

**STANDARDIZATION OF TEXTURE PROFILE ANALYSIS (TPA)
PARAMETERS FOR CHICKEN SALAMI**

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ABSTRACT

Textural properties are key indicators of quality in meat products. In this study, the effects of slice thickness (15, 20, 25 mm), compression ratio (30, 40, 50%), and test speed (1, 2, 3 mm/s) on the textural characteristics of chicken salami were investigated. Increasing slice thickness raised hardness and adhesiveness but reduced cohesiveness ($P < 0.05$). Higher test speed increased hardness, springiness, cohesiveness, and chewiness, while decreasing adhesiveness ($P < 0.05$). The compression ratio influenced hardness, adhesiveness, cohesiveness, and chewiness ($P < 0.01$); higher ratios enhanced hardness, adhesiveness, and chewiness, but decreased cohesiveness ($P < 0.05$). Significant interactions were found between slice thickness $\times$ compression ratio for adhesiveness ($P < 0.01$), and test speed $\times$ compression ratio for chewiness ($P < 0.01$) and springiness ($P < 0.05$). The compression ratio was more effective than other parameters. Optimal conditions with minimal variability were identified for each parameter, suggesting suitable standardization criteria for texture profile analysis of chicken salami.

Keywords: Salami, texture, slice thickness, test speed, compression ratio

**TAVUK SALAMI İÇİN TEKSTÜR PROFİL ANALİZİ (TPA)
PARAMETRELERİNİN STANDARDİZASYONU**

ÖZ

Tekstürel özellikler, et ürünlerinde temel kalite göstergeleridir. Bu çalışmada, tavuk salamın tekstürel özellikleri üzerine dilim kalınlığı (15, 20, 25 mm), sıkıştırma oranı (%30, 40, 50) ve test hızı (1, 2, 3 mm/s) değişkenlerinin etkileri araştırılmıştır. Dilim kalınlığının artması, sertlik ve yüzey yapışkanlığını artırırken, iç yapışkanlığı azaltmıştır ($P < 0.05$). Daha yüksek test hızları, sertlik, elastikiyet, iç yapışkanlık ve çiğnenebilirliği artırmış, buna karşılık yüzey yapışkanlığını düşürmüştür ($P < 0.05$). Sıkıştırma oranı ise sertlik, yüzey yapışkanlığı, iç yapışkanlık ve çiğnenebilirlik üzerinde anlamlı bir etkiye sahip olmuştur ($P < 0.01$); daha yüksek oranlar sertlik, yüzey yapışkanlığı ve çiğnenebilirliği

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artırmış, ancak iç yapışkanlığı azaltmıştır ($P < 0.05$). Ayrıca, dilim kalınlığı $\times$ sıkıştırma oranı etkileşimi yüzey yapışkanlığı üzerinde ($P < 0.01$), test hızı $\times$ sıkıştırma oranı etkileşimi ise çiğnenebilirlik ($P < 0.01$) ve elastikiyet ($P < 0.05$) üzerinde anlamlı bulunmuştur. Sıkıştırma oranının diğer ölçüm parametrelerine göre daha etkili olduğu belirlenmiştir. Her bir parametre için minimum değişkenlikle en uygun koşullar tespit edilmiş olup, bu sonuçlar tavuk salamının tekstür profil analizinde kullanılabilecek uygun standardizasyon kriterlerini ortaya koymaktadır.

Anahtar kelimeler: Salam, tekstür, dilim kalınlığı, test hızı, sıkıştırma oranı

INTRODUCTION

The consumption of meat and meat products is widespread worldwide because of their high bioavailability of nutrients, bioactive compounds, essential minerals, and vitamins (Babaoglu et al., 2025). Many meat products are produced in different parts of the world, classified as fresh processed meat products, formed meat, cured meat products, raw-cooked meat products, raw fermented sausages, and dried meat products (Valli et al., 2018). Emulsion sausages and salamis are widely consumed in Western and Asian countries (Dinçer et al., 2017). While these products are produced in the West by fermenting and drying the batter produced with the emulsion technique after filling it into casings (Alamprese et al., 2016; Stangierski et al., 2023), in Türkiye, they are produced by heat treating the batter obtained with the emulsion technique after filling it into casings (Anonymous, 2019). Previously produced using pork, especially for the Christian minority in Istanbul, these products now use mostly beef and poultry meats. In addition to the raw materials used in production, products with different textures and qualities are offered to the market depending on different processing and storage conditions (Öztan, 2003).

Texture is one of the key quality attributes used in the fresh and processed food industry to assess product quality and acceptability (Chen and Opara, 2013; Alemu, 2022). It plays an important role in consumer acceptance and market value by greatly affecting the palatability and quality of meat products (Erdemir and Karaoğlu, 2021). Among the texture characteristics, hardness is one of the most important parameters, often used to determine the freshness of foods. Springiness, adhesiveness, cohesiveness, and chewiness are significant properties for the texture evaluation of meat-based products (Alemu, 2022). Textural quality attributes of foods may be evaluated by

descriptive sensory (subjective) or instrumental (objective) analyses. Texture Profile Analysis (TPA) is one of the instrumental methods used to evaluate the texture of various food items, with one advantage to assess multiple variables at one-time measurement (Chen and Opara, 2013; Alemu, 2022).

Many studies have been conducted on the production and quality characteristics of salami. Some of these studies are on the possibilities of using goose meat in production (Güner et al., 2002), the effect of partial replacement of sodium chloride in Italian salami production on sensory and textural properties (Fieira et al., 2015), the synergistic effect of polysaccharides, betalain pigment and phenolic compounds of red prickly pear (*Opuntia stricta*) in the stabilization of salami (Kharrat et al., 2018), the effect of modified potato starch on some quality properties of salami produced from beef and chicken meat (Saimaiti, 2018), the possibilities of using dried oyster mushroom (*Pleurotus ostreatus*) in Hungarian salami production (Özünlü, 2019) and the effect of using olive pomace oil oleogel in chicken salami production on physicochemical, textural and sensory properties (Yazıcı, 2024). Although most of these studies include information on the textural properties of salami, TPA analyses were mainly performed under different measurement conditions, resulting in incomparable data.

In many cases, texture measurements obtained with TPA differ under different conditions. The biting and chewing activity of the mouth is simulated with the TPA device, and the texture of the foodstuff is measured accordingly. Therefore, these devices, unlike basic analysis devices, provide meaningful data depending on the similarity between the mechanical and sensory measurements of foodstuffs (Shin and Choi, 2021). In contrast, in texture studies, differences

in TPA values are often explained by measurement parameters, without considering the similarity between mechanical and sensory measurements or the reason for choosing certain conditions. As a result, it is unclear whether the observed differences in texture are due to the samples themselves or to the measurement conditions.

The most emphasized and changed measurement parameters in measuring the textural properties of salami are slice thickness, test speed, and compression ratio. Although there are many studies aimed at measuring and improving the textural properties of different poultry meat products, there is no specific study to determine the texture measurement parameters and their effects on textural properties. The primary aims of this study planned in this context were: i) to determine the textural parameters such as hardness, springiness, adhesiveness, cohesiveness, and chewiness of chicken salami samples using the TPA device at different slice thicknesses, compression ratio, and test speeds, and thus ii) provide basic data for establishing

standardized measurement conditions necessary for the textural analysis of salamis.

MATERIAL AND METHOD

Materials

In the study, four different brands of chicken salami were selected as the experimental material, and 6-7 samples were obtained from each brand. All samples were purchased from markets or delicatessens in Samsun. The samples were stored at 4 °C until their chemical composition and textural properties were analyzed (approximately 6 h).

Experimental design of texture measurement parameters

The experimental design included three measurement parameters: slice thickness, test speed, and compression ratio. The selected slice thicknesses were 15, 20, and 25 mm; the test speeds were 1, 2, and 3 mm/s; and the compression ratios were 30, 40, and 50% (Table 1). Preliminary experiments confirmed that these selected values did not cause any deformation in the salami samples.

Table 1. Measurement parameters and their variation ranges used in the experimental design

Measurement parameters	Variation ranges		
Slice thickness (mm)	15	20	25
Test speed (mm/s)	1	2	3
Compression ratio (%)	30	40	50

Proximate composition analysis

The moisture, protein ($N \times 6.25$), fat, and ash contents of chicken salami samples were determined using AOAC methods (AOAC, 2000). Carbohydrate contents were calculated by difference.

Texture profile analysis

The salami samples were kept in the refrigerator until analyzed, and their temperatures were balanced by keeping them at room temperature for ~20 min before slicing. Then, they were cut into cylindrical slices (diameter: 60 mm) of 15-, 20-, and 25-mm thickness using a slicing machine (Sönmez Vacuum, SN210, Türkiye). Textural properties of salami slices were measured at room temperature using a Texture Analyzer (TA-XT

Plus, Stable Micro Systems, Surrey, UK) with a P/50R probe at different test speeds (1, 2, and 3 mm/s) and different compression ratios (30, 40, and 50%). During the measurements, salami slices were subjected to two compressions, with 5 s between compressions. Three slices per thickness and brand were analyzed. The hardness, springiness, adhesiveness, cohesiveness, and chewiness parameters of the samples were calculated from the curves provided by the equipment.

Statistical analysis

The data obtained from the TPA measurements were analyzed by the General Linear Model, in which slice thickness, test speed, and compression ratio were the main factors using the SPSS

statistical package program (Version 10, SPSS Inc., Chicago, IL, USA). Differences among the means were compared using Duncan's multiple range test at $P < 0.05$ level. The results of the main factors were shown as boxplots, while the results of the interactions were presented as line charts. The minimum and maximum values, median, and first and third quartiles were shown on the boxplots.

RESULTS AND DISCUSSION

Proximate composition

In the present study, where the effect of measurement parameters on the textural properties of chicken salami was investigated, the proximate compositions of four different brands of chicken salamis were also investigated, and it was determined that salamis contained 63.93-69.49% moisture, 10.53-12.45% protein, 7.47-14.06% fat, 2.86-4.01% ash, and 4.71-7.73% carbohydrate. Similar proximate composition results were reported by Battaloğlu (2024) in chicken salamis sold in the Kayseri market in Türkiye.

Texture measurement parameters

Slice thickness

In the present study, the textural properties of chicken salamis were measured at three different slice thicknesses (15, 20, and 25 mm), and the effect of slice thickness on hardness, springiness, adhesiveness, cohesiveness, and chewiness is presented in Figure 1a-e. The slice thickness had a significant ($P < 0.01$) effect only on the hardness, adhesiveness, and cohesiveness. The lowest hardness value was measured at 15 mm slice thickness as 126.32 N, and as the slice thickness increased, the hardness values increased ($P < 0.05$). However, this increase was not significant in 15- and 20-mm slice thicknesses ($P > 0.05$) (Figure 1a). The increase in hardness values as the slice thickness increases could be explained by the need for a higher compression force to deform the thicker slice. Similar findings were also reported by Boles and Shand (2008) in beef stir-fry strips from the round and chuck. As with the hardness values, adhesiveness values increased as the slice thickness increased ($P < 0.05$), and the highest value was determined at 25 mm slice

thickness, resulting in 4.02 N.s (Figure 1c). However, increasing the slice thickness decreased the cohesiveness values of chicken salami ($P < 0.05$) (Figure 1d). This decrease could be attributed to the weak connection effect. It is thought that the connection weakened as the slice thickness increased, which caused a decrease in cohesiveness.

As seen in Figure 1a-e, the 1st and 3rd quartiles of the hardness values of salami slices with different thicknesses ranged from 70.00 to 196.51 N, the 1st and 3rd quartiles of the springiness values ranged from 0.89 to 0.97, the 1st and 3rd quartiles of the adhesiveness values ranged from 0.04 to 5.24 N.s, the 1st and 3rd quartiles of the cohesiveness values ranged from 0.77 to 0.85, and the 1st and 3rd quartiles of the chewiness values ranged from 55.84 to 140.48 N.s. However, narrower boxes were obtained in the measurements made at 20 mm slice thickness for hardness and chewiness, in the measurements made at 20- and 25-mm slice thickness for springiness, in the measurements made at 15 mm slice thickness for adhesiveness, and in the measurements made at 25 mm slice thickness for cohesiveness. A narrower box indicates less variability among the measurements, whereas a wider box indicates the opposite. Less variability is ideal for the standardization of measurement conditions. The results of the current study showed that, in terms of slice thickness standardization, measurements obtained at 20 mm for hardness and chewiness, at 20 and 25 mm for springiness, at 15 mm for adhesiveness, and at 25 mm for cohesiveness exhibited the least variability compared to other thicknesses, thereby indicating their suitability for standard conditions.

Test speed

This study conducted texture measurements at three different test speeds: 1, 2, and 3 mm/s. The effect of test speed on the textural properties is also presented in Figure 2a-e. The test speed significantly affected hardness at the 0.05 level and springiness, adhesiveness, cohesiveness, and chewiness at the 0.01 level. When the test speed was increased from 1 mm/s to 3 mm/s, the hardness, springiness, cohesiveness, and

chewiness values also increased ($P < 0.05$). However, these increases were not significant for hardness, springiness, and chewiness at 1 and 2 mm/s test speeds and for cohesiveness at 2 and 3 mm/s test speeds ($P > 0.05$) (Figure 2a, b, d, and e). The increase in hardness, springiness, cohesiveness, and chewiness values with the increase in test speed could be explained by increased internal pressure or friction resistance. Similarly, Mittal et al. (1992) reported that TPA measurements performed at different test speeds (0.5, 1.0, and 2.0 cm/min) affected salami samples' cohesiveness and chewiness values. Shin

and Choi (2021) also reported that the test speed affected not only the cohesiveness and chewiness of sausages but also their hardness and springiness, with the most notable occurring in cohesiveness values. Contrary to the hardness, springiness, cohesiveness, and chewiness values, adhesiveness values decreased as the test speed increased ($P < 0.05$), but this decrease was not significant in 2 and 3 mm/s test speed ($P > 0.05$) (Figure 2c). Similarly, Shin and Choi (2021) reported that the test speed affected the adhesiveness values of sausages.

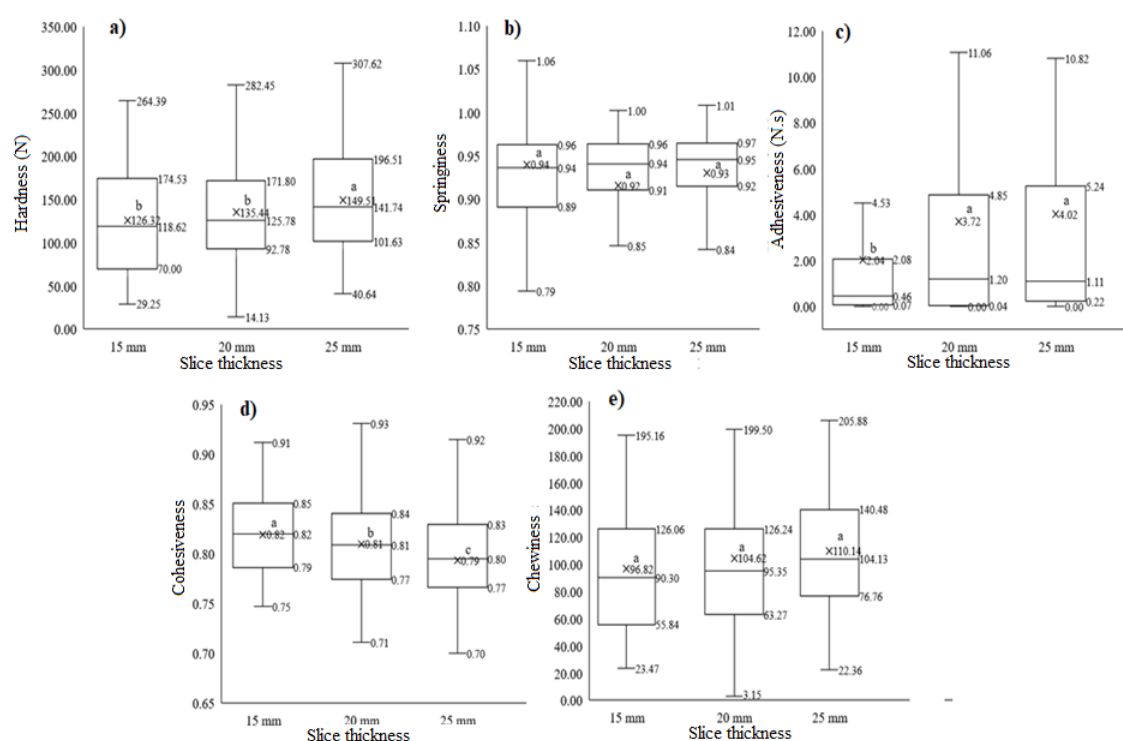


Figure 1. Effect of slice thickness on textural properties: a) Hardness, b) Springiness, c) Adhesiveness, d) Cohesiveness, e) Chewiness. Differences between means marked with different letters in each graphic are significant ($P < 0.05$).

The 1st and 3rd quartiles of the hardness values measured at different test speeds varied from 95.89 to 182.52 N at 1 mm/s test speed, from 91.08 to 166.45 N at 2 mm/s test speed, and from 89.00 to 195.83 N at 3 mm/s test speed, and a narrower box was obtained in the measurements made at 2 mm/s test speed (Figure 2a). Similarly, a narrower box was obtained at a test speed of 2

mm/s for adhesiveness (Figure 2c). In contrast, narrower boxes were obtained in measurements made at 3 mm/s for springiness (Figure 2b) and at a test speed of 1 mm/s for chewiness (Figure 2e). The 1st and 3rd quartiles of the cohesiveness values varied from 0.76 to 0.83 at 1 mm/s test speed, from 0.78 to 0.84 at 2 and 3 mm/s test speeds and narrower boxes were obtained in the

measurements made at 2 and 3 mm/s test speeds (Figure 2d). These results showed that, in terms of test speed standardization, measurements made at 2 mm/s for hardness and adhesiveness, 3

mm/s for springiness, 1 mm/s for chewiness, and 2 or 3 mm/s for cohesiveness exhibited the least variability compared to other test speeds, thereby indicating their suitability for standard conditions.

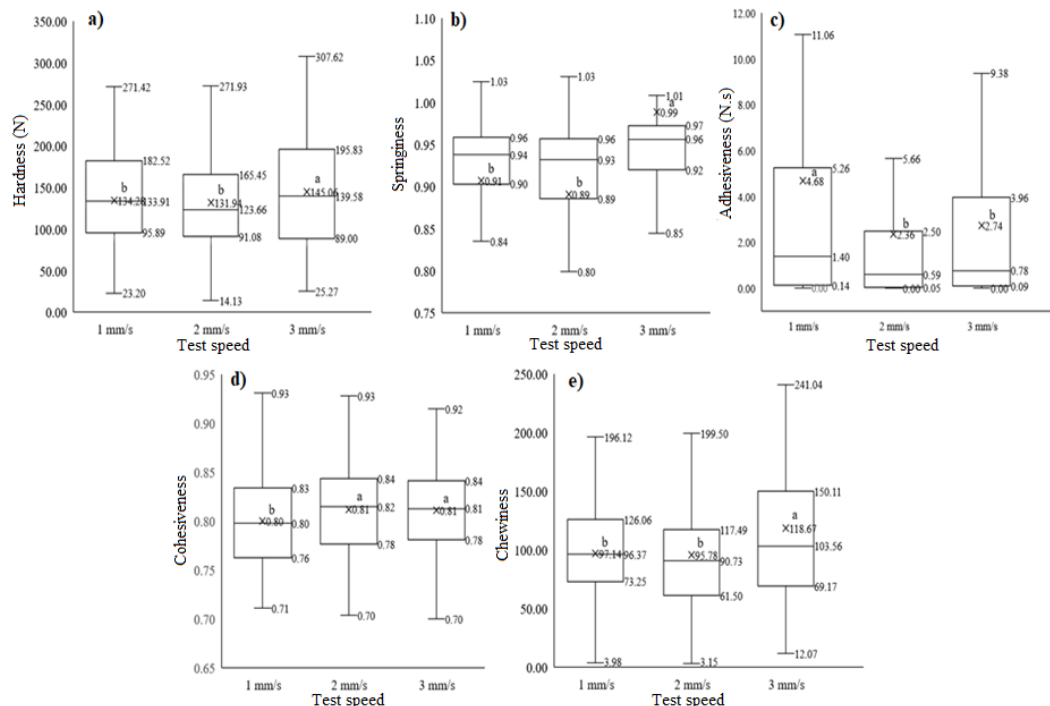


Figure 2. Effect of test speed on textural properties: a) Hardness, b) Springiness, c) Adhesiveness, d) Cohesiveness, e) Chewiness. Differences between means marked with different letters in each graphic are significant ($P < 0.05$).

Compression ratio

In measuring the texture of food products, in addition to slice thickness and test speed, the compression ratio is also an important parameter. The effect of compression ratio on textural properties is illustrated in Figure 3a-e. As seen, the compression ratio significantly affected hardness, adhesiveness, cohesiveness, and chewiness at the 0.01 level. The hardness values of chicken salamis ranged from 82.26 to 197.71 N, and as the compression ratio increased, the hardness values also increased ($P < 0.05$) (Figure 3a). As with the hardness values, the adhesiveness and chewiness values also increased as the compression ratio increased (Figure 3c, e). This could be explained by the increase in the internal pressure and, consequently, the friction resistance with the increase in the compression ratio. On the other hand, as the compression ratio was increased

from 30% to 50%, the cohesiveness values decreased from 0.85 to 0.76 ($P < 0.05$) (Figure 3d). Similarly, Mittal et al. (1992) reported that compression ratio (25, 50, and 75%) affected the hardness, cohesiveness, and chewiness values of salami samples and that increasing the compression ratio from 25 to 50% increased the hardness values while decreasing cohesiveness. In another study, Shin and Choi (2021) reported that the compression ratio changed the hardness, adhesiveness, springiness, cohesiveness, and chewiness values, and the highest change was observed in cohesiveness values and the lowest change in springiness values.

As seen in Figure 3a-e, narrower boxes were obtained in the measurements made at 30% compression ratio for hardness, adhesiveness, and chewiness, in the measurements made at 30 and

40% compression ratio for springiness, and in the measurements made at all three compression ratios for cohesiveness. These results showed that, in terms of standardization of compression ratio, measurements made at 30% compression

ratio for hardness, adhesiveness, and chewiness, 30 or 40% compression ratios for springiness, and 30, 40, and 50% compression ratios for cohesiveness exhibited fewer variable values, resulting in more ideal results.

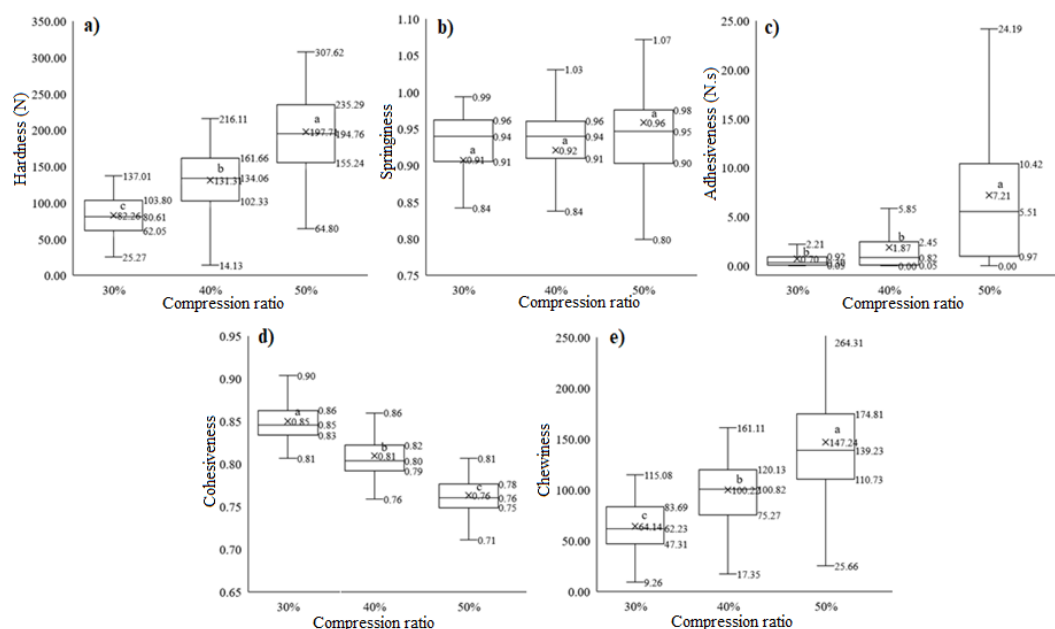


Figure 3. Effect of compression ratio on textural properties: a) Hardness, b) Springiness, c) Adhesiveness, d) Cohesiveness, e) Chewiness. Differences between means marked with different letters in each graphic are significant ($P < 0.05$).

Interaction analysis

The above explanations showed that the measurement parameters statistically affected most of the textural properties of chicken salami. However, the interactions between measurement parameters are not given. The interactions between the measurement parameters are also important to better understand the effect of the measurement parameters on the textural properties. Statistical analyses showed that the slice thickness x compression ratio interaction significantly affected adhesiveness at the 0.01 level, and the test speed x compression ratio interaction significantly affected chewiness at the 0.01 level and springiness at the 0.05 level. The graphs of these interactions are presented in Figure 4a-c.

In the slice thickness x compression ratio interaction, the highest adhesiveness value was measured with 8.79 N. s in the 20 mm slice thickness samples at 50% compression ratio, followed by the measurement with 8.66 N. s in the 25 mm slice thickness at 50% compression ratio, and the lowest value was determined in the measurement with 0.39 N. s in the 15 mm slice thickness at 30% compression ratio. In addition, for all slice thicknesses, measurements made at a 50% compression ratio showed higher values than measurements made at a 40% compression ratio, and measurements made at a 40% compression ratio showed higher values than measurements made at a 30% compression ratio (Figure 4a). In the test speed x compression ratio interaction, the chewiness values varied from 63.63 to 178.39 (Figure 4b). The highest value was determined as 178.39 in the measurement made at 50% compression ratio and 3 mm/s test speed,

followed by 131.88 at 50% compression ratio and 1 mm/s test speed. The lowest chewiness value was determined as 63.63 at a 30% compression ratio and 2 mm/s test speed. In all test speeds, measurements at a 50% compression ratio

exhibited higher values than measurements at 40%, and the 40% compression ratio exhibited higher values than measurements at a 30% compression ratio.

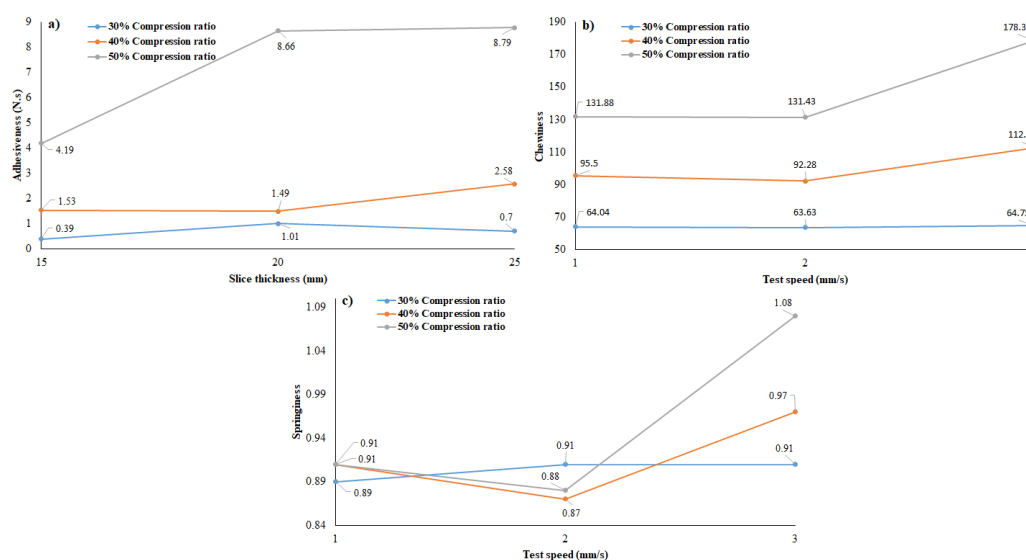


Figure 4. The interaction plots of measurement parameters: a) Effect of slice thickness x compression ratio interaction on adhesiveness, b) Effect of test speed x compression ratio interaction on chewiness, c) Effect of test speed x compression ratio interaction on springiness

As seen in Figure 4c, the springiness values in the test speed x compression ratio interaction varied from 0.87 to 1.08, and the lowest value was determined in the measurement made at 2 mm/s test speed at 40% compression ratio. In the measurements made at 1 and 3 mm/s test speeds, the 30% compression ratio exhibited the lowest springiness value, while the lowest value at 2 mm/s test speed was determined at the 40% compression ratio. These results showed that the measurement parameters affected the textural properties (hardness, springiness, adhesiveness, cohesiveness, and chewiness) at different significance levels. However, among the three tested measurement parameters, compression ratio was the main influencing factor. In addition, slice thickness x compression ratio and test speed x compression ratio had higher significance levels than all the factors.

CONCLUSION

This study comprehensively evaluated the effects of slice thickness, test speed, and compression

ratio on the textural properties of chicken salami. The findings revealed that slice thickness affected the hardness, adhesiveness, and cohesiveness values ($P < 0.01$), test speed affected the hardness ($P < 0.05$), springiness, adhesiveness, cohesiveness, and chewiness values ($P < 0.01$), and compression ratio affected the hardness, adhesiveness, cohesiveness, and chewiness values ($P < 0.01$). Among these parameters, the compression ratio emerged as the most critical factor affecting textural attributes, followed by slice thickness and test speed. Moreover, interaction effects, particularly slice thickness $\times$ compression ratio and test speed $\times$ compression ratio, demonstrated significant impacts, underscoring the importance of considering parameter interactions in TPA. In terms of standardization, the study identified optimal conditions for each textural attribute: 20 mm slice thickness for hardness and chewiness, 20–25 mm for springiness, 15 mm for adhesiveness, and 25 mm for cohesiveness; 2 mm/s test speed for hardness and adhesiveness, 3 mm/s for

springiness, 1 mm/s for chewiness, and 2–3 mm/s for cohesiveness; and a 30% compression ratio for hardness, adhesiveness, and chewiness, 30–40% for springiness, and 30–50% for cohesiveness. These standardized conditions minimize measurement variability and provide reliable reference points for future studies. Overall, the study contributes to the methodological improvement of texture profile analysis in processed meat products by establishing standardized measurement conditions. The results obtained are recommended as a suitable test protocol for quality control in the food industry.

CONFLICT OF INTEREST

There are no possible conflicts of interest between the authors.

AUTHOR CONTRIBUTION

This study was derived from Semiha Saraç's master's thesis. The thesis student, Semiha Saraç, prepared samples, analyses, reporting, and writing and correction of literature sources. Hilal Soyocak assisted in conducting analyses and writing-review-proofreading-publishing procedures. Furkan Türker Sarıcaoglu assisted in statistical analyses of data, writing the article, and writing-review-proofreading-publishing procedures. Sadettin Turhan contributed as the thesis supervisor to conducting analyses, writing the article, and writing review-proofreading-publishing procedures. The authors have read and approved the final version of the article.

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