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Machine Learning Method (Decision Tree) to Predict the Physicochemical Properties of Premium Lebanese Kishk Based on Its Hedonic Properties

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Abstract: This study sets the criteria of high-grade kishk (a dried fermented cereal–milk product) based on sensory attributes. For this, kishk samples were collected, and physicochemical attributes and sensory attributes were recorded. Subsequently, Spearman's correlation between sensory properties and physicochemical properties was calculated. A decision tree [DT] was applied with the mean total sensory score [MTSC] as the dependent factor to establish the physicochemical factor/s upon which the different kishk grades were set. To compare the physiochemical attributes of the different grades, the general linear model was applied. Moisture content is negatively and significantly correlated with most sensory attributes. Titratable acidity [TA] is positively and significantly correlated with most sensory attributes. The DT analysis showed that TA was the classifying factor [$p = 0.01$], and accordingly, grade A [TA $\geq$ 4.56], grade B [2.50 < TA < 4.56], and grade C [TA $\leq$ 2.50] kishk data were established, showing MTSC values of 6.32 $\pm$ 0.32, 5.26 $\pm$ 0.36, and 4.40 $\pm$ 0.20, respectively. Applying DT analysis with kishk grades as independent variables, pH was a classifying factor, with 3.95 as the cutoff point. Moisture [$p = 0.018$], the protein-to-fat ratio [P:F] [$p = 0.027$] and pH [$p < 0.001$] differ significantly between the different kishk grades. Accordingly, the criteria for grade A kishk are TA $\geq$ 4.56, pH $\leq$ 3.95, moisture < 4%, P:F < 2.03, and particle density < 1489. The low pH and moisture content render it a shelf-stable high-acid food.

Keywords: machine learning; decision tree; kishk; grades; physicochemical properties; sensory attributes

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Citation: Dimassi, O.; Iskandarani, Y.; Shaib, H.; Jaber, L.; Hamadeh, S. Machine Learning Method (Decision Tree) to Predict the Physicochemical Properties of Premium Lebanese Kishk Based on Its Hedonic Properties. *Fermentation* **2024**, *10*, 584. https://doi.org/10.3390/fermentation10110584

Academic Editor: Nikos G. Chorianopoulos

Received: 3 September 2024
Revised: 27 September 2024
Accepted: 9 October 2024
Published: 14 November 2024

1. Introduction

Cereal grains are a major global source of dietary nutrients. However, they frequently lack certain essential components, particularly specific amino acids. In contrast, milk is an important source of calcium and animal protein, but it is highly perishable. Fermentation, initially developed as a method for food preservation, is now employed to improve the physicochemical, sensory, nutritional, and safety properties of various food products [1]. Kishk, a traditional food product, entails the incorporation of yogurt into bulgur, which is composed of cracked, bran-free parboiled wheat. The resulting paste-like mixture undergoes fermentation at ambient temperature for varying durations prior to drying [2].

Fermentation is the oldest, most widely spread and largely economical method for producing and preserving food [2]. Fermentation leads to an improvement in food nutritional value, sensory properties, and functional qualities [2,3]. It also naturally leads to the production of a safer product, the enhancement of the nutritive value of the food and a reduction in the energy required for cooking to make a safer product [2]. Fermentative microorganism products in food have been associated with health benefits [4]. Amid fermentation, lactic acid bacteria, a well-elucidated group of fermentative microorganisms, synthesize vitamins and minerals, produce biologically active peptides through enzymes such as proteinases and peptidases, and eliminate certain non-nutritional components. [4,5]. Examples of their health benefits are anti-oxidant, anti-microbial, anti-fungal, anti- inflammatory, anti-diabetic and anti-atherosclerotic activity products [4].

Physicochemical properties, particularly fat and protein content, play a crucial role in determining the sensory attributes of fermented foods, such as stirred yogurt. A descriptive analysis was conducted to examine the effects of fat, protein, and the casein-to-whey protein ratio on the sensory properties of stirred yogurt, as well as the interactions among these factors [6]. Furthermore, an investigation of fat and protein content in stirred yogurt concluded that fat was the most significant component, followed by its interaction with protein, the overall effect of protein, and the influence of the casein-to-whey protein ratio [6]. In another study focused on systematically controlled variations in milk fat and protein content, the authors found that understanding the relative effects of various milk protein ingredients on the textural and flavor characteristics of milk-based beverages could guide product reformulation and ingredient selection to achieve specific sensory profiles [7].

Kishk, a traditional dried mixture of fermented milk and bulgur, is a widely consumed stable food in various regions of the Middle East. Variations in production methods and raw materials result in a diverse range of physicochemical properties, both within and across geographical locations [8–15]. The production of kishk involves the incorporation of yogurt into bulgur, which consists of cracked, bran-free parboiled wheat. This resulting paste-like mixture is then allowed to ferment at ambient temperature for varying durations before undergoing the drying process [2]. In certain cases, this mixture may be maintained at a temperature of 40 °C for one day [16].

Flavor plays a crucial role in determining consumer acceptance of kishk, a fermented cereal-milk product. Kishk can be classified as an acidic food. Kishk is considered safe due to its low moisture content and pH, causing it to be considered sour [15,17]. Sour taste perception is a complex event from both chemical and physiological standpoints. A clear understanding of the chemistry and physiology of sour taste is needed to achieve a consistent flavor through the control of titratable acidity, buffer capacity, molar concentration, and physical and chemical structure [18].

The literature regarding the impact of processing conditions on sensory properties is limited [15,17]. To our knowledge, no studies have examined the relationships among geographical location, sources of fermented milk, physicochemical attributes, and the organoleptic properties of dry kishk. Moreover, our review indicates that no research has employed decision trees to analyze sensory scores in order to establish and define the quality attributes of different grades of kishk. Machine learning algorithms are instrumental in analyzing sensory data, facilitating the accurate identification and assessment of sensory scores based on various physicochemical attributes of the food. This approach parallels existing reviews on food quality assessment utilizing machine learning and electronic nose systems, with the e-nose data in our study being substituted with sensory scores [19].

The primary objective of this study is to investigate and elucidate the relationship between the sensory attributes and the chemical properties of kishk. This research aims to identify the physicochemical properties that are most critical to the hedonic characteristics of the product. Following the identification of these key properties, kishk will be systematically categorized into distinct groups based on its characteristics. Subsequently, the physicochemical properties of the various grades of kishk will be thoroughly examined to gain a deeper understanding of how these attributes influence overall sensory perception and consequently consumer preference.

2. Materials and Methods

2.1. Sample Collection

Thirty-three kishk samples were collected from the Chouf-17-producing and Western Beqaa-16-producering regions of Lebanon, well known for its kishk production. Chouf district producers used cow's milk [12 producers], goat's milk [4 producers] and goat and cow mixed milk [1 producer]. From the 16 Western Beqaa district kishk producers, 5 used cow's milk, 6 used goat's milk and 5 used mixed goat and cow's milk.

2.2. Physiochemical Properties

The Official Methods of Analysis AOAC INTERNATIONAL Method 930.15 [20] was followed to determine moisture content using the oven-drying method [21]. AOCS Official Procedure Am 5-04, AOAC 920.39 [22], was used to determine fat content using high-temperature solvent ether extraction [23,24]. The Kjeldahl method with a conversion factor of 6.25 was used to determine protein content [23,25]. Briefly, around 0.5 g of each sample was digested at 400 °C with concentrated sulfuric acid, which converted nitrogen into ammonium sulfate. Following digestion, 50 mL of 50% NaOH was added to the digestion vessel to convert ammonium sulfate to ammonia, which was distilled and captured in a 2% boric acid indicator solution, and then quantified through titration with standard HCl (0.1 N). Using the ANKOM 200 Fiber Analyzer (ANKOM Technology, Macedon, NY, USA) with a measuring range of 0 to 100%, fiber content was determined [26,27]. Briefly, 1 g of sample was weighed in an F57 filter bag and defatted with acetone for 10 min. The sample was then subjected to sequential extraction with 0.255 N sulfuric acid and 0.313 N NaOH solutions to remove soluble components. The remaining residue's weight was measured after drying and incineration to conclude the crude fiber contents. Ash content was determined by ashing at 550 °C [23,28]. A HygroLab-3 Bench top humidity temperature indicator (HygroLab3) (Rotronic Instrument Corp., Hauppauge, NY, USA) was used to determine water activity at 25 °C, using around 5 g of each sample [14]. pH, titratable acidity, electrical conductivity and total dissolved solids (TDS) were determined by weighing 10 g of kishk and adding 20 mL of deionized water to 50 mL disposable centrifuge tubes to make a 1:2 soil/deionized water solution and proceeding according to the standard operating procedure for pH and electrical conductivity in soil and soil-like media [29–31]. The determination of all physicochemical properties was repeated three times per one sample

2.3. Calculated Properties: Protein-to-Fat Ratio, Carbohydrate, Particle Density

The protein-to-fat ratio was calculated by dividing the protein by the fat percentage. Carbohydrates were calculated by subtraction, where moisture, fat, protein, fiber and ash content were added and subtracted from the kishk sample weight [32]. As for the particle density, it was calculated based on particle density values given in the introduction to a food engineering book, shown in Appendix 2, with the title Physical Properties of Food with the sub-table A.2.9, with the following caption: Coefficients to Estimate Food Properties Equation (1) [33].

$$\begin{gathered}\text{Particle density} = (\text{kg/m}^3)\\ \text{Protein\%} * \text{Protein density } (1316.9) + \text{Fat\%} * \text{Fat density}(915.2) + \text{Carbohydrate \%} * \text{Carbohydrate}\\ \text{density } (1591.3) + \text{Fiber\%} * \text{Fiber density } (1302.4) + \text{Ash \%} * \text{Ash density } (2416.8)\\ + \text{Moisture \%} * \text{Water density } (994.9)\end{gathered} \tag{1}$$

Equation (1): particle density equation for protein, fat, carbohydrate, fiber, ash and water densities calculated using Singh, R Paul, and Dennis R Heldman 2001, assuming temperature = 25 °C [33].

2.4. Sensory Analysis

A sensory panel evaluated the kishk samples following the protocol established by Muir et al. (1995), which was applied to a variety of commercial samples [34]. The tasting panel comprised seven experts involved in the production and consumption of kishk and one without specific experience in kishk. The unexperienced panelist was familiarized with the sensory characteristics of kishk by tasting selected commercial samples [17].

Initially, the panel collaborated to create a list of descriptors. During the sensory assessment, they evaluated pre-oral sensory attributes before assessing the oral sensory attributes [35–37], which are summarized in Table 1. A ten-point hedonic scale was employed, ranging from excellent (score = 10) to very poor (score = 0) as the extremes [38]. Each kishk sample was coded, with the origin disclosed only after the evaluations were completed, ensuring that five experts assessed each sample.

Table 1. Sensory attributes.

Pre-Oral Sensory Attributes	Oral Sensory Attribute
Texture	Mouthfeel
Aroma	Saltiness
Appearance	Taste

2.5. Statistical Analysis

All tests were conducted using IBM SPSS statistics version 21. As for the statistical analysis of the sensory data, an independent paired t-test was used to assess if there was a difference between the panelist with no experience and those with experience. When none was detected, the data were included in the analysis.

The general linear model was used to check for the difference in taste scores based on the district and the type of fermented milk used. After finding no significant difference between the different sensory scores based on geographical location and the milk type used, all the sensory data were pooled for Spearman's correlation and machine learning analysis, mainly involving the decision tree method. The general linear model was also used to check for the difference in the physicochemical properties of grades A, B and C kishk. Only in case of the protein-to-fat ratio was the type of milk was taken as a covariate.

Spearman's correlation was applied to the physicochemical properties and different sensory attributes, including the average total score. As for the decision tree, it was chosen since decision trees are suitable methods for analyzing the relationship between independent variables, the physicochemical properties of food, and a dependent variable, the average total sensory score. In this study, we applied the decision tree to the objective and explanatory variable described above. To construct the decision tree, we adopted the chi-square automatic interaction detector (CHAID) algorithm. The maximum depth of the decision tree was set to 3 provisionally, and the minimum cases in the parent node was set to 10 and the minimum cases in the child node to 3.

3. Results

3.1. District and Type of Milk Used

After analyzing the data, no significant difference was detected in all the sensory attributes, such as texture, aroma, appearance, mouthfeel, saltiness and taste of kishk, from Chouf district when compared with those from the kishk from Western Beqaa district, with means of 5.0 ± 0.5 and 5.5 ± 0.3, respectively (Figure 1). The same is true when the sensory attributes based on the type of milk—goat, cow and mixed goat and cow milk—used in kishk production, with means amounting to 5.3 ± 0.4, 5.3 ± 0.3 and 5.0 ± 0.7, respectively (Figure 2).

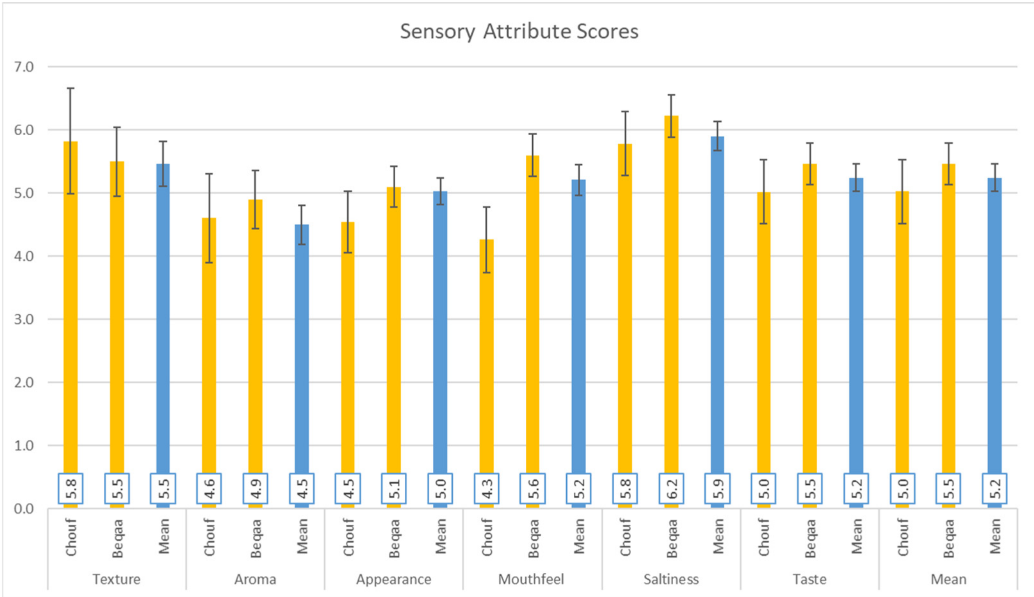

Figure 1. Sensory attributes scores based on district (Mean ± SE); Chouf: 17 samples and Beqaa: 16 samples.

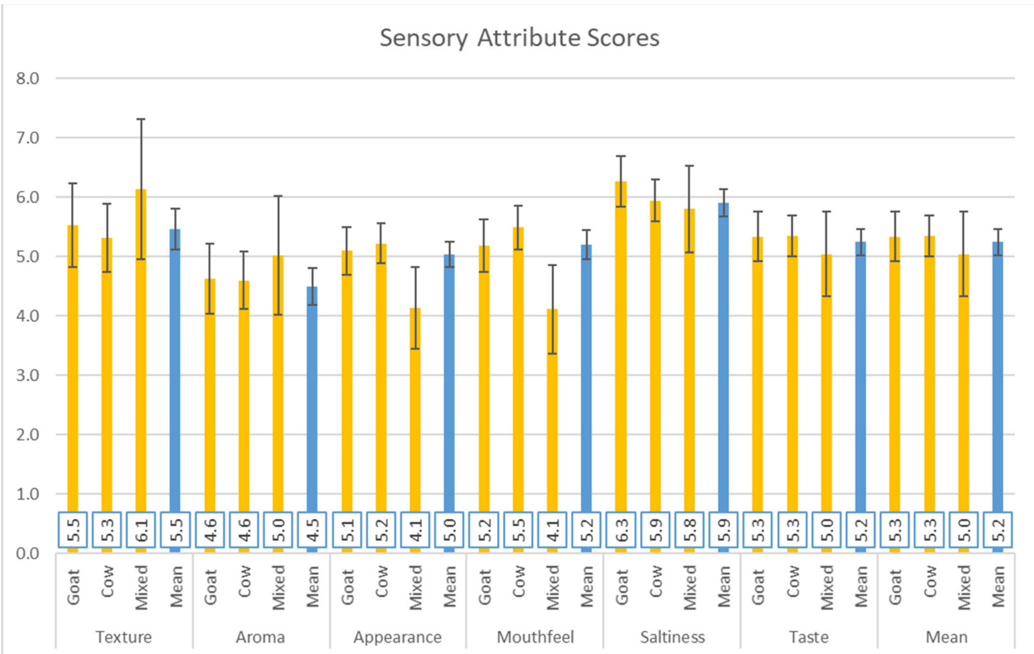

Figure 2. Sensory attributes scores of kishk dependent on milk type (Mean ± SE). Goat: 10 samples; Cow: 17 samples; mixed goat and cow milk: 6 Samples.

3.2. Protein-to-Fat Ratio

The protein-to-fat ratio did not exhibit significant differences when analyzed according to geographical origin. However, a notable distinction emerged when the ratios were evaluated based on the type of milk utilized in the production of kishk. Specifically, kishk made from goat's milk demonstrated a significantly lower protein-to-fat ratio in comparison to kishk produced with cow's milk. Furthermore, the protein-to-fat ratio of kishk made from a blend of cow and goat milk did not show a statistically significant difference when compared to the ratios of kishk made solely from either goat or cow milk (Table 2).

Table 2. Protein-to-fat ratio of kishk carried out for different milk types.

Milk Type	Producers	Kishk Protein-to-Fat Ratio
	N	Mean ± SE
Goat	10	1.73 ^{a} ± 0.05
Cow	17	2.47 ^{b} ± 0.04
Mix of goat and cow	6	2.16 ^{ab} ± 0.01
Total mean		2.18 ± 0.02

Within the mean column, means with different alphabetic superscripts that are significantly different. $p = 0.027$.

3.3. Spearman's Correlation

None of the evaluated sensory attributes of kishk exhibited significant correlations with the measured values of fat, protein, carbohydrate, fiber, ash, water activity, or particle density. However, moisture content demonstrated a significant negative correlation with most sensory attributes, with an overall mean score correlation of −0.376 (Table 3). Regarding pH, it was only significantly and negatively correlated with the appearance attribute of kishk. Electrical conductivity (EC, ms/cm) and total dissolved solids (TDS, ppt) showed positive and significant correlations exclusively with the mouthfeel sensory attribute, with correlation coefficients of 0.361 and 0.449, respectively (Table 3). Additionally, titratable acidity (TA, expressed as % lactic acid) was found to have a positive, significant, and strong correlation with all sensory attributes, except for aroma, which did not show significant correlations with any of the physicochemical properties of kishk (Table 3).

Table 3. Spearman's correlation between physiochemical attributes and the sensory attributes of kishk.

Attribute	Moisture	pH	EC (ms/cm)	TDS (ppt)	TA (% Lactic Acid)
Texture	Ns	Ns	Ns	Ns	0.384
Aroma	Ns	Ns	Ns	Ns	Ns
Appearance	−0.462 **	0.491	Ns	Ns	0.565
Mouthfeel	−0.382 *	Ns	0.361	0.449	0.622
Saltiness	Ns	Ns	Ns	Ns	0.577
Taste	−0.376 *	Ns	Ns	Ns	0.607
Mean Score	−0.376 *	Ns	Ns	Ns	0.607

EC: electrical conductivity; TDS: total dissolved solids; TA: titratable acidity; **: $p < 0.01$; *: $p < 0.05$, Ns: not significant.

3.4. Decision Tree to Create Grades

The mean sensory score was taken as the dependent variable and the physicochemical attributes were taken as the independent variable. After conducting the decision tree analysis, the only significant physicochemical attribute was titratable acidity, where the sensory scores could be classified into three categories (Figure 3).

Grade A constituted TA more than or equal to 4.56, with a sensory mean score of 6.231 ± 1.027, grade B constituted TA between 2.50 and 4.56, with a sensory mean score of 5.264 ± 1.154, and grade C constituted TA less than or equal to 2.50, with a sensory mean score of 4.399 ± 0.727 (Figure 3).

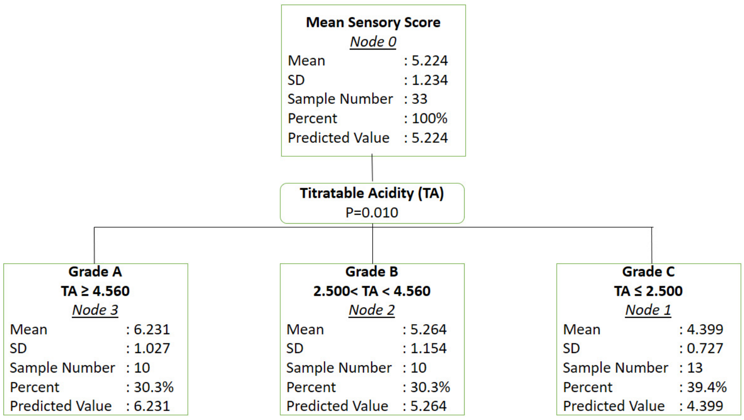

Figure 3. Decision tree with mean sensory score as the dependent variable.

3.5. Kishk Category Physicochemical Properties

The physicochemical properties of the three categories, A, B and C, created based on the decision tree analysis were analyzed. There was no significant differences between the three categories in terms of fat, protein, carbohydrate, fiber, ash, water activity, electrical conductivity, total dissolved solids and particle density attributes. Moisture, the protein-to-fat ratio and pH values were significantly different between all the categories with grade A, with the highest sensory score, scoring the lowest values (Table 4).

Table 4. Physicochemical properties of grades A, B, and C kishk.

	p **Value**	**Grade A** **TA $\geq$ 4.56** **n:10**	**Grade B** **2.50 < TA < 4.56** **n:10**	**Grade C** **TA $\leq$ 2.50** **n:13**	**Total**
		Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Moisture	0.018	$2.94^{a} \pm 0.61$	$4.64^{ab} \pm 0.61$	$5.43^{b} \pm 0.56$	4.41 ± 0.38
Fat	0.126	13.68 ± 1.36	13.88 ± 1.36	10.48 ± 1.24	12.54 ± 0.79
Protein	0.411	23.47 ± 1.32	25.06 ± 1.32	25.86 ± 1.20	24.86 ± 0.73
P/F Ratio	0.045	$1.88^{a} \pm 0.20$	$2.03^{ab} \pm 0.20$	$2.56^{b} \pm 0.18$	2.18 ± 0.03
CHO	0.644	49.88 ± 2.29	47.06 ± 2.29	49.42 ± 2.09	48.83 ± 1.26
Fiber	0.587	6.55 ± 0.47	6.14 ± 0.47	5.89 ± 0.43	6.17 ± 0.26
Ash	0.759	3.50 ± 0.56	3.23 ± 0.56	2.93 ± 0.52	3.20 ± 0.31
Aw	0.297	0.46 ± 0.02	0.51 ± 0.02	0.50 ± 0.02	0.49 ± 0.01
EC (ms/cm)	0.177	22.12 ± 1.79	20.90 ± 1.79	17.68 ± 1.63	20.08 ± 1.03
TDS (ppt)	0.204	10.76 ± 0.84	10.17 ± 0.84	8.76 ± 0.76	9.82 ± 0.48
pH	<0.001	$3.77^{a} \pm 0.10$	$3.80^{a} \pm 0.10$	$4.42^{b} \pm 0.09$	4.03 ± 0.08
D (Kg/m^3)	0.541	1465 ± 12	1446 ± 12	1461 ± 11	1458 ± 7

P/F ratio: protein content divided by fat content; CHO: carbohydrate, D: particle density; Aw: water activity; EC: electrical conductivity; TDS: total dissolved solids; means with different alphabetic superscripts are significantly different.

To identify the physicochemical attributes that are significant for classifying kishk samples, a decision tree analysis was performed, using categories, grades A, B, and C, as the dependent variable (Figure 4). The only attribute identified as significant was the pH value, with a cutoff established at 3.95. Samples with a pH below 3.95 have a 90% likelihood of being classified as grade A or B but not grade C. Conversely, samples with a pH above 3.95 have an 85% likelihood of being classified as grade C, excluding grade A or B (Figure 4).

Furthermore, within the node of pH < 3.950, kishk samples with a particle density within 1455 and 1489 had the highest possibility of being grade A, kishk with a particle density less than 1455 had a 75% chance of being grade B, and if the particle density was higher than 1489, kishk had a 40% chance of being grade C (Figure 4).

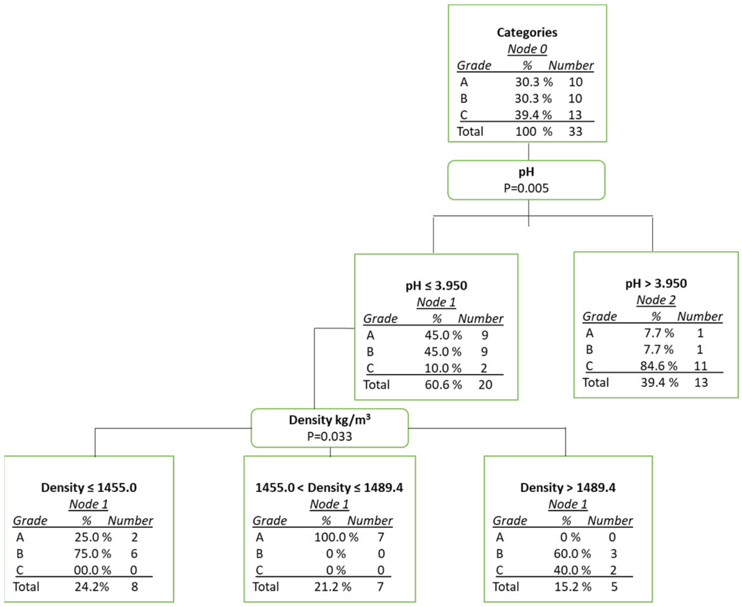

Figure 4. Decision tree with kishk grade as the dependent variable.

4. Discussion

Kishk is a traditional fermented cereal product made from bulgur (cracked wheat) and yogurt. As a fermented food that is stored and consumed over an extended period, moisture content and acidity are critical factors influencing its preparation, storage, and potential spoilage [38]. Notably, the consumption of spontaneously fermented dairy products significantly contributes to the diversity of gut microbiota. Additionally, probiotics found in fermented dairy products, such as Bifidobacterium and Lactobacillus, have been positively associated with various health indices, including body mass index and blood glucose levels [39]. This suggests that kishk, as a fermented mixture of milk and bulgur, could enhance the variety of traditional foods while also offering health benefits [39].

The data obtained in this study indicated that there were no significant differences in sensory attribute scores based on the district or type of milk, which facilitated the pooling of sensory data for subsequent analysis. This finding contrasts with a previous study that evaluated the sensory properties of kishk made from bovine and caprine milk [34], where 15 kishk samples were analyzed: 5 from cow's milk, 5 from goat's milk, and 5 from a mixture of both. In the current study, however, 17 samples were derived from cow's milk, 10 from goat's milk, and 6 from a mixed source of cow and goat milk. This discrepancy underscores the necessity for further research to better understand the factors influencing differences in taste.

Moisture content was found to negatively impact sensory scores, which was congruent with the observed positive correlations between electrical conductivity, total dissolved solids, and total acidity (TA). This relationship can be attributed to the fact that a higher moisture content corresponds to lower values of these parameters. Furthermore, TA emerged as a significant factor correlated with most sensory attributes, consistent with findings from a study that investigated the physicochemical and sensory properties of kishk enriched with microencapsulated probiotic cultures [40]. The influence of titratable acidity on taste is notably more pronounced than that of pH, a trend also observed in other products such as coffee [41]. While pH measures the concentration of dissociated hydrogen ions, titratable acidity quantifies the total acidic protons present. Consequently, titratable acidity provides a more accurate assessment of the types of acids in food, including organic acids that do not fully dissociate but still contribute to flavor [18,42].

To determine the physicochemical attributes that would classify different categories of kishk based on sensory scores, a decision tree analysis was employed. The only attribute found to be significant in distinguishing the three grades of kishk was titratable acidity

(TA) (Figure 3). This finding is congruent with the results of the Spearman's correlation analysis conducted in this study and is consistent with previous sensory evaluation studies on kishk [18,40,42], which have also classified kishk as an acidic food.

When comparing the physicochemical attributes of kishk across the three grades, only the moisture content, protein-to-fat ratio, and pH exhibited significant differences. Although pH and sour taste are not necessarily correlated [18], pH remains a critical factor for evaluating food safety and conducting shelf-life analyses. The FDA recommends maintaining a pH of less than 4.6 to ensure food safety by preventing the growth of harmful bacteria, classifying such products as high-acid foods. Most foodborne pathogens cannot thrive at pH levels below 4.2 [43]. The pH values for grade A and grade B kishk did not differ significantly from one another, but both were significantly lower than the pH of grade C kishk. This finding was consistent with the decision tree analysis, which identified pH as the first significant physicochemical attribute for constructing classification nodes among the three grades of kishk. Consequently, establishing a criterion of a pH less than 3.96 for quality kishk could be advantageous as it indicates a higher likelihood of the kishk belonging to grade A or B while also being a relatively shelf-stable product.

In the category with a pH of less than 3.96, a particle density of less than 1489 was found to be a significant indicator for kishk samples classified as grade A or B. Given that fat is the least dense component in food, it can be inferred that a higher particle density corresponds to s lower fat content. Thus, it can be posited that grade C kishk likely possesses the lowest protein-to-fat ratio, which aligns with findings from comparisons of fat-to-protein ratios across different grades. This observation supports the understanding that food components significantly influence the sensory attributes of food, particularly in milk-based products [7].

This assertion was further corroborated by a study on stirred yogurt, which demonstrated that a creamy taste and texture, as well as visual and textural viscosity, increased with higher fat and protein content. The researchers noted that the effect of protein diminished as the fat content increased, concluding that fat was the most influential component, followed by its interaction with protein [6]. Given that the fat content in kishk primarily originates from yogurt—since bulgur contains a relatively low fat percentage—the fat-to-protein ratio serves as an indicator of the bulgur-to-yogurt ratio in grade A and B kishk and warrants further investigation [44].

Kishk, as a complex food composed of cereal and milk, is further complicated by the use of milk from different species in its production. The protein-to-fat ratio of cow's milk varies widely (between 0.70 and 1.15) [45] in contrast to goat milk, which has a narrower range (between 0.96 and 0.80) [46]. Although no significant differences were observed in the kishk made from different milk sources, the protein-to-fat ratio could serve as a valuable indicator in evaluating kishk quality [47,48]. This is supported by its application in the cheese industry, where it also varies widely. Moreover, the protein-to-fat ratio is utilized as a "good feeding" indicator by many organizations, making it a suitable criterion for studying the impact of feeding management at the farm level on the sensory properties of produced kishk [49].

Moisture content exhibited significant differences when comparing kishk across grades A, B, and C. Notably, there was no significant difference between grades A and B, both of which had moisture content significantly lower than that of grade C. Furthermore, moisture content was negatively correlated with most sensory attributes. However, foods that are dried to excessively low moisture levels (below approximately 2–3%) may become vulnerable to oxidation [50–52]. Consequently, it is advisable to adopt a moisture content criterion of less than or equal to 4%, but not lower than 3%, for grade A or B kishk, a guideline that is also recommended for milk powder products [53].

Kishk, as a combination of yogurt and cereal, along with the addition of salt and varying fermentation times post-yogurt addition, underscores the complexity of the reaction dynamics within this product. This complexity was reflected in the water activity values, which did not show significant differences despite the notable variations in moisture content. This finding aligns with the sorption curve presented in a study that examined the physicochemical and rheological properties of Lebanese kishk powder [36]. Similar sorption curves have been observed in crystalline powders [54], where variations in the curves correspond to different degrees of crystallization.

All kishk samples exhibited water activity values below 0.6, the threshold recommended for stability against microbial growth; however, chemical and enzymatic reactions can still occur, potentially leading to deterioration [50–52]. Moreover, lower water activity values, particularly below 0.4, reduce the susceptibility of the product to oxidation [52,55]. Consequently, it is advisable to maintain water activity values between 0.4 and 0.5 for optimal stability.

5. Conclusions

Following the outcomes of this study, to have kishk with a high sensory score, it is necessary for the titratable acidity value to be 4.56 or more, the pH value to be 3.96 or less, the recommended moisture content value to be between 3 and 4%, the particle density to be lower than 1489, and the protein-to-fat ratio to be between 1.8 and 2.0. Furthermore, to ensure the stability of the kishk produced, the water activity value should be between 0.4 and 0.5. Due to the complexity of kishk's physicochemical dynamics and the fact that it originates from both animal and plant raw material, in addition to the fermentation stage it undergoes, more studies should be conducted to evaluate and fine-tune these values and to construct a sorption curve specific for kishk, taking into consideration the variation in the compositional and procedural variations that might lead to different crystallization profiles.

Author Contributions: Conceptualization, S.H. and O.D.; methodology, O.D.; software, O.D.; validation, S.H. and L.J.; formal analysis, H.S.; investigation, Y.I.; resources, S.H.; data curation, O.D. and Y.I.; writing—original draft preparation, O.D.; writing—review and editing, L.J.; visualization, O.D.; supervision, S.H.; project administration, Y.I.; funding acquisition, S.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all experts involved in the study.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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