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Preservation of squeakiness and exploring consumer perception of geographical origin of Lički škripavac cheese

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Abstract

Lički škripavac is a PGI protected traditional Croatian soft, unripened cheese characterized by rubbery, pliable texture and distinctive squeaking property during consumption that diminishes over storage. This study evaluated the effect of hot-water submersion of vacuum-packed cheese (50 °C for 2 min) on the preservation and restoration of squeakiness throughout its shelf life, and examined consumer perception of its geographical origin. Cheeses from a single batch were randomly divided into three groups based on hot-water treatment: (1) control - no submersion, (2) submersion immediately after production, and (3) submersion immediately prior to analysis. All groups were evaluated at 0, 14, and 28 days of storage. Texture profile analysis was performed, and squeaking intensity was assessed by trained sensory panellists, while consumer perception and purchasing habits were investigated through a structured survey. Hardness parameters increased significantly during storage in all treatments ($p<0.01$). Hot-water submersion applied immediately before analysis significantly reduced hardness values ($p<0.05$). Sensory evaluation confirmed that this treatment produced the highest squeaking intensity scores ($p<0.01$). Survey results showed that most consumers (77 %) associate Škripavac cheese with the Lika region, consistent with its PGI status, while consumption and purchase frequency were generally monthly or rare across age groups. The results indicate that brief hot-water submersion prior to consumption is a simple and practical measure to restore squeakiness and support the maintenance of the key sensory attribute of PGI Lički škripavac cheese during its declared shelf life.

Keywords: Lički škripavac cheese; squeakiness; texture; sensory analysis; consumers' perception; Protected Geographical Indication (PGI)

Introduction

The process of globalization, particularly the liberalization of international trade in agricultural products, has significantly influenced the agricultural policies of individual EU member states. As a result, most European countries have acknowledged the necessity of protecting indigenous cheeses as a means of supporting domestic producers and preserving traditional food heritage (Samaržija and Antunac, 2002). As part of its food quality policy, the European Union (EU) promotes three official quality schemes for agricultural products and foodstuffs: Protected Designation of Origin (PDO), Protected Geographical Indication (PGI), and Traditional Specialty Guaranteed (TSG). The primary objective of the EU's quality policy is to safeguard the names of specific products in order to highlight their unique characteristics, which are intrinsically linked to their geographical origin and traditional production methods (European Commission). PDO, PGI, and TSG designations play a crucial role in the protection and promotion of traditional cheeses by ensuring their authenticity and traceable origin for consumers. In recent years, consumer interest in cheeses produced in limited quantities, originating from well-defined regions and manufactured using traditional or specific production methods has increased. Nevertheless, price remains the predominant factor influencing purchasing decisions. Studies have shown that the combined use of different food quality labels can positively affect consumer perception by reinforcing associations with quality, authenticity, and origin (Claudia and Mendes, 2018; Menozzi et al., 2022).

Owing to its specific geographical characteristics, Croatia, although a relatively small country, possesses a rich heritage of production of traditional cheeses, including several cheeses protected by PDO and PGI quality schemes (Barukčić and Tudor Kalit, 2019). Three distinct climatic zones strongly influence cheese characteristics and production technologies. Along the Adriatic coast, the Mediterranean climate favors sheep farming and the production of hard sheep's milk cheeses such as PDO Paški cheese (Wendorff and Kalit, 2017), Krčki cheese (Antunac et al., 2008), PDO Istrian sheep's milk cheese (Magdić et al., 2013), Brački cheese (Rako et al., 2022), and whey sheep's milk cheese Skuta (Rako et al., 2018). In contrast, continental Croatia is characterized by unripened cow's milk cheeses, including Zagrebački svježi sir (Tratnik, 1980), Kuhani cheese (Kirin, 2006), Preveli cheese (Dolenčić Špehar et al., 2018), and cone-shaped dried cheeses such as PDO Bjelovarski Kvargl (Valkaj, 2013a). Despite their geographical proximity, there is limited interaction between these two climatic zones, primarily due to the mountain range that functions as a natural barrier separating the Mediterranean and continental regions of Croatia. Within this transitional mountainous area of Lika and Kordun, Lički škripavac cheese is traditionally produced as a full-fat, soft, unripened, rindless variety at the farm level and in small-scale dairy plants (Figure 1).

Lički škripavac cheese is characterized by its rubbery and pliable texture and, most importantly, by its characteristic squeaking sensation during consumption. Traditionally, it can be produced using two different salting methods, dry



Figure 1. Schematic division of Croatian territory according to cheese-making heritage

salting of curd grains or salting of milk prior to coagulation. Cheeses produced from milk salted before coagulation exhibit higher water content, lower protein content, and higher pH values compared to those made from salted curd grains. Furthermore, these cheeses demonstrate higher milk fat recovery as well as greater actual and adjusted yields. In terms of textural properties, cheeses produced by salting the curd grains are firmer, less crumbly, and less elastic than those produced by salting the milk (Ivaniš et al., 2024).

Although classified as a soft cheese, the production of Lički škripavac involves an atypical technological step, namely intensive cheese grain cooking (up to 45 °C) following moderate whey drainage, combined with the absence of fermentation and ripening (Kalit et al., 2021). This specific process results in the formation of a dense protein network responsible for the distinctive squeaking property (Magdić et al., 2006). Squeakiness occurs when the protein matrix resists compression during mastication and subsequently rebounds, generating vibrations perceived as an audible squeak (Johnson, 2016). This can be supplemented by research of Nurkkala et al. (2024) who found that shear forces created by the teeth when biting cheese produced audible squeaks amplified by cheese cavities which served as a resonating chamber. This sensory attribute is reflected in the cheese's name (the Croatian verb "škripiti" means "to squeak") and represents its defining characteristic and the basis for its PGI protection.

An empirical survey of producers and consumers revealed that Lički škripavac exhibits its most pronounced squeaking attribute within the first 5-7 days following production. When vacuum-packed and stored at 4-8 °C, the squeaking property gradually diminishes during storage, despite the cheese retaining microbiological and sensory freshness for up to one month. This loss of squeakiness is primarily attributed to the weakening of calcium–protein bonds within the protein matrix

(https://foodsci.wisc.edu/squeakiness-of-cheese/). Since PGI certification requires that a product maintains its distinctive characteristics throughout its declared shelf life, the reduction of squeakiness represents a significant technological and regulatory challenge for Lički škripavac cheese. Thermal treatments have been shown to promote the reformation of calcium-protein interactions within the cheese matrix, thereby potentially restoring squeakiness (https://foodsci.wisc.edu/squeakiness-of-cheese/). Consequently, exploring simple and technologically feasible post-packaging treatments may offer a solution for preserving the characteristic squeaking texture of Lički škripavac cheese during storage, since retention of this defining sensory attribute was essential for maintaining its EU Protected Geographical Indication (PGI) status.

Therefore, the primary objective of this study was to evaluate the effect of submerging vacuum-packed Lički škripavac cheese in warm water (50 °C) for 2 min on the preservation and restoration of its characteristic squeakiness throughout its shelf life, assessed through instrumental texture analysis and consumer sensory evaluation. A secondary objective was to investigate consumer perceptions of Lički škripavac cheese in relation to its geographical origin, considering increasing production of this type of cheese outside the traditional PGI-defined area, where it is marketed under the name Škripavac without reference to the term "Lički," which denotes geographical origin.

Materials and methods

Vacuum-packed Lički škripavac cheeses (n = 18) were obtained from a single production batch at the main cheese-making facility located in the town of Otočac (Lika region, Croatia). Cheeses were produced from full-fat milk. The average composition of cheese per 100 g written at the nutritive label was: fat 25.9 g, saturated fatty acids 19.3 g, proteins 20.1 g, carbohydrates 2.4 g, salt 0.74 g. The cheeses had a declared shelf life of 28 days at refrigeration temperature. Cheeses were randomly assigned to three experimental groups based on the hot water submersion treatment: i) Treatment 1 (control): vacuum-packed cheeses not subjected to hot water submersion and analyzed during shelf life (at days 0, 14, 28), ii) Treatment 2: vacuum-packed cheeses submerged in hot water (50 °C for 2 min) immediately after production (day 0), then stored at 4–8 °C for 28 days and analyzed at days 0, 14, and 28, iii) Treatment 3: vacuum-packed cheeses stored without initial treatment (same as the control) and submerged in hot water (50 °C for 2 min) immediately prior to each analysis (days 0, 14, 28) (Figure 2). Thus, the experimental design differed in the timing of hot water submersion relative to storage time (Figure 2).

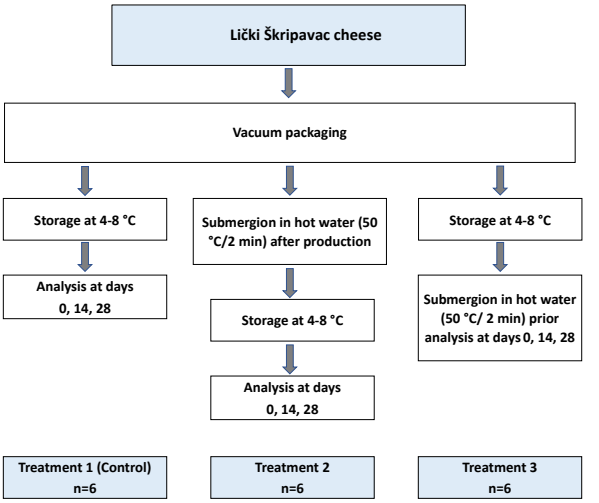


Figure 2. Experimental design according to hot water submersion treatments (50 °C for 2 min) during storage

Texture analysis

Texture profile analysis (TPA) was carried out using a two-bite compression test with a TA Plus Texture Analyser (Lloyd Instruments Ltd., Fareham, England) equipped with a round aluminum compression plate (ST 6/1-50 mm). Prior to testing, cylindrical samples were equilibrated to room temperature (25 °C). To minimize friction, the compression plate was lubricated with mineral oil. The TPA test was performed using Nexygen Plus 3 software at 70 % compression with a crosshead speed of 50 mm/min and a retention time of 5 sec between the first and second compression cycles. The parameters measured included hardness 1, hardness 2, cohesiveness, springiness and gumminess. According to the software manual, hardness 1 and 2 are defined as the peak force during the first and second compression cycle. Cohesiveness is defined as the ratio of the area under the second compression curve to that under the first compression curve, while springiness is defined as the ratio of sample height at the beginning of the second compression cycle to the height at the beginning of the first cycle.

Sensory analysis of squeaking intensity

Sensory evaluation of squeaking intensity was conducted by panelists familiar with the properties of this type of cheese. The evaluation took place at the University of Zagreb Faculty of Agriculture. Each of forty-six panelists received three coded cheese samples from all three treatments on days 0, 14, and 28 of the shelf life (138 sensory analyses per treatment; Figure 2). All samples were anonymized using random three-digit codes to ensure blind testing. Panelists were instructed to evaluate whether the cheeses exhibited squeaking during chewing. If squeaking was perceived, they were asked to determine if there were differences in the intensity of squeaking among the samples. Finally, they were asked to rank the cheeses according to the intensity of squeaking, indicating which cheese squeaked the most intensely, which had medium intensity, and which squeaked the least/did not squeak at all.

Consumers' perception survey

The survey was conducted on a sample of 100 respondents, all consumers of Škripavac cheese. Data were collected over a three-month period through face-to-face interviews. A structured questionnaire comprising 12 questions was used to collect information on socio-demographic characteristics (including gender, age, and place of residence), knowledge of Croatian traditional cheeses, specifically Škripavac cheese and awareness of its geographical origin. Furthermore, the questionnaire explored consumer behavior related to Škripavac cheese, such as frequency of consumption, typical consumption occasions, purchase frequency, and preferred points of buying.

Statistical analysis

The procedures of the statistical program SPSS software (IBM SPSS Statistics, Version 21, 2012) were used for the processing analysis of the textural and sensory (squeaking) characteristics of Lički škripavac cheese. A two-way analysis of variance (ANOVA) based on the general linear model (GLM) was applied to assess the effects of treatment and storage duration on the cheese's textural properties. Pairwise comparisons of mean values were conducted using the least significant difference (LSD) test. Descriptive statistics were obtained through univariate analysis (frequency and distribution) to describe the participants and distribution of respondents according to their answers regarding the region of origin of Škripavac cheese. Sensory squeakiness scores and consumption behavior were analyzed using the chi-square test, with multiple comparisons adjusted by the Bonferroni correction at a significance level of $p<0.05$.

Results and discussion

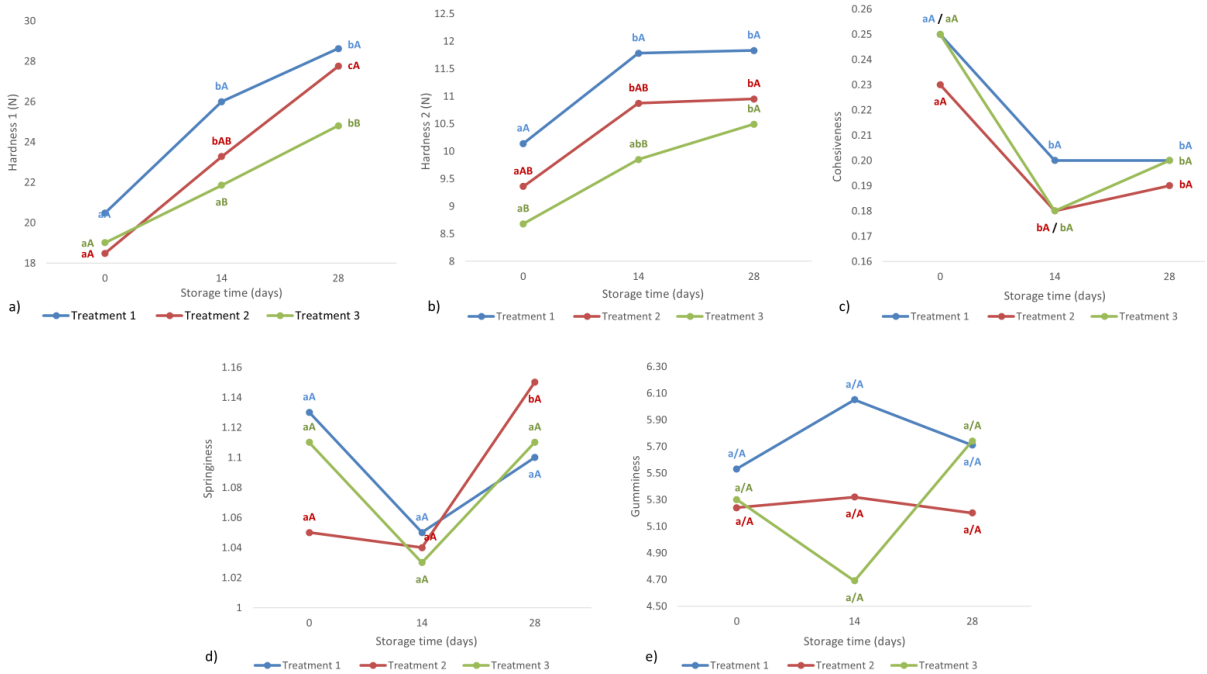
Texture analysis

Textural characteristics, including hardness 1, hardness 2, cohesiveness, springiness, gumminess is shown in Figure 3. Texture may be defined as the sensory manifestation of a cheese's structural properties and the way these properties respond to applied forces. It strongly influences consumers' immediate perception of product quality through visual and auditory cues, thus serving as a critical sensory indicator (Kongo and Malcata, 2016). The textural attributes of Lički škripavac cheese are distinctive and differ substantially from those of typical ripened cheeses. The hardness (Hardness 1) of Lički škripavac, regardless of treatment and storage time, ranges from 18.48 to 28.62 N (Figure 3a), which is considerably lower than that of Cheddar cheese, whose hardness values range from 71.6 to 73.5 N depending on age (Lakhani et al., 1991). Similarly, hardness 2, cohesiveness, and gumminess values are all significantly lower in Lički škripavac compared with Cheddar (Lakhani et al., 1991). By contrast, the textural profile of Lički škripavac more closely resembles that of Halloumi cheese. Zhao et al. (2025) reported that Halloumi cheese with a pH of 6.5, similar to that of Škripavac cheese, had a hardness value of 2103.97 g (20.64 N).

Both Hardness 1 and Hardness 2 increased significantly during storage in cheeses from all three treatments, whereas cohesiveness decreased significantly ($p<0.05$; Figure 3a, 3b and 3c). In contrast, gumminess and springiness were not significantly affected by either treatment or storage time (Figure 3d and 3e). Subjecting Lički škripavac to immersion in hot water (50 °C/ 2 min) prior to analysis (Treatment 3) significantly reduced hardness at the end of storage ($p<0.05$) compared to the cheeses from Treatment 1 and 2 (Figure 3a and 3b). Since the cheese was subjected to a large strain (70 %) during the first compression cycle, the paracasein network lost its integrity and continuity. This explains why hardness 2 values are half those of hardness 1. Warm water heated not only the protein network but also the water and fat in the outer parts of the cheeses that were submerged in hot water (50 °C/2 min) immediately before textural and sensory analyses. Exposure of the protein network to warm water tends to increase the strength of hydrophobic interactions among casein molecules, particularly the reassociation of ß-casein and calcium, which forces the protein molecules to interact more closely, leading to rearrangement of the protein network (Pastorino et al., 2002; Feng et al., 2021; Sözeri Atik and Huppertz, 2023). Consequently, the available spaces within the protein network were reduced, leading to the expulsion of water and liquid fat from the outer parts of the cheeses in warm water. Although hydrophobic interactions increase with rising temperature, the net result may be a weakening of the protein network due to a reduction in contact area between casein molecules (Lucey et al., 2003). Nöbel et al. (2012) suggested that the voluminosity of casein micelles decreased with increasing temperature and asymptotically reached a plateau (>30 °C), which is thought to be a compensating effect of hydrophobicity and intra-micellar migration. Since the outer parts of the cheese lack water and milk fat as the main lubricants, compression of the protein network by the teeth was accompanied by squeakiness. However, as mastication proceeds, the incorporation of saliva and the formation of a cohesive bolus improve lubrication, which consequently reduces the squeakiness of cheese.

Sensory analysis of squeaking intensity

Traditionally, Lički škripavac was produced at the farm level for household consumption, where a short squeaking period was sufficient. By contrast, contemporary production is predominantly market-oriented, and a shelf life of less than one month is commercially unviable. To address this limitation, Lički škripavac is now commonly packaged in vacuum pouches to extend the duration of its squeaking characteristic. The present results indicate that immersion of vacuum-packed cheese in hot water at 50 °C for two minutes may further enhance or restore squeaking intensity. Table 1 presents the frequencies of panelist ratings by squeaking intensity category, indicating a shift from predominantly low



a, b Means marked with different letters on each line of individual treatment differ significantly (p<0.05);
A, B Means within the same sampling time across three different treatments marked with different letters differ significantly (p<0.05). Treatment 1 (control) = cheeses not subjected to hot water submersion, Treatment 2 = cheeses submerged in hot water (50 °C/ 2 min) immediately after production and vacuum packaging (day 0), Treatment 3 = consisted of cheeses submerged in hot water (50 °C/ 2 min) immediately prior to textural analyses.

Figure 3. *Effect of warm water submersion on the textural characteristics of Lički škripavac cheese*

squeaking in Treatment 1 to predominantly high squeaking in Treatment 3, with Treatment 2 most frequently rated as medium.

The previously mentioned reduction in hardness was associated with a significantly higher (p<0.01) squeaking characteristic of cheeses from Treatment 3 compared to Treatment 1 and 2 evaluated by sensory panelists (Table 1). Importantly, immersion treatment improved squeaking intensity from medium to high, demonstrating that the procedure can effectively restore the defining sensory attribute of Lički škripavac immediately prior to consumption.

Table 1. *Frequency of panelist responses for squeaking intensity categories of Lički škripavac cheese*

Treatment	Intensity of squeaking		
	Low	Medium	High
1	72^{a}	34^{b}	32^{b}
2	36^{a}	67^{b}	35^{a}
3	26^{a}	41^{a}	71^{b}

Values represent the number of panellist responses classified into each squeaking intensity category. a, b Means marked with different letters in the same row marked with different letters differ significantly (p<0.01); Treatment 1 (control) = cheeses not subjected to hot water submersion, Treatment 2 = cheeses submerged in hot water (50 °C/ 2 min) immediately after production and vacuum packaging (day 0), Treatment 3 = consisted of cheeses submerged in hot water (50 °C/2 min) immediately prior to sensory analyses.

Consumers' perception survey

Among the participants in this study, males from urban areas aged 31-50 years predominated (Table 2). This is consistent with the findings of Kupiec and Revell (1998), who reported that the dominant group purchasing artisanal cheese consisted of consumers aged 33-55 years. In contrast to our results, Ouyang et al. (2021) surveyed predominantly female participants when investigating preferences for and consumer behavior toward cheese among young, educated, internationally mobile Chinese consumers. Similarly, Valkaj et al. (2013b) reported a slightly higher proportion of male participants (56 %) in their study on the recognition of Turoš cheese by consumers from the Međimurje region (its place of origin). Furthermore, Kupec and Revell (1998) noted that the typical customer of a specialty shop falls within the 35-55 age category, which is also consistent with our findings (Table 2). The findings of this study indicate that most respondents (77 %)

associate Škripavac cheese with the Lika region (Figure 4), supporting the recognized geographical and cultural linkage reflected in its Protected Geographical Indication (PGI) status.

Table 2. Description of the participants (n=100)

Descriptor	Parameter	Percentage
Sex	Male	66
	Female	34
The place of residence	City	70
	Village	30
Age	≤30	29
	31-50	57
	≥51	14

Table 3. Purchasing and consumption habits related to Škripavac cheese by age group (% of responses)

Question	Answer	Age		
		≤30 years	31-50 years	≥51 years
How often do you eat Škripavac cheese?	Weekly	3.5^{b}	3.5^{b}	7.1^{c}
	Monthly	51.7^{a}	49.1^{a}	21.5^{b}
	Rarely	44.8^{a}	47.4^{a}	71.4^{a}
How often do you buy Škripavac cheese?	Weekly	3.4^{c}	3.5^{c}	7.1^{b}
	Monthly	34.5^{b}	35.1^{b}	14.3^{b}
	Rarely	51.7^{a}	57.9^{a}	42.9^{a}
	I do not buy it at all	10.4^{c}	3.5^{c}	35.7^{a}
In which occasion do you usually eat Škripavac cheese?	With dried cured meat	41.4^{a}	39.5^{a}	57.1^{a}
	With wine	31.0^{b}	36.8^{a}	14.3^{b}
	Other	27.6^{b}	23.7^{b}	28.6^{b}
Where do you purchase Škripavac cheese?	From relatives/ friends	28.6^{a}	22.0^{b}	16.7^{b}
	Green markets	19.0^{a}	24.3^{b}	8.3^{b}
	Supermarkets	28.6^{a}	53.7^{a}	33.3^{a}
	Other	23.8^{a}	0^{c}	41.7^{a}

$^{a, b, c}$*Means within the same column (age group) within each question marked with the different letter differ significantly (p<0.05)*

Table 3 shows purchasing and consumption habits related to Škripavac cheese by age group. The lowest frequency ($p<0.05$) of weekly consumption and purchase of Škripavac cheese was observed among respondents regardless of age. Valkaj et al. (2013b) reported that more than half of Turoš cheese consumers purchase it several times per month or less, which is consistent with our findings for Lički škripavac cheese. In contrast, Kupiec and Revell (1998) found that almost half of consumers purchase artisanal cheeses on a weekly basis. According to Matijević et al. (2015), artisanal cheeses in central Croatia are most commonly consumed at breakfast, which aligns with our finding that Škripavac cheese is primarily consumed with dried cured meat, a dominant breakfast food. The market for traditional cheeses such as Škripavac still relies heavily on direct sales and purchases at farmers' markets (Table 3). However, among the main



Figure 4. Distribution of respondents by perceived region of origin of Škripavac cheese (% of responses)

age group of consumers (31-50 years), supermarkets represent the predominant market channel for purchasing Škripavac cheese ($p<0.05$). Furthermore, Užar and Filipović (2023) confirmed that municipalities can collaborate with farmers, retail outlets, and supermarkets to make traditional cheeses with geographical indications more accessible, thereby reducing consumer effort in purchasing them. Our findings are also in line with those of Ivanović et al. (2024), who reported that consumers in Southeastern Europe most frequently (67.3 %) purchase cheese in supermarkets and grocery stores.

Conclusion

Škripavac cheese is one of the most prominent traditional Croatian cheeses, produced in several regions across the country. Nevertheless, consumer surveys performed as part of this research have shown that it is mainly associated with the mountainous region of Lika, in line with its recognized geographical origin and PGI status granted in 2021 under the name Lički škripavac. A key quality attribute described for this cheese type is its characteristic squeaking texture. Our research demonstrates that this defining sensory property can be preserved throughout the declared 28-day shelf life when vacuum-packed cheese is immersed in hot water (50 °C) for two minutes prior to consumption. These findings support the quality characteristics specified for PGI-protected Lički škripavac and contribute to a better understanding of cheese texture preservation in general. It is therefore recommended that producers of PGI Lički škripavac consider including label instructions advising consumers to submerge the cheese in hot water (50 °C) for two minutes to restore its characteristic squeaking attributes.

Conflict of interest

The authors declare no conflict of interest.

Authors contribution

Conceptualization, S.K. and M.T.K.; Methodology, S.K., A.R., I.D.Š., M.T.K.; Software, A.R.; Validation, I.D.Š., M.T.K., D.S.; Formal analysis, S.K, A.R., I.D.Š., M.T.K.; Investigation, S.K, A.R., I.D.Š., M.T.K., D.S.; Data curation, A.R. and S.K.; Writing (original draft preparation), S.K., M.T.K.; Writing (review and editing), S.K., A.R., I.D.Š., M.T.K., D.S.; Visualisation, A.R. and S.K.; Supervision, M.T.K.; Funding acquisition, S.K.

All authors have read and agreed to the published version of the manuscript.

Očuvanje škripavosti i istraživanje percepcije potrošača o zemljopisnom podrijetlu sira Lički škripavac

Sažetak

Lički škripavac je tradicionalni hrvatski meki sir koji ne zrije, zaštićen oznakom zemljopisnog podrijetla (PGI), te ga karakterizira plastična tekstura i prepoznatljivo svojstvo škripanja tijekom konzumacije koje se smanjuje tijekom pohrane. U ovoj studiji procijenjen je učinak potapanja vakuumski pakiranog sira u vruću vodu (50 °C/2 min) na očuvanje i obnovu svojstva škripavosti tijekom roka trajanja te je ispitana percepcija potrošača o njegovom geografskom podrijetlu. Sirevi iz jedne serije nasumično su podijeljeni u tri skupine na temelju obrade vrućom vodom: (1) kontrolna - bez potapanja, (2) potapanje odmah nakon proizvodnje i (3) potapanje neposredno prije analize. Sve skupine analizirane su nakon 0, 14 i 28 dana pohrane. Provedena je analiza profila teksture, a intenzitet škripanja procijenili su senzorni ocjenjivači, dok su percepcija potrošača i navike kupnje istraživane putem strukturiranog istraživanja. Parametri tvrdoće značajno su se povećali tijekom pohrane u svim tretmanima ($p<0,01$). Potapanje u vruću vodu primijenjeno neposredno prije analiza značajno je smanjilo vrijednosti tvrdoće sira ($p<0,05$). Senzorska evaluacija potvrdila je da sirevi iz ovog tretmana imaju najveći intenzitet škripanja ($p<0,01$). Rezultati ankete pokazali su da većina potrošača (77 %) povezuje sir škripavac s regijom Lika, što je u skladu s njegovom zaštićenom oznakom zemljopisnog podrijetla (PGI), dok su konzumacija i učestalost kupnje uglavnom bile mjesečne ili rijetke među dobnim skupinama. Rezultati pokazuju da je kratko potapanje u vruću vodu prije konzumacije jednostavna i praktična mjera za vraćanje škripavosti i podršku održavanju ključnog senzornog svojstva sira Lički škripavac sa zaštićenim nazivom tijekom njegovog deklariranog roka trajanja.

Ključne riječi: sir škripavac; škripavost; tekstura; senzorska analiza; percepcija potrošača; zaštićena oznaka zemljopisnog podrijetla (PGI)

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