According to the recommendations for proper nutrition of this group of consumers, three basic principles should be met: a variety of products and dishes, regular consumption of meals, and energy balance. In order to meet senior consumers' demand for carbohydrates, simple carbohydrates in their diet should be replaced mainly by complex ones, but with a moderate supply of rich sources of dietary fibre. The daily fibre intake should be about 25 g. Fatty acids should provide up to 10 % of energy, whereas essential unsaturated fatty acids should provide 4–8 % of energy [19]. Elderly people's demand for protein is also different. The supply of protein in their diet should be 15–20 %. The daily protein intake of seniors with chronic diseases should be 1.2–1.5 $g \cdot kg^{-1}$ of body weight. Those suffering from serious diseases, injuries or malnutrition need a daily protein intake of up to 2.0 $g \cdot kg^{-1}$ of body weight [20]. Elderly people should, above all, consume complete protein from animal products, including lean meats, cold cuts, and dairy products with reduced fat content, which cover half of their total demand for protein. Seniors should also limit the sodium intake in their diet due to the risk of water accumulation in the body, which may lead to oedema, hypertension, and other cardiovascular diseases [21].

Texture analysis

When biting meat, its hardness is a critical factor, especially for elderly consumers. The raw

Tab. 1. The ingredients and nutritional values of the innovative beef roulade with groats in vegetable sauce and the commercial product – a commercial specification.

Ingredients	Type of sample			
	Model product		Commercial product	
	Value	*RI* [%]	Value	*RI* [%]
Energy	370 kJ (88 kcal)	4	486 kJ (116 kcal)	6
Fat including:	3.0 g	4	6.0 g	9
– saturated fatty acids	1.2 g	6	2.4 g	12
Carbohydrates, including:	7.5 g	3	6.3 g	2
– sugar	0.8 g	1	1.3 g	1
Dietary fibre	1.5 g	6	0.5 g	2
Protein	7.0 g	14	9.0 g	18
Sodium chloride	0.9 g	15	1.2 g	20

Values per 100 g of product are given.
RI – reference intake for an average adult (8 400 kJ or 2 000 kcal).

material was initially minced in a grinder in order to obtain the desired tenderness and size of the muscle tissue fragments. Then, it was minced in a bowl chopper and finally formed through co-extrusion in a special device.

Fig. 1 shows the shear force values of the model roulades during the storage period. On the 1st and 7th days of storage, there were no statistically significant differences in the shear force, whose average value was 22.7 N. On the 14th and 21st days, there was a small but statistically significant increase in the hardness of the samples, i.e. 24.8 N and 25.9 N, respectively ($p < 0.05$).

The shear force, as a physical parameter, is a component of the force that needs to be applied to cut the textured beef and vegetable filling placed inside the roulade. The total hardness of the roulade as a culinary dish was undoubtedly influenced by the beef and vegetable filling inside. Polysaccharides contained in plant materials, alone or in interaction with proteins, can create a network that traps water and prevents its release [22]. The hydrated additives had a positive effect on the hardness of the roulades. They also caused a favourable sensory experience of high humidity of the samples. Meat juiciness strongly affects the consumer's satisfaction with food. Undoubtedly, it is particularly important for elderly consumers. This fact was confirmed by the sensory panel. A slight increase in the hardness of the samples on the 14th and 21st days of storage may have been caused by the release of some water from the plant ingredients and from the textured meat.

The extent of cooking loss from meat and meat products depends primarily on the parameters of heat treatment, the quality of the raw meat used (e.g. type and quantity of proteins, fat), as well as the functional additives applied (e.g., fibre and starch) [23]. The mechanical properties of cross-linked systems result not only from changes in their molecular structure caused by thermal treatment but also from the reorganization of the system during storage [24].

The attributes of meat texture are based on several components: mechanical properties, geometric properties, and the water and fat content of the samples. The mechanical characteristics are defined when meat samples respond to stress, e.g. when being chewed. The geometric properties refer to the size, shape, and orientation of the product before and while it is being bitten. The other two elements, i.e. moisture and fat content, are determined by mouthfeel and are related to juiciness [25]. It is noteworthy that the model roulade was characterised by a lesser shear force and shear work and lower fat content than the commercial product. At the same time, thanks to the meat texturisation process, it is easier to cut the product into smaller pieces, which is important for elderly consumers.

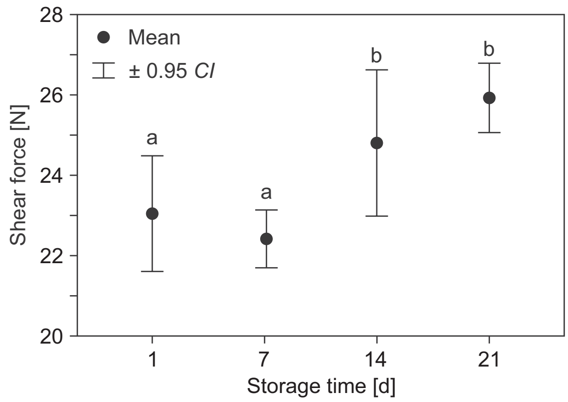

Fig. 1. The shear force of the model beef roulade vs its storage time.

Different letters above segments indicate a significant difference at $p < 0.05$ ($n = 4$).
0.95 *CI* – 95% confidence interval.

The work that needed to be applied to cut the model roulade was also measured (Fig. 2). Similarly to the shear force, the first two storage periods were characterised by lower values (on average 572.4 N·s) than the next two. The highest value, which was statistically different from the others ($p < 0.05$), was measured on the 14th day of storage (694.7 N·s). On the 21st day, the shear work value decreased to an average of 601.3 N·s, which was similar to the first two periods ($p > 0.05$). In general, the shear work

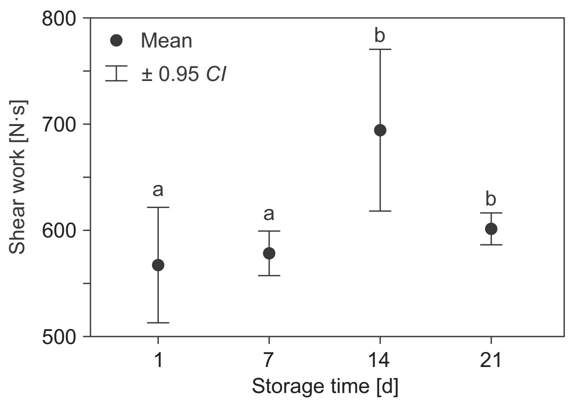

Fig. 2. The shear work of the model beef roulade vs its storage time.

Different letters above segments indicate a significant difference at $p < 0.05$ ($n = 4$).
0.95 *CI* – 95% confidence interval.

values correspond to the direction of variation in the shear force values of the sample. Presumably, a lower shear force value will result in a lower work value. This should translate into better sensory experiences because less force will have to be used to bite off and chop up pieces of meat. Additionally, consumers will have to move their jaws at a lower frequency to achieve the desired size of the chunks of the product.

A soft texture, which is easy and safe to chew/swallow, results in a better sensory experience for elderly consumers. The maintenance of appropriate moisture is an important feature of minced meat products with modified texture. Meat tenderness is a critical factor in the oral processing and forming of a food bolus, especially for people suffering from dysphagia. An increase in the hardness of the tested samples does not always affect the number or duration of the chewing cycle. However, the distribution of the size of the chewed food chunks is significant because it increases along with the hardness of the sample [26].

In order to compare the properties of the texture of the industrially produced innovative roulades, the mechanical properties of the traditional roulade were also analysed on the 1st and 21st days of storage. The results are shown in Fig. 3. The average value of the shear force that had to be applied to cut the commercial roulade on the 1st day of storage was 49.1 N, whereas on the last, i.e. the 21st day of storage, it increased by a third, up to 63.6 N ($p < 0.05$). By comparison, the average shear force value of the model roulade on the 1st day was slightly more than two times smaller than the shear force measured in the commercial sample. On the last day of storage, the shear force was more than 2.5 times smaller. The analysis of the shear work revealed a very similar trend of changes.

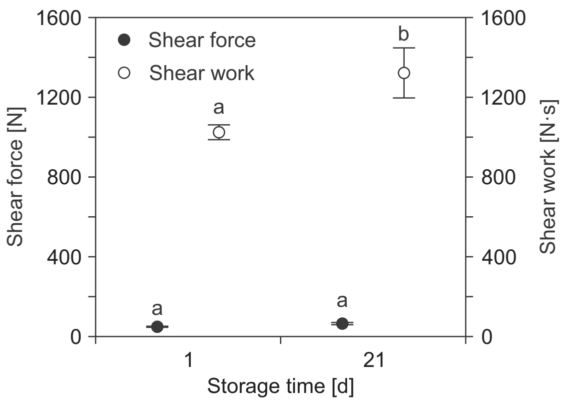

Fig. 3. The texture parameters of the traditional roulade.

Different letters above segments (separately for shear force and shear work) indicate a significant difference at $p < 0.05$ ($n = 4$).

Unlike meat in its native form, minced meat does not have an anisotropic structure. The comminuted muscle fibres are unevenly distributed throughout the sample volume. The stresses occurring during shear force tests cause damage and the division of both individual muscle fibres and fibre bundles. These stresses are distributed through the gelled protein hydrocolloid, which forms spatial matrices binding all the ingredients of the meat filling. Its elastic properties are determined by the density of the network segments. As the storage time increases, so does the degree of cross-linking of the spatial protein matrices [27]. This is due to the formation of new nodes of the spatial structure as a result of connections between adjacent macromolecular segments formed by low-molecular protein fractions. This effect may be accompanied by the displacement of water from the network. All these structural changes contribute to the formation of a denser system, resulting in greater elasticity of the meat. In restructured products, hardness determines the strength of bonds between individual elements of the structure. It is a measure of the compactness of the system, which is conditioned by the density of the segments of the spatial protein matrices that bind them. Therefore, the greater the elasticity of the system is, the harder the system is [28].

In the production of comminuted meat products (restructured roulades), the functional properties of muscle proteins determined by their quantity and type (especially myofibrillar and stromal proteins) are of major importance. These proteins are responsible for interactions within the water-protein system (water-binding capacity), for protein-fat associations (fat emulsifying capacity), and for protein aggregation processes (gelling ability) [29]. In all these processes, collagen proteins, as well as starch-based additives and dietary fibre used in product formulation, play a significant role. During meat texturization, muscle fibres, including collagen fibres, are cut and dispersed, thereby losing their structural integrity. As a result, the hardness of the raw material decreases. The finer the degree of comminution, the faster the hydration of collagen and the more efficient its thermal transformation. At the same time, comminution increases the surface area available for protein–water interactions, facilitating improved incorporation of collagen into the product structure through the formation of a dense protein matrix. This process may also

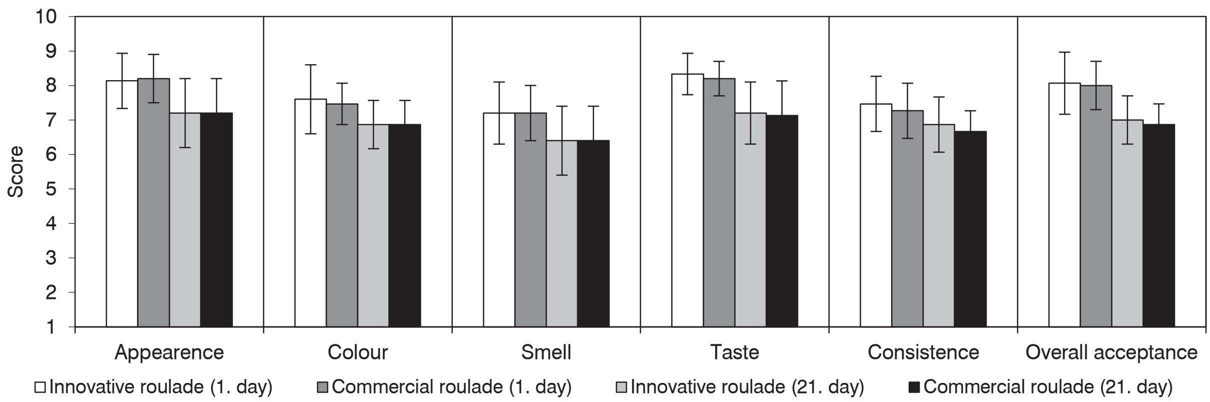

Fig. 4. The preferences of the target group of consumers concerning the two beef roulade variants.

Values are expressed as mean ± standard deviation (n = 15).

enhance water retention following gelatinisation [30].

The roulades contained a vegetable stuffing (as a source of dietary fibre) and starch additives in the form of couscous and pearl barley. In meat products, dietary fibre and collagen do not participate in classical chemical reactions; however, they exhibit functional and technological correlations. Both components interact within the same protein-water matrix of the product, influencing texture, water retention, and processing yield. After collagen gelatinisation, the two components may act synergistically, increasing overall water retention. Collagen reinforces the protein structure, while dietary fibre binds water at the microscale level, collectively improving the textural and technological properties of the final product [31].

Sensory evaluation

Organoleptic (sensory) quality is a range of factors that affect meat marketability. Some of these factors are more important at the moment the meat is being purchased, e.g. the colour of the meat and the fat content. Others become more important once the meat has been cooked, e.g. flavour and tenderness. During consumption, meat acceptability is mainly determined by the perception of its texture, i.e. tenderness and juiciness. It is important for consumers, meat producers and processors to understand the mechanisms underlying such perceptions. Besides visual cues, the perception of meat texture in the mouth, when the product is being chewed and transformed, is also important [6].

The model beef roulade with vegetables and sauce was assessed after being heated, in accordance with the usual way lunch dishes are consumed. The traditional beef roulade in sauce, formed from slices of beef with intact tissue structure, was also assessed. Semi-consumer evaluations were made in the assumed storage periods. They enabled verification of the degree of acceptability of the model beef roulades within the assumed shelf life. As the results of the sensory evaluation of the roulades on the 7th and 14th days of their storage were very similar, the results of the evaluation on the 1st and 21st days of storage were presented in this manuscript. On the 1st day of storage, the two types of roulades were characterised by similar ratings of general acceptability (Fig. 4). The best ratings of taste, appearance, and general acceptability were recorded in the initial storage period.

The results of the sensory evaluation showed that both beef roulades were generally accepted and the determinants of their sensory quality were rated very similarly. There were some differences in the ratings of general appearance, taste, and aroma, but they were not statistically significant ($p > 0.05$). The rating of appearance is particularly important because consumers are used to a specific shape of a product or the way it is served. These are habits rooted in individual's sensory memory and tradition. Sometimes consumers may find the appearance (shape, form) of a product so strongly unacceptable and discouraging that they are reluctant to continue consumption or negatively perceive the other sensory characteristics of the product.

One of the sensory quality characteristics differentiating the beef roulades was consistency. The consistency of the innovative roulade was rated higher than that of the commercial product, but the difference was not statistically significant ($p > 0.05$). However, the result of the sensory evaluation of this indicator is significant in view of the design assumptions allowing for the needs of elderly consumers with biting and food crushing limitations. Following these assumptions, as well as on the basis of the low values of texture parameters, which were measured instrumentally, it is possible to conclude that it is unlikely that seniors will have problems consuming the innovative product.

While food is being chewed, it is broken into pieces by compressive and shear bite forces as saliva is involved in the process. The resulting mixture is shaped into a cohesive bolus by the agglomeration of small particles to trigger a swallow. The bolus formation basically depends on the chewing activity. During healthy ageing, the chewing behaviour and chewing efficiency evolve and induce changes in meat boli properties. When mastication is impaired because of ageing, as is the case with denture wearers, the chewing efficiency is considerably reduced [32]. For this reason, meat is usually one of the most rejected foods.

As can be seen in Fig. 4, in the last storage period, the sensory quality characteristics of the model beef roulade show that the product received positive ratings from the consumers. The evaluators had similar preferences for the model beef roulade and the traditional beef roulade. It is noteworthy that the model beef roulade was rated higher for its overall acceptability, consistency, and taste, though the difference was not statistically significant. It is important for the adaptation of the product to the consumers' needs.

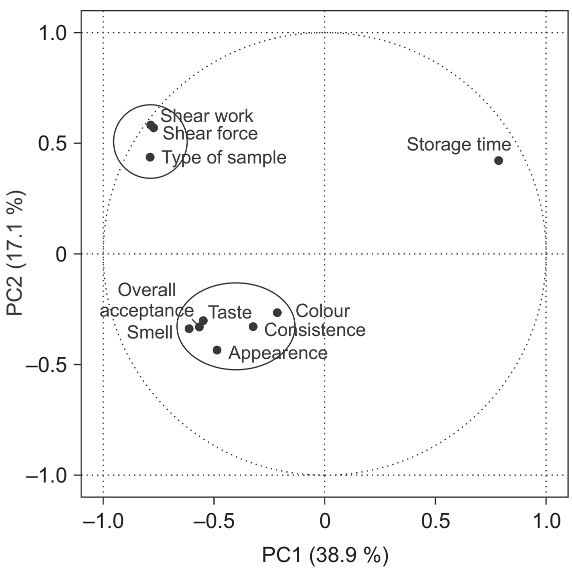

Fig. 5. The results of the principal component analysis and loadings of selected beef roulade characteristics vs the sample type, preparation method, and storage time (n = 60).

Principal component analysis

Fig. 5 shows the results of the PCA based on correlation. The PCA was conducted for the two beef roulades (1 – model roulade; 2 – traditional roulade) stored for 21 days (1, 7, 14, 21). The PCA was based on all results obtained for the following determinants: shear force, shear work, overall acceptance, appearance, colour, aroma, taste, and consistency. PC1 (38.9 %) and PC2 (17.1 %) explained 56.1 % of the total variance. Although the cumulative variance of the first two components is relatively low, further analysis showed that PC3 accounted for only 8.8 % of the variance, with an eigenvalue below 1.0. This suggests that the remaining unexplained variance (43.9 %) results from the inherent biological variability of the meat matrix and the subjective nature of sensory evaluation rather than overlooked structural trends. The results of the shear force and work and the type of sample are in a separate cluster, which is negatively correlated with the determinants of sensory characteristics and storage time. Specifically, storage time is positioned along the positive axis of PC1, opposite to the majority of quality attributes, indicating a clear time-dependent degradation. The signs of loading show higher values of the determinants of quality characteristics for the model roulades. By contrast, the traditional roulades were characterised by higher values of the shear force and shear work.

Microbiological analysis

Consumers need to be guaranteed that meat products are safe, wholesome, and will not cause any health problems. This can be achieved through better management of farm animals, good personal hygiene and by providing adequate knowledge on food safety to all meat handlers in the production chain. The low microbiological quality of beef is caused by (pathogenic) bacterial contamination during primary production, as well as inadequate hygiene in the farm-to-fork chain. Therefore, it is extremely important to subject the finished product to adequate heat treatment or to use the hurdle method, especially for products containing minced meat. In Europe alone, each year, the consumption of raw or undercooked meat is responsible for 2.3 million cases of foodborne illnesses [33].

This manuscript does not provide detailed results of microbiological tests of the model beef roulades due to the specific hurdle methods used in the production plant; the manufacturer's food safety and quality assurance systems are confidential. The results of microbiological analyses conducted on the last day of storage (21st day) showed that the microbiological contamination of the model beef roulade was low and the product was safe for consumers. The total count of mesophilic microorganisms was < 4.0×10^1 CFU·g^{-1}; the count of mesophilic lactic acid bacteria was < 4.0×10^1 CFU·g^{-1}; the count of *Listeria monocytogenes* bacteria was < 1.0×10^1 CFU·g^{-1}. There were no *Salmonella* spp. bacteria in 25 g.

It is noteworthy that there is only one official regulation concerning the microbiological quality of meat preparations in the food safety legislation – there must be no *Salmonella* spp. in 25 g of minced meat and meat preparations intended for consumption after thermal processing. The legislation does not provide any legal requirement for the microbiological safety of ready-to-eat meat preparations [34]. According to the guidelines of good manufacturing practice, the total microbiological contamination of raw meat and raw meat preparations should not exceed 10^5 CFU·g^{-1} (maximum 10^7 CFU·g^{-1}). In thermally processed meat products, the contamination must not exceed 10^4 CFU·g^{-1}. The contamination of raw meat and raw meat preparations with *Escherichia coli* should not exceed 10^2 CFU·g^{-1} (maximum 10^4 CFU·g^{-1}). The contamination of meat products with *Enterobacteriaceae* and *Escherichia coli* should not exceed 10^2 CFU·g^{-1} (maximum 10^4 CFU·g^{-1}) and 10 CFU·g^{-1} (maximum 10^3 CFU·g^{-1}), respectively [35]. The tested product met the microbiological safety requirements.

CONCLUSIONS

The favourable characteristics of the model beef roulade, tailored to the needs of older adults in terms of textural properties and nutritional value, achieved a high level of sensory acceptance among senior consumers. The high tenderness of the innovative roulade resulted primarily from the applied beef restructuring process. Texturised beef containing natural collagen, together with the addition of vegetables (including cereal products) rich in dietary fibre, allowed for greater water retention in the model product compared with the commercial roulade. This contributed to the desirable perception of consistency and overall acceptance of the innovative product. From a nutritional standpoint, an important advantage of the developed product is the reduced fat and salt content, accompanied by an increased proportion of dietary fibre. At the end of the assumed shelf-life period, the recommended limit for total bacterial count was not exceeded, indicating that the developed product does not pose a health risk to consumers. As a ready-to-eat product, the developed roulade may serve as a convenient main meal, facilitating the daily functioning of older adults while simultaneously addressing their specific nutritional requirements.

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