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Effects of milk type, pasteurization, and in-container heating on Nabulsi cheese yield, chemical composition, and texture

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ABSTRACT

Nabulsi cheese is a white-brined cheese made from different types of milk using different processing methods. This research aimed to investigate the effects of the following three factors on the quality of Nabulsi cheese: milk type (cow's, goat's, and sheep's milk), milk pasteurization (unpasteurized vs. pasteurized), cheese pasteurization (traditional boiling vs. in-container heating), and their two- and three-way interactions. The effect of the first two factors on the cheese yield and those of all three factors on the chemical composition and texture profile analysis (TPA) of cheese were investigated. The type of milk significantly affected all parameters tested. Similarly, milk pasteurization affected all parameters evaluated except ash content and hardness, while cheese pasteurization affected moisture content and cohesiveness. The two-way interaction between the type of milk and milk pasteurization affected the cheese yield, chemical composition (except for protein, fat, and ash contents), and TPA. The three-way interaction significantly affected the chewiness of cheese. The type of milk had the highest effect on cheese yield, fat and ash contents, and chewiness. In comparison, the interaction between the kind of milk and milk pasteurization had the highest effect on cheese hardness. In contrast, milk pasteurization had the highest effect on the remaining tested parameters.

Keywords: white-brined cheese, Nabulsi cheese, chemical composition, yield, texture profile analysis

INTRODUCTION

White-brined Nabulsi cheese is one of the most important cheeses produced in Jordan and surrounding countries **[1]**. It is classified as a semi-hard cheese made without starter cultures **[2]**. Nabulsi cheese is usually processed from sheep's and goat's milk due to the absence of carotenoid pigments in its fat; these types of milk produce white cheese, an important attribute as its name implies **[3]**. Since Nabulsi cheese is traditionally made from sheep's milk, its production peaks in spring. Due to its seasonality and the increased demand for cheese, other types of milk, including cow's milk, are usually used **[4]**. Unpasteurized milk is used in the traditional procedure of making Nabulsi cheese **[5]**, **[6]**, **[4]**, **[7]**. The resulting cheese is subjected to heat treatment by boiling it in a brine solution (>18%), and after that, the cheese and brine are allowed to cool separately. Large enamelled metal containers of variable sizes (1-5 kg) are then filled with cheese and brine **[8]**. Nabulsi cheese is intended to have a shelf life longer than a year **[2]**. There are few scientific studies on the impact of various milk types on the quality of white-brined Nabulsi cheese.

The cheese deteriorates in quality during storage **[1]**, **[9]**, **[10]**, particularly in texture **[4]**. Deterioration manifests as surface slime, discoloration, off-flavor, and gas formation. The traditional method of Nabulsi cheese production needs to improve the following three areas: the use of unpasteurized milk in cheese processing, boiling cheese before packing, and cheese storage in large metal containers. A large proportion of the Nabulsi cheese production is small-scale or family business near the location where the milk is available. Due to the difficulty in controlling the microbial load in milk – which may impair the cheese boiling step's effectiveness – and the increased demand for large quantities of milk to produce larger amounts of cheese, milk pasteurization is increasingly deemed necessary **[4]**. After boiling the cheese in a brine solution, there is a risk of cross-contamination from different sources, such as from unboiled brine, the surrounding environment, and cheese handlers **[11]**. Using large metal containers for storage also exposes the cheese to cross-contamination from repeated opening and closing during usage **[12]**, **[8]**, **[2]**. Several studies investigated the use of in-container heating of Nabulsi cheese using small containers as an alternative to the traditional boiling step **[5]**, **[13]**, **[2]**. On the commercial scale, some producers started to produce Nabulsi cheese with in-container heating in small containers.

Milk pasteurization and in-container heating are expected to be industrial standards in the production of Nabulsi cheese, in addition to the increased need to use different types of milk to meet the growing demand for this type of cheese. To the best of our knowledge, little information is available on the use of different kinds of milk, milk pasteurization, and in-container heating on the quality of Nabulsi cheese. Therefore, this research aimed to investigate the effects of these factors on the yield, chemical composition, and texture profile analysis (TPA) of the Nabulsi cheese.

Scientific Hypothesis

The three investigated factors (type of milk, milk pasteurization, and cheese pasteurization) and their two- and three-way interactions are expected to significantly affect the quality of Nabulsi cheese. Knowing the factors with the most significant effects will be of great importance in optimizing the process of Nabulsi cheese processing.

MATERIAL AND METHODOLOGY

Samples

Samples of cheese were prepared using the three types of milk (cow's, goat's, and sheep's milk) from the same batch. The experiment was repeated two times. Samples of milk were tested immediately for chemical analysis. For chemical analysis of cheese, cheese was tested in its salted form immediately after processing. For texture analysis of cheese, cheese was desalted first by soaking it in tap water overnight under refrigeration.

Animals, Plants, and Biological Materials

Cow's milk (moisture: 88.40%; dry matter: 11.6%; protein: 3.85%; fat: 3.3%; ash: 0.73%; specific gravity: 1.028; pH: 6.3), goat's milk (moisture: 87.94%; dry matter: 12.6%; protein: 4.02%; fat: 3.7%; ash: 0.85%; specific gravity: 1.026; pH: 6.4), and sheep's milk (moisture: 83.14%; dry matter: 16.86%; protein: 5.96%; fat: 5.00%; ash: 0.89%; specific gravity: 1.032; pH: 6.4) were obtained from a dairy plant (Faculty of Agriculture, Al-Karak, Jordan), and cheese coagulant (Rennimax 2100 Granula, Spain).

Instruments

The following equipment was used: texture analyzer (6700 TVT; Perten, Sweden), Kjeldahl (VAP 450; Gergardet, Germany), Gerber (Funke Gerber, Denmark), Oven (TR 240; Nabertherm, Germany), muffle furnace (Nat 30/65; Nabertherm, Germany), and pH meter (S400; Mettler Toledo, Switzerland).

Laboratory Methods

Chemical milk analysis: Association of Official Analytical Chemists (AOAC) methods were used to determine moisture, protein, fat, and ash percentages **[14]**. The following methods were used: Kjeldahl for protein, the Gerber method for fat, the oven method for moisture, and the muffle furnace for ash. The pH was determined using a calibrated pH meter (S400; Mettler Toledo, Switzerland). Specific gravity was determined using a lactometer.

Chemical cheese analysis: AOAC methods **[14]** were used to determine the chemical composition of the cheese samples, which were assessed immediately after processing without desalting. The following methods were used: Kjeldahl for protein, the Gerber method for fat, the oven method for moisture, and the muffle furnace for ash. The pH was determined using a calibrated pH meter (S400; Mettler Toledo, Switzerland).

Cheese yield: Following the pressing and salting steps, the cheese yield was calculated using the following equations:

$$\text{Yield}_{\text{After pressing}} = \text{weight of cheese after pressing / weight of milk} \times 100$$

$$\text{Yield}_{\text{After salting}} = \text{weight of cheese after salting/weight of milk} \times 100$$

TPA cheese: A texture analyzer (6700 TVT; Perten, Sweden) was used to measure hardness, cohesiveness, chewiness, adhesiveness, and gumminess. A 20-kg load cell and cylindrical probe made of stainless steel (45 mm × 50 mm, height × diameter) were used. The instrument was programmed using the software Texcalc (Perten) with the following program: two compression cycles, a 5-mm starting distance from the sample, 50% compression, and 1 mm/s test speed. The software calculates the TPA parameters from the distance/time and force curve. The maximum force observed during the first compression cycle was hardness. Cohesiveness was calculated by dividing the area under the second compression cycle by the area of the first compression cycle. The distance recorded during a sample's second compression compared with the distance recorded during its first compression was used to measure springiness. The hardness, cohesion, and springiness values were multiplied to determine chewiness. The adhesiveness area was measured when the probe was pushed away from the sample during the adhesive withdrawal phase.

Description of the Experiment

Sample preparation: Nabulsi cheese samples were produced according to the steps shown in Figure 1. The milk was divided into two portions; the first was pasteurized (72 °C, 5 mins), while the second was not. Both parts were tempered to about 35 °C, and 0.02% $CaCl_2$ was added only to the pasteurized milk. The coagulant was added per the manufacturer's recommendation and left for about 30 minutes to allow curd formation. The curd was divided into small cubes and left for 10 mins. It was then placed into cheesecloth, drained for 15 mins, and pressed under a heavy weight for 2 hrs. After that, the cheese block was cut into small pieces ($3 \times 3 \times 2$ cm^3) and sprinkled with salt.

The salted pieces were left overnight at room temperature (25 °C) to drain the maximum water. The salted cheese pieces were further divided into two parts. The first part was heat-treated by in-container heating; in this method, glass jars were filled with cheese pieces and a hot 18% brine solution. The jars were immediately closed, heated in a hot water bath until the cold spot inside the jars (the center of the jar) reached 85 °C, and then immediately cooled. The jars were stored at room temperature. The second salted cheese part was heat-treated using the traditional method; in this method, the cheese pieces were boiled in an 18% brine solution until the center of the cheese pieces reached 85 °C. Then, the cheese pieces were removed from the brine solution, and both were allowed to cool separately. After cooling, glass containers were filled with the cheese pieces, and brine solution was added to cover them entirely. The glass containers were closed and stored at room temperature.

No special sample preparation was performed for the chemical analysis of milk, cheese, and cheese yield determination. For TPA, cheese samples were first desalted by soaking them in water overnight at a refrigerator temperature of 5 °C. A stainless steel cylindrical cutter cut the cheese samples with identical dimensions (15 mm × 20 mm, height × diameter). Four cheese samples from each treatment were tempered at room temperature before testing.

Number of samples analyzed: 24.

Number of repeated analyses: Four for cheese TPA and two for other tests.

Number of experiment replication: two.

Design of the experiment: Firstly, the experimental design was performed. For cheese's yield, two-way analysis of variance (ANOVA) was used to investigate the effect of the type of milk (cow's, goat's, and sheep's milk), milk pasteurization (raw versus pasteurized), and their interaction on the yield of Nabulsi cheese. For cheese's chemical analysis and TPA, three-way ANOVA was used to investigate the effects of the type of milk (cow's, goat's, and sheep's milk), milk pasteurization (raw versus pasteurized), and cheese heat treatment (traditional versus in-container heating), as well as their two-way and three-way interactions on the chemical composition and TPA of Nabulsi cheese. The whole experiment was repeated twice. Secondly, different types of milk were collected, and the cheese samples were prepared according to the steps described previously in the sample preparation section. Thirdly, cheese samples were analyzed for chemical composition and TPA. Fourthly, the data were statistically analyzed.

Statistical Analysis

The data were analyzed using Minitab 19 (Minitab Inc., USA). Backward elimination (alpha to remove = 0.05) minimizes the model. Means separation was performed using Tukey's test with $p \leq 0.05$ regarded as statistically significant. Furthermore, a residual normal probability plot was used to verify that the model satisfied the ANOVA assumptions.

RESULTS AND DISCUSSION

The two-way interaction results are presented if they are significant for yield data. If not, the results of the significant main effects are presented. When the three-way interaction effect is significant for chemical analysis results and TPA, it is presented below. When it is not, the significant results of two-way interactions are presented. Only the significant main effects are shown if no significant interactions are detected.

Yield: Both yield values (after pressing and after salting) were affected by the type of milk and milk pasteurization and the two-way interaction between them; therefore, only the results of the effects of the two-way interaction are presented. Of all the significant factors, the type of milk had the greatest standardized effect on yield values (Figure 2 and Figure 4). Figure 3 shows the significant differences between the yield after pressing for cheese made from the three milk types, whether pasteurized or raw. The highest yields were for sheep's milk

(29.95% and 26.73% for pasteurized and raw milk, respectively), followed by goat's milk (17.45% and 17.72% for pasteurized and raw milk, respectively), and the lowest values were for cow's milk (14.93% and 13.48% for pasteurized and raw milk, respectively) with significant differences between them. Toufeili and Ozer **[11]** reported comparable results for sheep's milk white cheese yield (26-28%) and goat's and cow's milk yield (15-16%). Tadjine et al. **[15]** divided the yield factors into milk quality (type of milk and protein's genetic variant) and the cheese-making process. Skeie **[16]** reviewed the factors affecting cheese yield. Milk pasteurization affected the yield depending on the type of milk used; it increased significantly in sheep's milk cheese by 12.05% and was not affected in cow's milk cheese and goat's milk cheese.

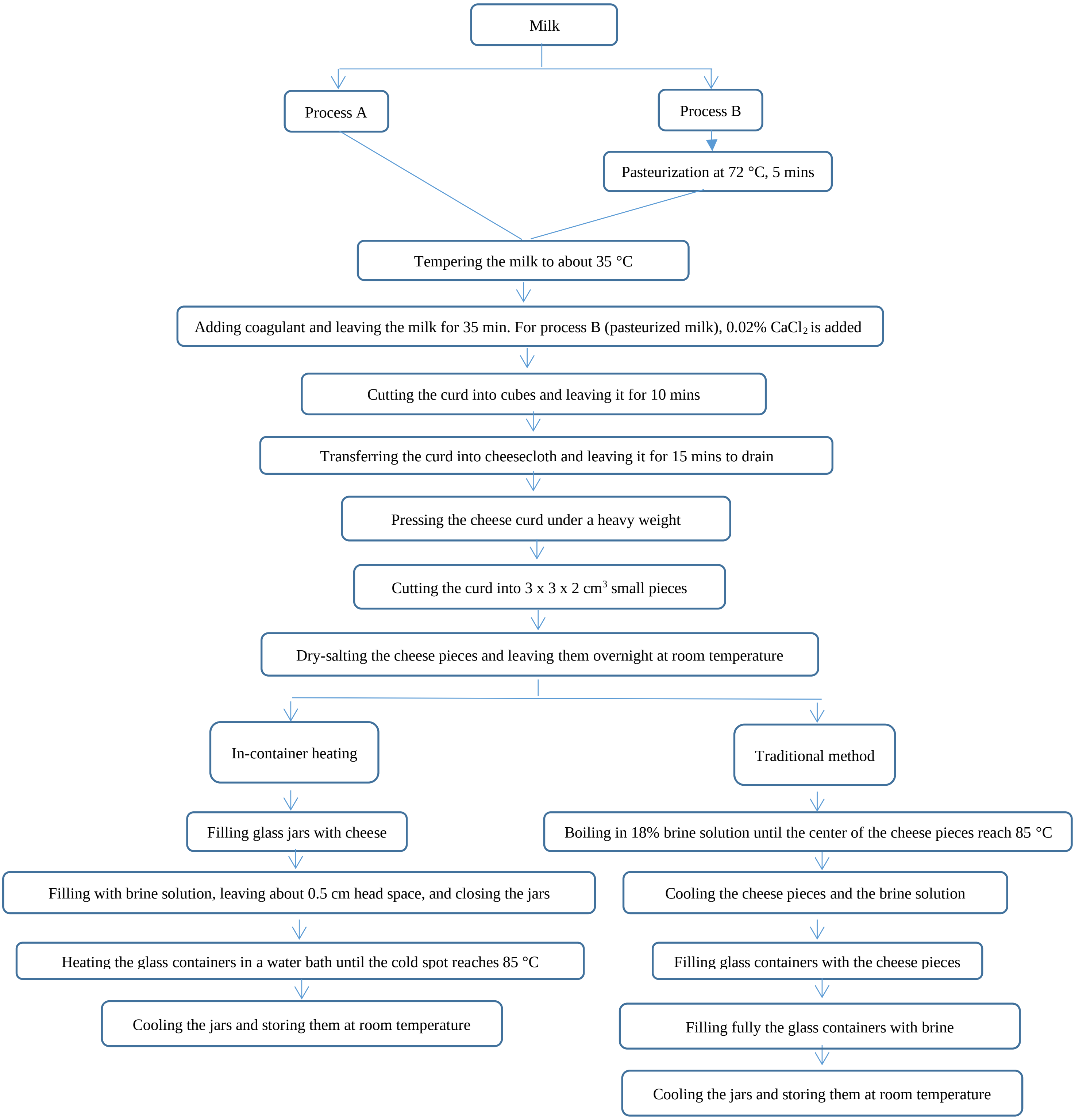


Figure 1 Flow diagram for Nabulsi cheese processing steps.

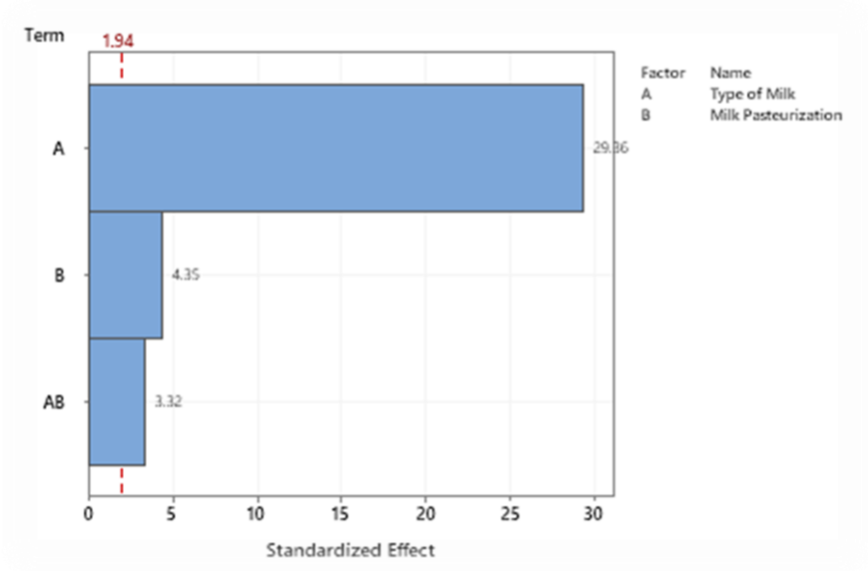


Figure 2 Standardized effects of different factors on the cheese yield after pressing.

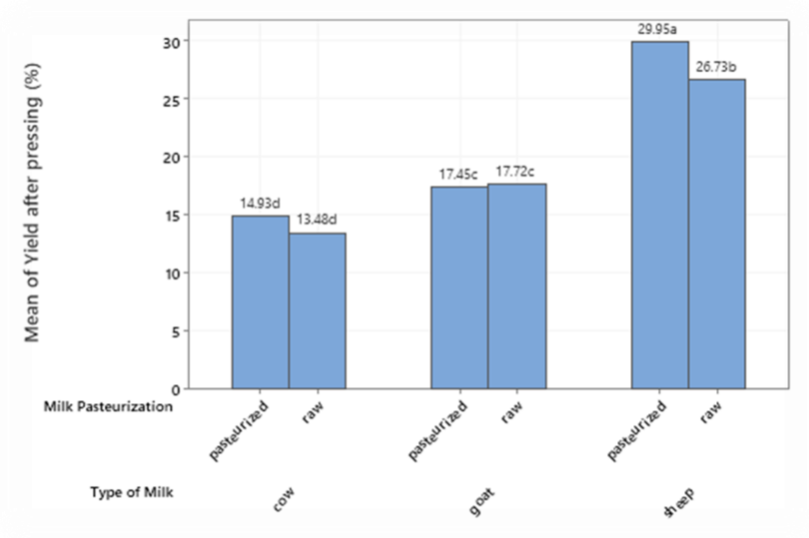


Figure 3 Effect of the two-way interaction between the type of milk and milk pasteurization on the cheese yield after pressing.

After-salting cheese yield values are presented in Figure 5. As expected, all yield values after salting were lower than after pressing due to the dry salting of the cheese pieces. The differences between different types of cheese follow almost the same pattern discussed before for the yield after pressing; the highest yields were for sheep's milk cheese, either using pasteurized milk (26.08%) or raw milk (21.85%), which were significantly higher than those for goat's milk cheese (13.70% and 12.82% using pasteurized and raw milk, respectively) and cow's milk (12.70% and 10.51% using pasteurized and raw milk, respectively). The effect of pasteurization on the cheese yield after salting depended on the type of milk used; it significantly increased in sheep's milk cheese by 19.36% and in cow's milk cheese by 20.84%, but it was not affected in goat's milk cheese.

Several studies reported the positive effect of milk pasteurization on cheese yield **[15]**, **[16]**, **[17]**, **[18]**, **[19]**, **[20]**, **[21]**, **[22]**, **[23]**. In contrast, Drake **[24]** reported no effect of milk pasteurization on cheese yield. These differences in the effect of pasteurization on cheese yield could be related to the quality of the milk, pasteurization treatment, and cheese processing method **[15]**. In our results, the effect of milk pasteurization on the percentage of yield increase after salting for cow's milk cheese was slightly higher than that for sheep's milk cheese. No agreement exists between studies on the type of milk that provides the highest yield upon pasteurization. This might be related to varied factors, including fat and protein ratio, milk composition, and the genetic variant of proteins **[15]**. The percent of yield increase after pasteurization was reported in different studies. For instance, **[15]** reported 8.1% and 13.9% for cow's and goat's milk, respectively; **[20]** reported 8.05% for cheese made from cow's milk; and **[25]** reported 41% for cheese made from cow's milk. The increase in cheese yield after milk pasteurization is due to the increase in water retention of the cheese and the recovery of whey proteins and salt **[15]**. Makhal et al. **[23]** investigated the effect of different heat treatments on yield. However, only one heat treatment was used in this study, and the cheese yield is expected to change with different heat treatments.

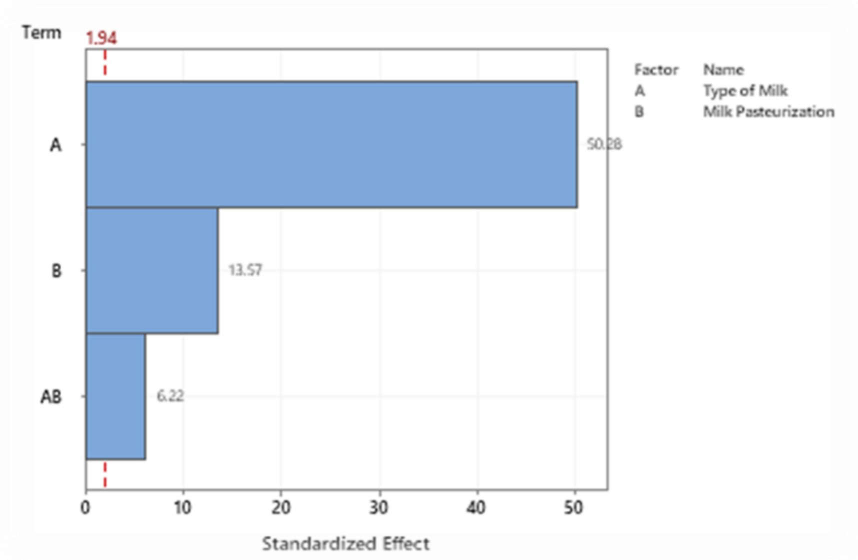


Figure 4 Standardized effects of different factors on the cheese yield after salting.

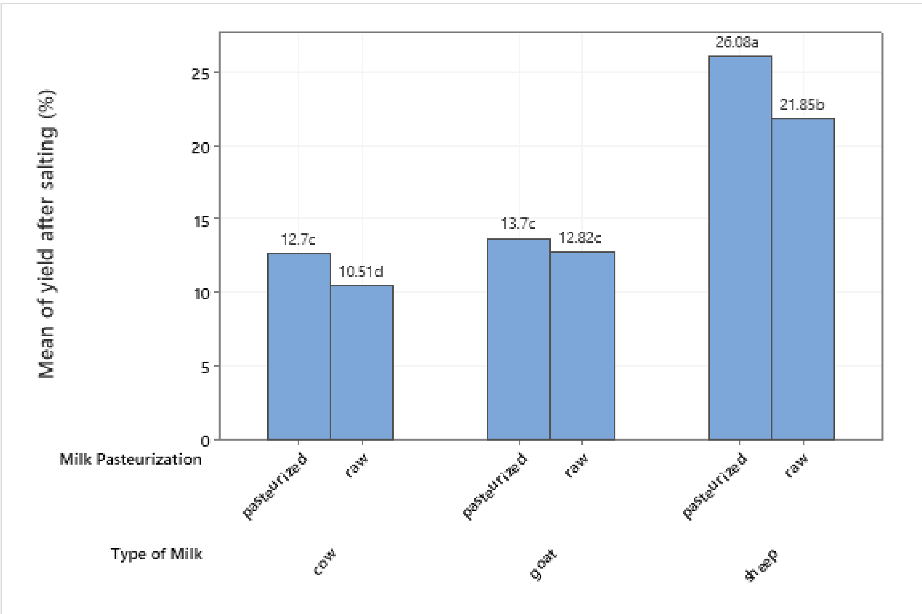


Figure 5 Effect of the two-way interaction between the type of milk and milk pasteurization on the cheese yield after salting.

In this study, it seems that the differences in cheese yield between raw and pasteurized milk were not just related to the pasteurization but also to the addition of 0.02% $CaCl_2$, which was confirmed to affect the cheese yield in previous studies **[22]**, **[23]**. Ocak et al. **[22]** relate the increase in yield caused by the addition of $CaCl_2$ to the rapid curd formation rate, which results in increased rigidity at an early stage of curd formation that, in turn, lowers the syneresis, consequently increasing the cheese yield. Makhal et al. **[23]** found that adding 0.02% $CaCl_2$ to milk without pasteurization increased the cheese yield by 4.9%, and when combined with pasteurization, the cheese yield increased to 11.18%; however, no improvement in yield when $CaCl_2$ was used in a concentration of 0.012% or 0.016% was observed. In this research, it is impossible to determine the effect of $CaCl_2$ separately from the effect of pasteurization. Therefore, the increase in yield was probably due to the combined effect of heat treatment and $CaCl_2$ addition.

Chemical Analysis: Figure 6 shows the Pareto chart for the standardized effect of different factors on moisture content. It is clear that the moisture content was significantly affected by all three main factors (type of milk, milk pasteurization, and cheese pasteurization) and the two-way interaction (type of milk*milk pasteurization), and the largest standardized effect was for milk pasteurization (7.45). Therefore, the following discussion will present the results of the two-way interaction between the milk and milk pasteurization type and the main effect of cheese pasteurization. Figure 7-a shows the main effects of cheese pasteurization (in-container heating vs. traditional boiling); in-container heating significantly increased the moisture content of cheese (40.73%) compared with traditional cheese heating (38.83%). Figure 7-b shows the effect of the two-way interaction between the type of milk and milk pasteurization. The moisture contents of cheese made from raw cow's, goat's, and sheep's milk were 35.54%, 41.11%, and 36.95%, respectively. The moisture content in cheese from raw goat's milk was significantly higher than in raw cow's or sheep's milk. Pasteurization of milk significantly increased the moisture content of cheese made from cow's and sheep's milk by 14.83% and 14.53%, respectively. However, pasteurization did not affect the moisture content in cheese made from goat's milk.

The cheese protein content was affected by the milk and milk pasteurization type without interaction effects, and the largest standardized effect was for milk pasteurization (Figure 8). Therefore, the following discussion will be limited to the significant main effects (type of milk and milk pasteurization). Milk pasteurization significantly reduced the protein content to 18.69% compared with no pasteurization, which was 21.14% (Figure 9-a). Cheese made from cow's and goat's milk had the highest protein content (21.09% and 20.31%, respectively), which differed significantly from that of cheese made from sheep's milk (18.35%) (Figure 9-b).

The fat content of cheese was significantly affected by the type of milk and milk pasteurization with no interaction effects, and the highest standardized effect was for the type of milk (6.83) (Figure 10); therefore, the following discussion will be limited to the significant main effects (type of milk and milk pasteurization). Cheese made from cow's and sheep's milk had the highest fat content (25.56% and 27.69%, respectively), significantly higher than that of cheese made from goat's milk (21.31%) (Figure 11-a). Cheese made from pasteurized milk had a significantly lower fat content (23.96%) than cheese made from raw milk (25.75%) (Figure 11-b).

The ash content of cheese was only affected by the type of milk (Figure 12). Cheese made from goat's milk had the highest ash content (15.31%), which was significantly higher than that of cheese made from cow's and sheep's milk (13.34% and 12.49%, respectively) (Figure 13).

The salt content of cheese was affected by the milk type and milk pasteurization and the interaction between them, with milk pasteurization having the highest standardized effect (4.92) (Figure 14). Therefore, the following discussion will consider only the two-way interaction between the type of milk and milk pasteurization. Cheese made from pasteurized cow's and goat's milk had significantly higher salt content (12.91% and 12.79%, respectively) than of cheese made from pasteurized sheep's milk (11.69%) (Figure 15). Milk pasteurization significantly increased the salt content in cheese made from goat's milk (12.79%) compared with that made from raw goat's milk (10.23%). However, it did not affect the salt content in other types of cheese (Figure 15). The differences in salt content derived from the milk type used might be related to variations in salt diffusion coefficient in distinct types of cheese **[26]**. The effect of milk pasteurization on salt content in goat's milk cheese might be explained by the changes in whey protein structure, affecting the salt diffusion coefficient.

As illustrated in Figure 16, the pH value of cheese was significantly affected by the milk and milk pasteurization type and the two-way interaction between them; therefore, only the two-way interaction between milk type and milk pasteurization will be presented. The type of milk had the highest standardized effect (9.16) on the pH of cheese (Figure 16). Milk pasteurization significantly increased the pH values of cow's and goat's milk cheese. However, it did not affect the pH of cheese made from sheep's milk (Figure 17).

Summarizing the chemical analysis results, the milk type significantly affected the cheese's chemical composition. Cheese made from cow's and goat's milk (either raw or pasteurized) had significantly higher protein content (21.09% and 20.31%, respectively) (Figure 9) and salt levels when using pasteurized milk (12.91% and 12.79%, for cow's and goat's milk, respectively) (Figure 15). Cheese from cow's and sheep's milk had significantly higher fat content (25.56% and 27.69%, respectively) (Figure 11-a), whereas cheese from goat's milk had significantly higher ash content (15.31%). Pasteurization of milk significantly lowered the fat (Figure 11-b) and protein contents (Figure 9-a) in the cheese and significantly increased the cheese's moisture (Figure 7-b), salt content (Figure 15), and pH (Figure 17), depending on the type of milk used. In-container heating of cheese significantly increased the moisture content of cheese.

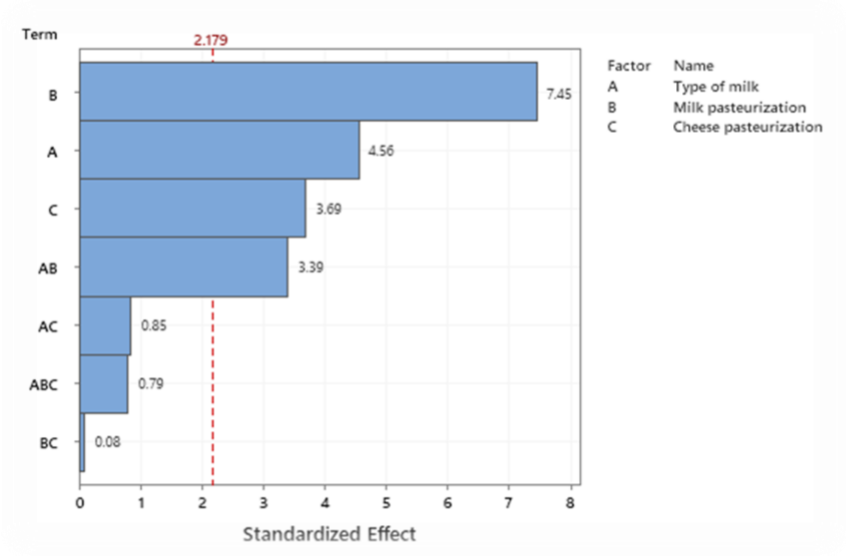
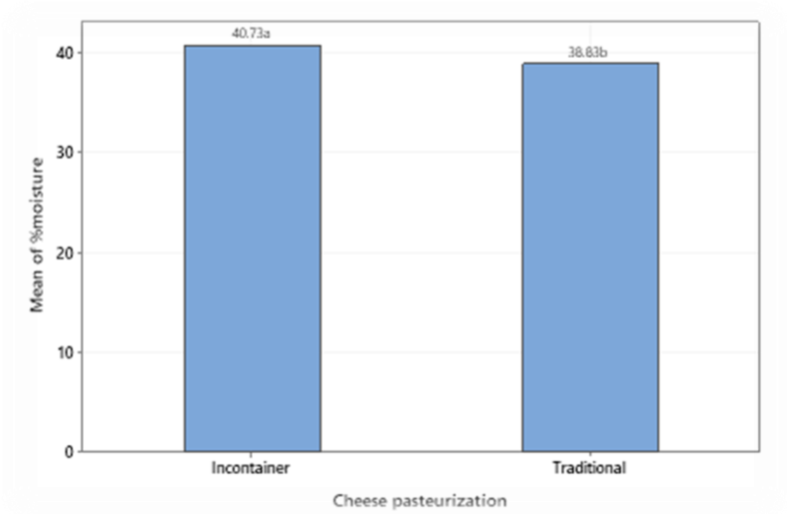


Figure 6 Standardized effects of different factors on the moisture in Nabulsi cheese.

A. Cheese pasteurization



B. Two-way interaction between the type of milk and pasteurization

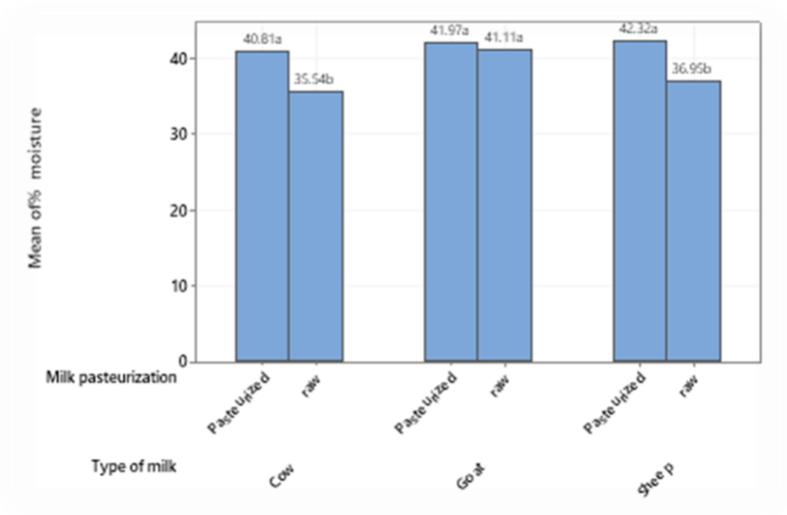


Figure 7 Effects of cheese pasteurization (A) and two-way interaction between the type of milk and milk pasteurization (B) on moisture in Nabulsi cheese.

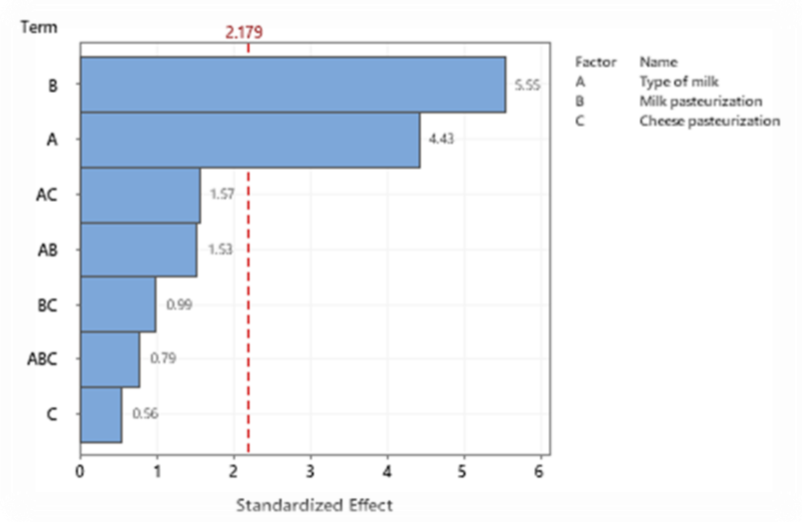
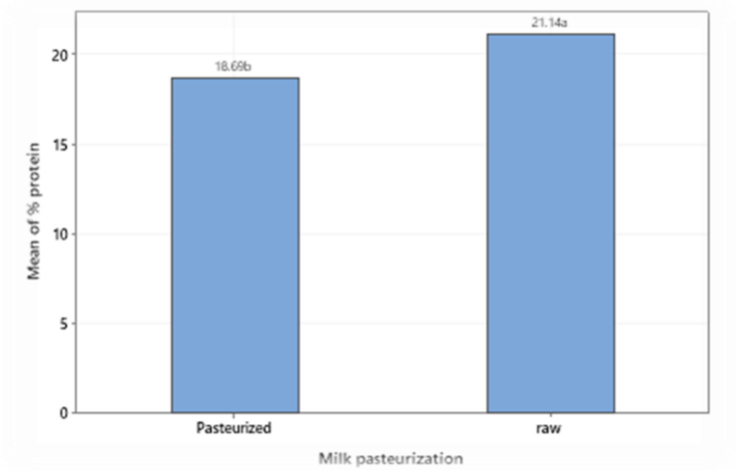


Figure 8 Standardized effects of different factors on the protein content in Nabulsi cheese.

A. Milk pasteurization



B. Milk type

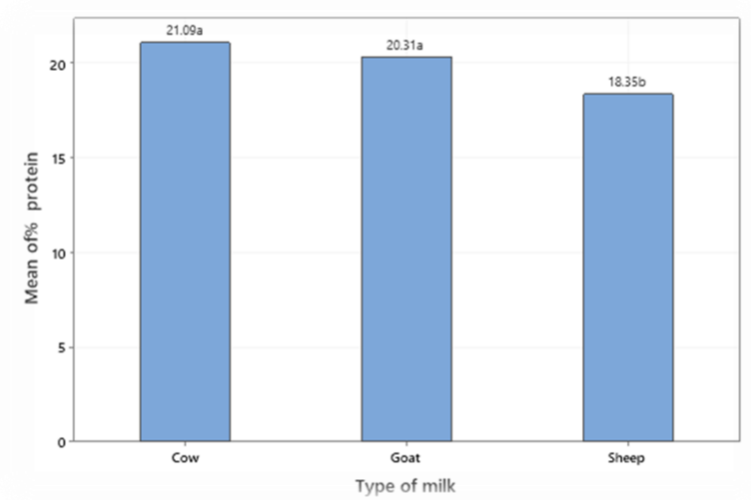


Figure 9 Effects of milk pasteurization (A) and type of milk (B) on the protein content in Nabulsi cheese.

In this study, the chemical composition of cheese made from raw cow's milk was lower than those of **[27]** for moisture, pH, and protein content and higher for fat and ash contents. Compared with the results reported by **[28]**, it has lower moisture content and higher protein, fat, and ash contents. Raw sheep's milk cheese it contains lower moisture and higher protein, fat, and ash contents compared with that reported by **[5]**. The chemical composition of cheese was attributed to the milk type and source, cheese manufacturing methods, seasonal fluctuations, cattle diet, curd pressing degree, and whey drainage **[28]**.

The effects of milk pasteurization on cow's and sheep's milk cheese chemical analysis agreed with those for white cheese found by **[20]**, **[29]**. The effect of milk pasteurization on the chemical composition of cheese might be related to the water and salt retention by cheese related to the pasteurization of milk and to $CaCl_2$ addition, discussed previously in the yield section.

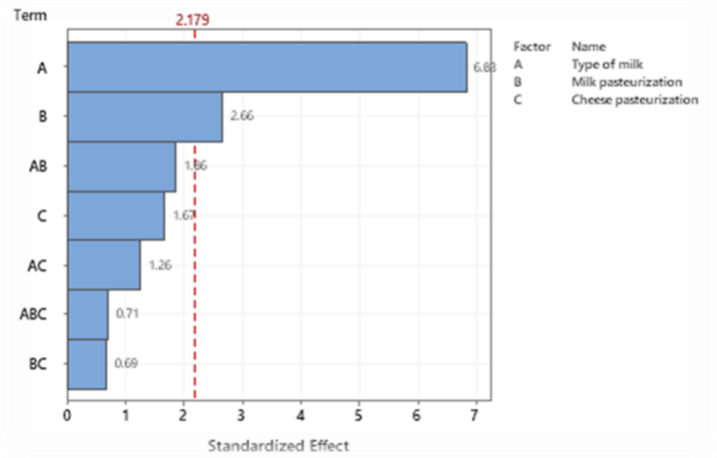
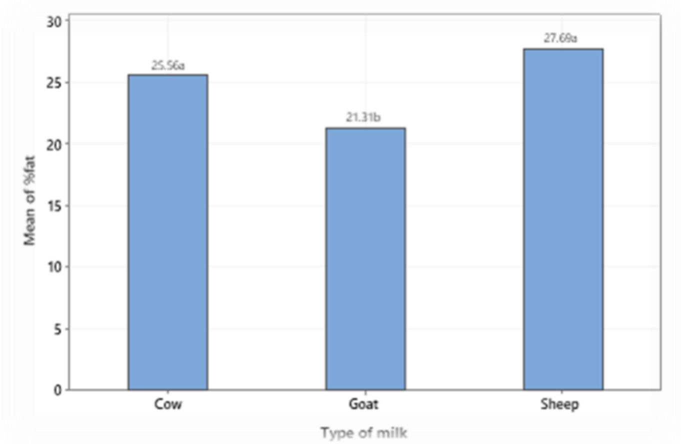


Figure 10 Standardized effects of varied factors on the fat content in Nabulsi cheese.

A. Type of milk



B. Milk pasteurization

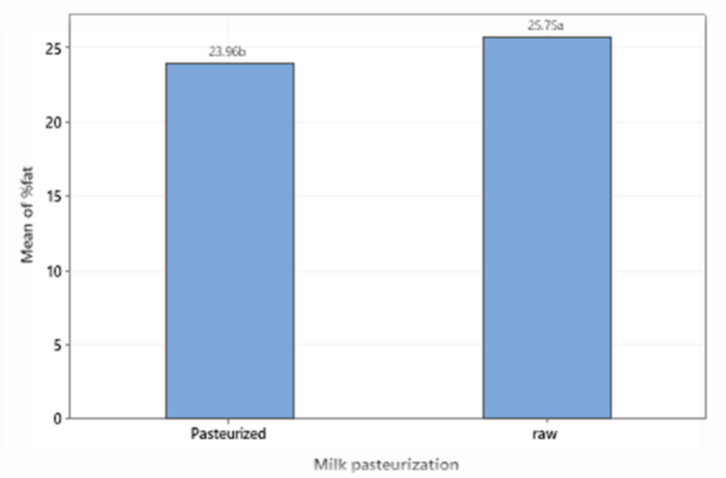


Figure 11 Effects of the type of milk (A) and milk pasteurization (B) on the fat content in Nabulsi cheese.

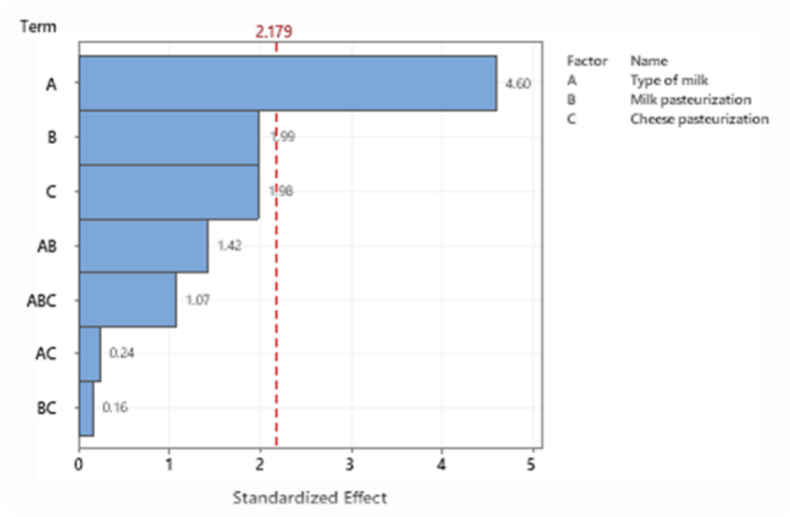


Figure 12 Standardized effects of distinct factors on the ash content in Nabulsi cheese.

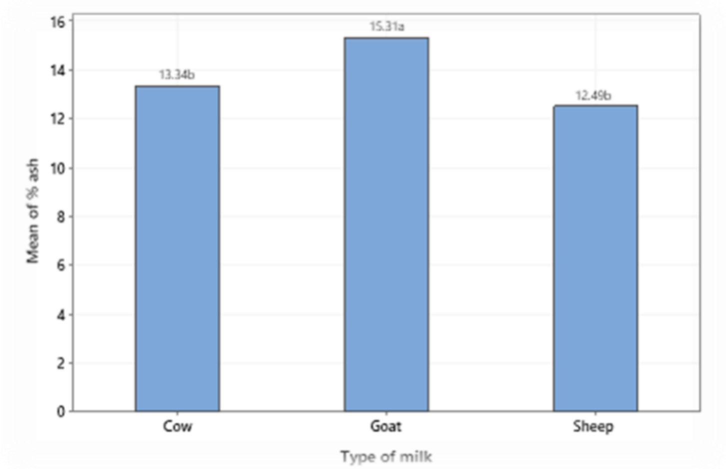


Figure 13 Effect of the type of milk on the ash content in Nabulsi cheese.

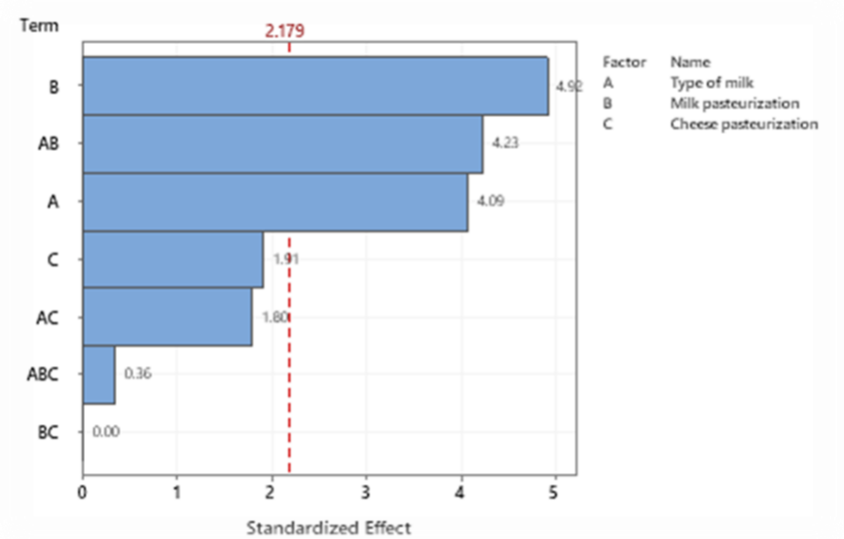


Figure 14 Standardized effects of distinct factors on the salt content in Nabulsi cheese.

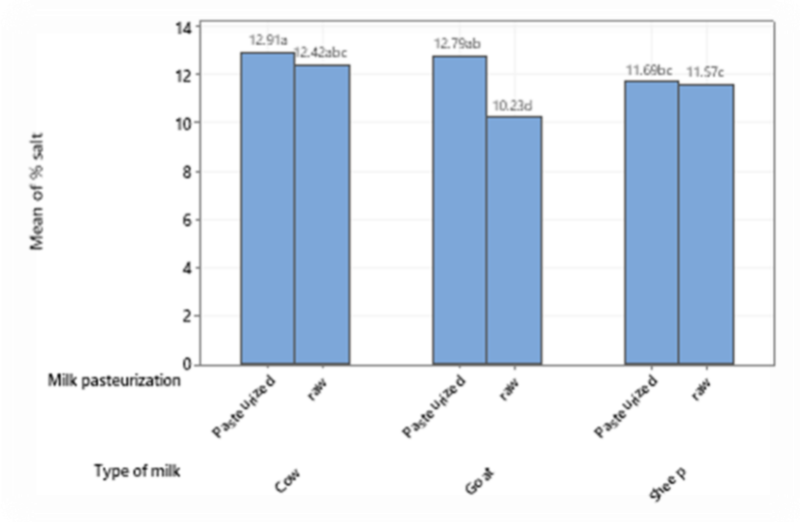


Figure 15 Effects of the two-way interaction between the type of milk and milk pasteurization on the salt content in Nabulsi cheese.

The effect of in-container heating in increasing the moisture content of cheese might be related to the prevention of water evaporation from cheese, which is encountered during the traditional boiling step; this is commercially made in water baths open to the surrounding atmosphere. This evaporation was prevented during in-container heating, which resulted in the cheese's increased moisture content.

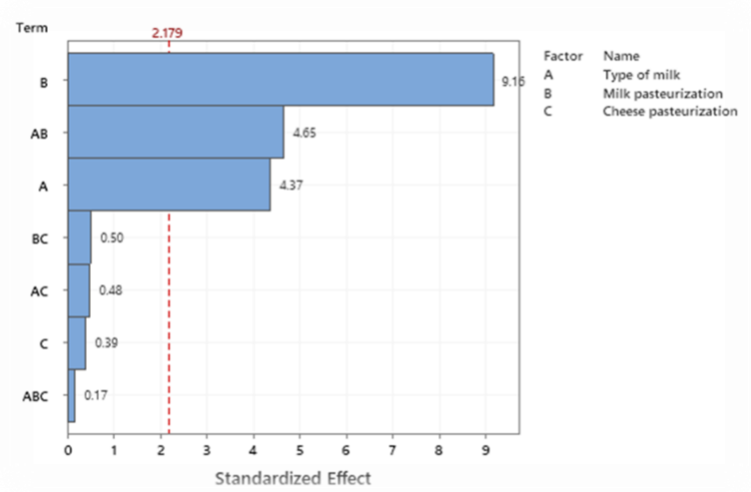


Figure 16 Standardized effects of distinct factors on the pH of Nabulsi cheese.

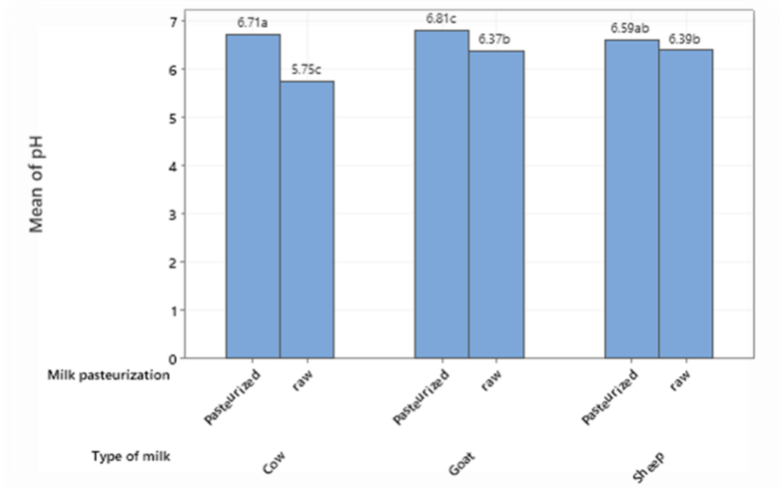


Figure 17 Effects of the two-way interaction between the type of milk and milk pasteurization on the pH of Nabulsi cheese.

TPA: In the following discussion of TPA parameters, the springiness values were not presented because they were close to 1 and not significantly affected by the factors investigated in this study. Similarly, the adhesiveness results were not presented because they were too small to be of practical importance and were not affected by the factors investigated in this study.

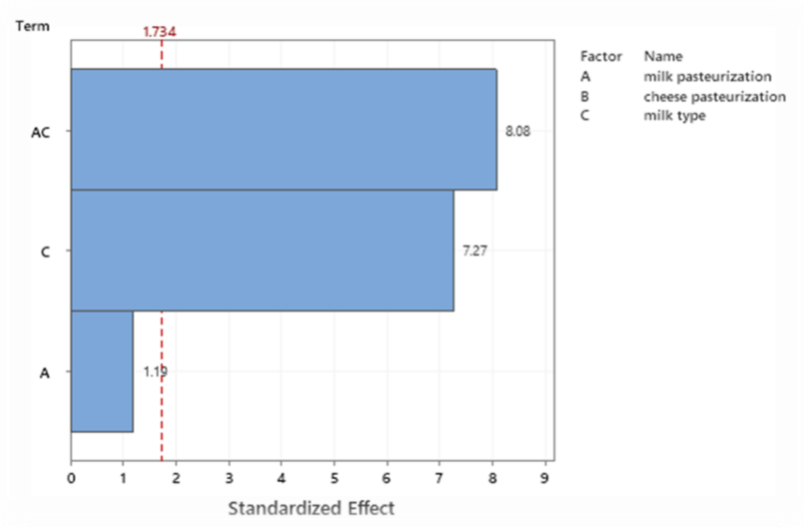


Figure 18 Standardized effects of different factors on the hardness of Nabulsi cheese.

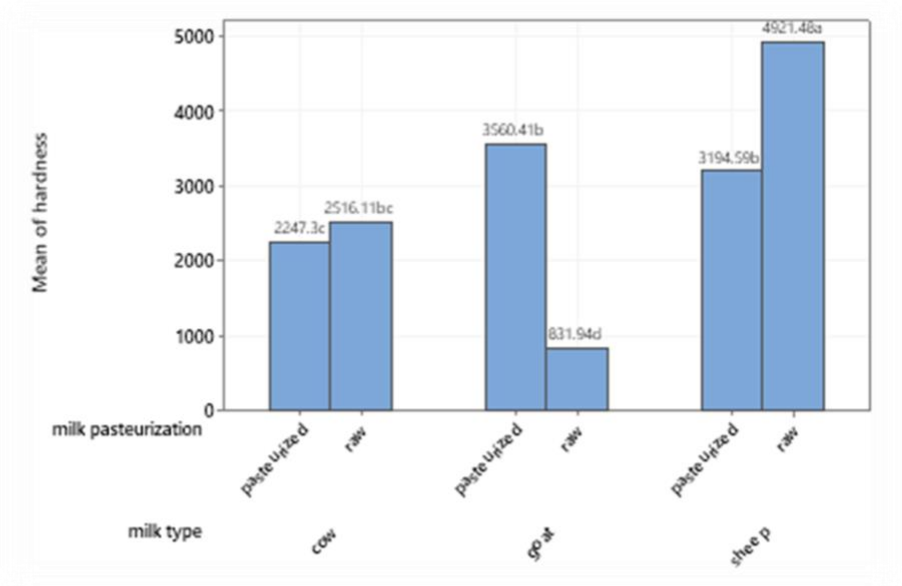


Figure 19 Effects of the two-way interaction between the type of milk and milk pasteurization on the hardness of Nabulsi cheese.

Hardness was affected by the type of milk and the two-way interaction between the type of milk and milk pasteurization (Figure 18); therefore, the following discussion will be limited to the significant two-way interaction (type of milk*milk pasteurization). The hardness values (Figure 19) for cheese made from raw cow's, goat's, and sheep's milk (2516.11, 831.94, and 4921.48 g, respectively) differ significantly from each other, with the highest value for cheese made from sheep's milk and the lowest for cheese made from goat's milk. These findings agreed with previous studies showing that sheep's milk cheese had higher hardness values than cow's milk cheese **[30]**, **[31]**, **[32]**. Milk pasteurization affected the hardness of Nabulsi cheese depending on the type of milk used. For cow's milk, pasteurization did not significantly affect the hardness (2247.3 g), whereas, for goat's milk, pasteurization significantly increased hardness to 3560.41 g.

In contrast, sheep's milk was significantly reduced to 3194.59 g. The decrease in hardness values due to milk pasteurization was previously reported **[34]**, **[29]**. On the contrary, **[33]** reported increased hardness for cheese made from pasteurized milk. The difference in the effect of pasteurization on the hardness of cheese made from different types of milk might be related to the protein structure **[26]**, extent of denaturation upon heating **[33]**, and severity and type of heat treatment **[29]**. The decrease in hardness upon milk pasteurization might be related to the protein's increased moisture-holding capacity **[34]**, **[29]**. The significant increase in moisture in cheese made from sheep's milk upon pasteurization (Figure 7-b) and the subsequent decrease in hardness (Figure 19) supports the previous hypothesis. Conversely, the increase in hardness upon milk pasteurization might be related to the denaturation of whey protein and complex formation with casein micelles **[33]**.

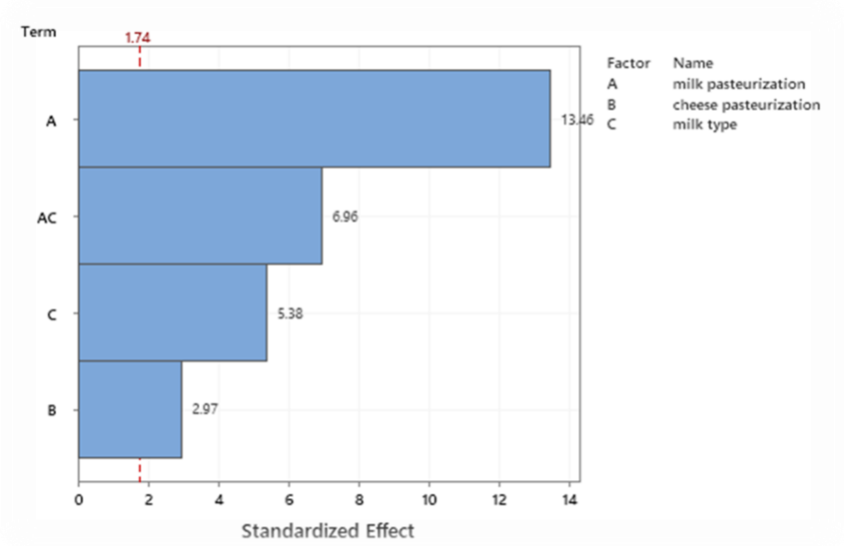
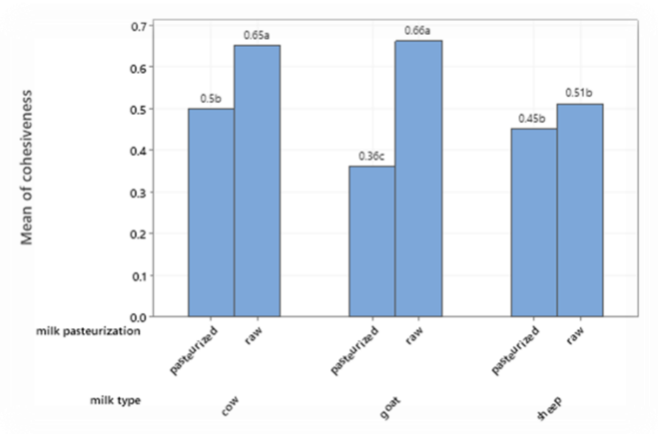


Figure 20 Standardized effects of distinct factors on the cohesiveness of Nabulsi cheese.

A. Two-way interaction between the type of milk and milk pasteurization



B. Cheese pasteurization

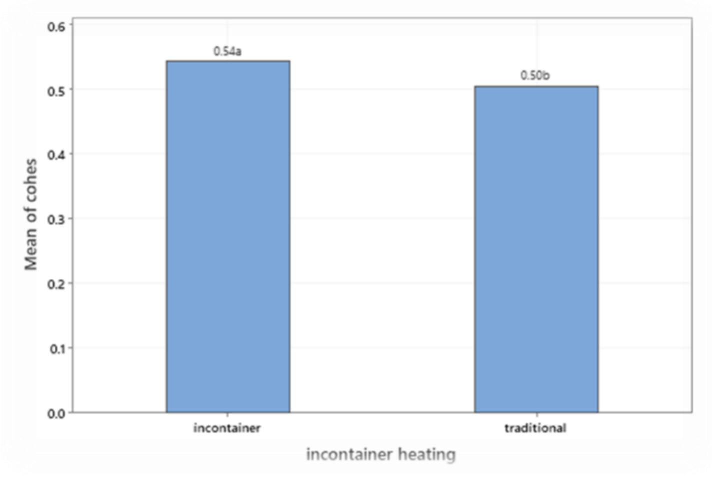


Figure 21 Effects of the two-way interaction between the type of milk and milk pasteurization (A) or cheese pasteurization (B) on the cohesiveness of Nabulsi cheese.

Cohesiveness is the strength of the internal bonds that comprise the product's body **[33]**. The cohesiveness values of Nabulsi cheese were affected by the three studied factors and by the two-way interaction between the type of milk and milk pasteurization (Figure 20); therefore, the results of the main effect of cheese pasteurization and the two-way interaction type of milk*milk pasteurization will be presented.

As shown in Figure 21-a, the cohesiveness of cheese made from raw cow's and goat's milk (0.65 and 0.66, respectively) did not differ significantly. However, they were significantly higher than cheese made from raw sheep's milk (0.51). Milk pasteurization significantly reduced the cohesiveness values of cheese made from cow's and goat's milk (0.5 and 0.36, respectively), with significant differences between them. However, pasteurization did not significantly affect the cohesiveness of cheese made from sheep's milk (0.45). In-container heating of cheese significantly increased cohesiveness to 0.54 compared with the traditional method (0.50) (Figure 21-b), which may be related to the higher moisture content of cheese heated in-container. This is in line with the results reported by **[27]**, who found that cheese cohesiveness increased with increasing moisture content. The differences in cohesiveness values from different types of cheese made from different types of milk might be related to the changes in protein–protein and protein–water interactions.

Chewiness is the amount of energy required to chew a solid food until it is ready to swallow and is calculated as the product of hardness, cohesiveness, and springiness **[33]**. As shown in Figure 22, the chewiness values were significantly affected by the type of milk and milk pasteurization, two-way interaction (type of milk*milk pasteurization), and three-way interaction (type of milk*milk pasteurization*heat treatment of cheese); therefore, the results of the three-way interaction will be presented. The three-way interaction is illustrated in Figure 23; in-container heating of cheese did not significantly affect chewiness compared with traditional heating of cheese regardless of the type of milk used or whether the milk used was raw or pasteurized. Milk pasteurization did not affect chewiness compared with no pasteurization for cheese made from cow's and goat's milk. However, milk pasteurization significantly affected chewiness in cheese made from sheep's milk. Cheese made from pasteurized milk and heated in-container had the lowest value (1192.07 g), which differed significantly from other cheese made from raw sheep's milk and heated either by in-container heating or using the traditional method. The lowest chewiness values were for cheese made from raw goat's milk whether heated in-container or using the traditional method (517.45 and 385.35 g respectively), and the highest values were for cheese made from raw sheep's milk whether heated in-container or using the traditional method (2620.45 and 2341.86 g, respectively). Chewiness is a secondary parameter calculated from primary parameters (hardness, cohesiveness, and springiness) and therefore affected by factors affecting these parameters.

A sample of the produced Nabulsi cheese is shown in Figure 24.

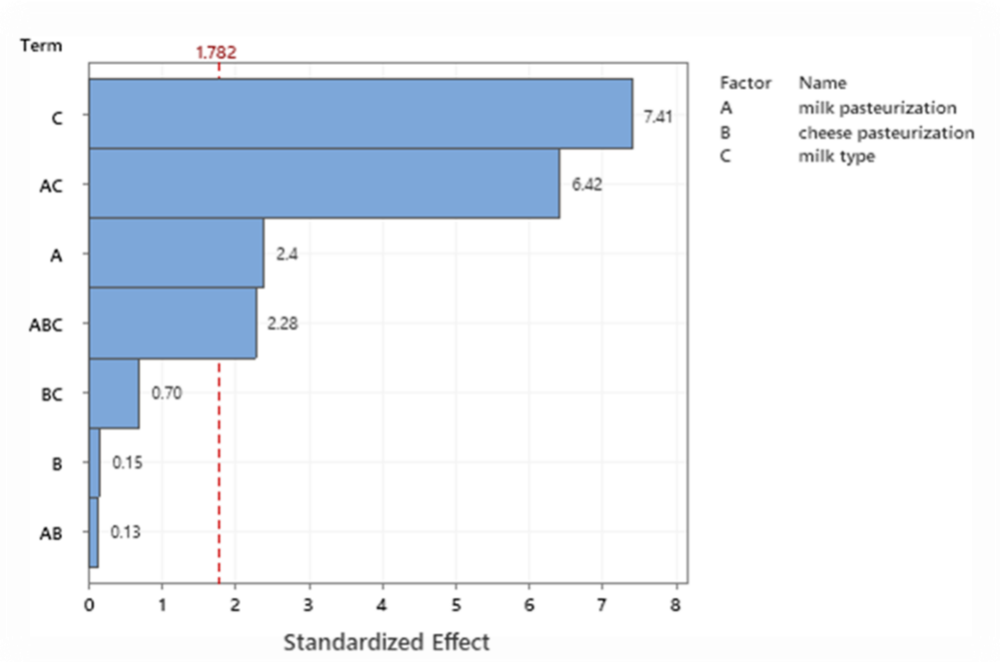


Figure 22 Standardized effects of distinct factors on the chewiness of Nabulsi cheese.

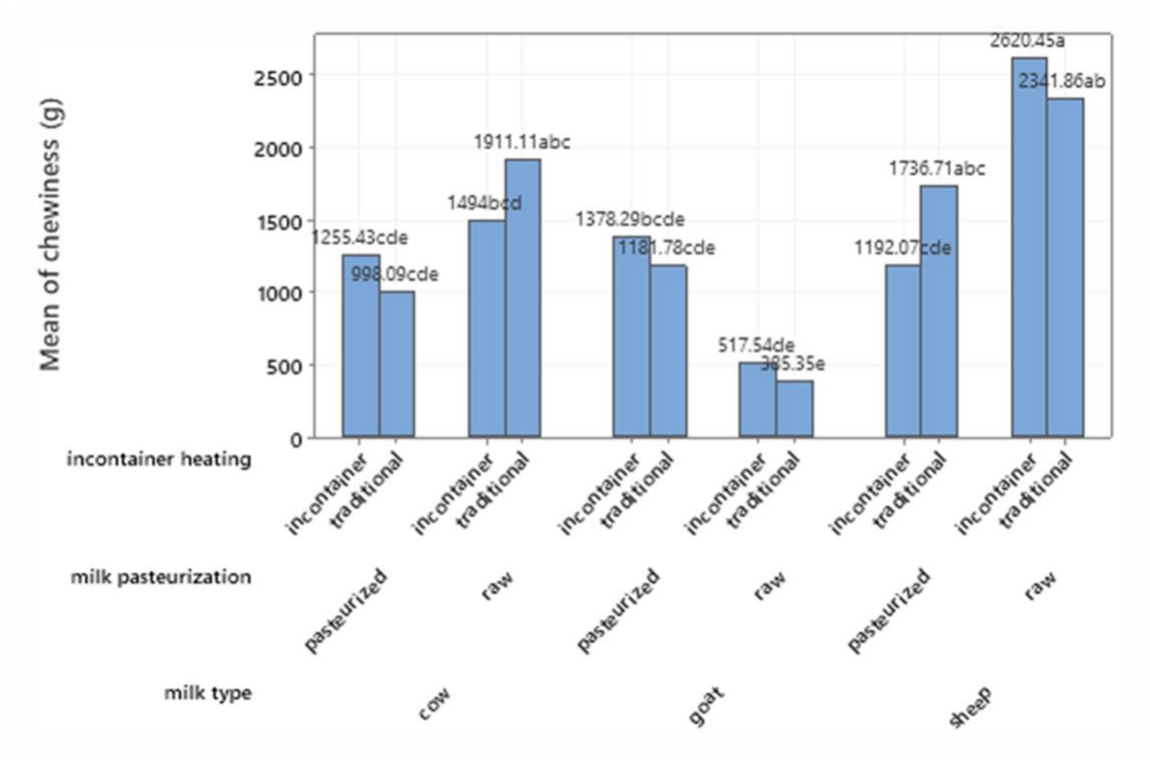


Figure 23 Effects of the three-way interaction (type of milk*milk pasteurization*cheese in-container heating) on the chewiness of Nabulsi cheese.

Figure 24 Nabulsi cheese.

CONCLUSION

White-brined Nabulsi cheese producers increasingly adopt milk pasteurization, $CaCl_2$ addition, and in-container heating as industry standards, which indicates the importance of investigating their effects on the yield, chemical composition, and TPA of cheese produced from different types of milk. Cheese made from sheep's milk had the highest yield after pressing or salting, followed by goat's and cow's milk. Pasteurization of milk significantly increased the yield (after pressing and salting) of cheese made from cow's and sheep's milk but did not affect the yield of cheese made from goat's milk. The type of milk significantly affected the chemical composition of cheese. Cheese made from cow's and goat's raw or pasteurized milk had significantly higher protein content (21.09% and 20.31%, respectively), and when using pasteurized milk, had higher salt (12.91% and 12.79%, respectively) than cheese made from sheep's milk. Cheese from cow's and sheep's milk had significantly higher fat content (25.56% and 27.69%, respectively), whereas cheese from goat's milk had significantly higher ash content (15.31%). Pasteurization of milk significantly lowered the fat and protein contents of cheese. It significantly increased the cheese's moisture, salt levels, and pH depending on the type of milk used. In-container heating of cheese significantly increased the moisture content of cheese. There were significant differences in the hardness of cheese made from raw milk, with the highest value for sheep's milk and the lowest for goat's milk. Cheese made from sheep's milk had significantly lower cohesiveness than cow's or goat's milk. Cheese made from raw sheep's milk had the highest chewiness value, which significantly differs from other types of cheese. The literature contains almost no information regarding the effects of the factors investigated in this study on the quality of Nabulsi cheese; therefore, the results of this research will give cheese producers an insight into the impact of adopting the new processes investigated in this research on the quality of Nabulsi cheese and the cost of production as it is affected by the cheese yield. In addition, the results give information about the factors affecting the quality attributes of Nabulsi cheese measured in this study that could be used for future studies to optimize the process of Nabulsi cheese production.

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Ethical Statement:

This article does not contain any studies that would require an ethical statement.

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