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Chemometric Comparison and Classification of 22 Apple Genotypes Based on Texture Analysis and Physico-Chemical Quality Attributes

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Abstract: The large number of cultivars belonging to the cultivated apple (*Malus* × *domestica* Borkh.) reflects an extremely wide range of variability, including for fruit quality traits. To evaluate some characteristics of fruit quality, 22 apple genotypes were selected from a collection of germplasms containing more than 600 accessions, based on different considerations, including the use of fruits (dessert, cooking, processing, juice, cider, multipurpose). The mean water content of the studied apple genotypes was 85.05%, with a coefficient of variation (CV) of 2.74%; the mean ash content was 2.32% with a CV of 22.1%, and the mean total soluble solids was 16.22% with a CV of 17.78%, indicating a relatively small difference between genotypes for these indices. On the contrary, relatively large differences were registered between genotypes for fruit weight, volume, and titratable acidity with means of 119.52 g, 155 mL, and 0.55% malic acid, and CVs of 35.17%, 34.58%, and 54.3%, respectively. The results showed that peel hardness varied between 3.80 and 13.69 N, the toughness between 0.2 and 1.07 mm, the flesh hardness between 0.97 and 4.76 N, and the hardness work between 6.88 and 27.84 mJ. The current study can emphasize the possibility of choosing the appropriate apple cultivars to cross in the breeding process and how future strategies can help apple breeders select breeding parents, which are essential key steps when breeding new apple cultivars. In addition, multivariate analysis has proven to be a useful tool in assessing the relationships between *Malus* genetic resources.

Keywords: apple quality; apple genotype classification; apple textural attributes; peel hardness; flesh hardness; fruit texture analysis; apple peel color

1. Introduction

The apple is one of the most popular fruits in the world because of its sweet taste and crispy texture, being the second most produced fruit tree crop in the world, with 86.44 M metric tons of production in 2020, succeeding bananas (119.83 M tons), and preceding oranges (75.46 M metric tons) [1]. Apples are one of the staple fruits in most European grocery stores, and several imported and domestic apple cultivars are available year round. It is assumed that the modern cultivated apple (*Malus* × *domestica* Borkh.) is probably the result of interspecific hybridization and, currently, around ten thousand apple cultivars are listed in the European Apple Inventory. This large number of apple cultivars determines the broad variability of the quality attributes [2]. For apples, the most novel cultivars, named "mutants" or "sports", were identified in clonal populations. Indeed, many "sports" that show distinct phenotypic differences compared to the cultivars from which they originated might exist. Recent technological advances and the availability of several high-quality apple genomes now provide the bases to understand the exact nature of the underlying molecular changes that are responsible for the observed phenotypic changes observed in sports [3]. It is well known that disease- and stress-resistant apple trees, or apple fruits with improved taste, appearance, processing characteristics, or yield, have been developed over the years by breeders [4]. As the flesh of almost all apple cultivars changes to brown after cell disruption, there is a growing trend in apple breeding to develop cultivars with extremely low polyphenol oxidase activity, with apple fruits maintaining the flesh color after slicing for at least five days, already being reported [5]. With the increasing diversity of pome fruit cultivars, fruit quality recognition is becoming more and more important. In general, fruit quality includes a wide group of internal and external traits. Internal quality (determining the eating quality) consists of taste, texture, aroma, nutritional value, sweetness, and acidity (contributing to flavor). External fruit quality includes mainly the color as one of the major factors in creating a fruit's image [6]. Color preferences depend on the uniformity of the external color, the repeatability of fruit color in the crop, the differences between high and ground color, the intensity of blush and ground color (the saturation of red), the size of high color area, brightness–darkness, the whiteness shape, and size [7,8]. Initially, the consumer judges the product by its appearance (color, size, and shape) and then by its eating quality, although the latter may determine whether or not a customer will buy the product again [9]. The color control of apples and fruits has a great effect on sales; however, in most cases, it is performed visually, relying on the accuracy of an individual's eyes to evaluate and determine color. Unfortunately, each individual perceives color in a different way. Additionally, it is extremely difficult to accurately describe color in words, since each person will interpret the color slightly differently [10]. Apple peel color is determined by the contents of carotenoids, anthocyanins, and chlorophyll, as well as their distribution over the peel surface [11].

As an internal quality trait, texture is a comprehensive concept, which can include several parameters as follows: adhesiveness, cohesiveness, hardness, springiness, gumminess, and chewiness, which can affect the taste, aroma, and mouth feel of the fruits [12]. In apples, it has been shown that among the textural traits, crispness accounts for 90% of texture appreciation, and it has been largely recognized as the key attribute affecting consumer acceptability [13]. In crispy apples, the cell breakage generates a sound wave which causes a vibration between the molecules around their equilibrium, consequently propagating the pressure wave and thus producing the sound [14].

The quality characteristics of horticultural products are the most important parameters for determining the proper standards of design for grading, conveying, processing, and packaging systems [15]; hence, there is a need to assess the physico-chemical attributes and their relationships. Among the physical characteristics, weight and volume are the most important attributes in determining sizing systems [16]. In the food industry, the determination of the fruit dimensions is central to assessing the fruit mass and heat transfer, which are important parameters for determining the shelf life, or designing the facilities used for storage, or other postharvest technologies (coatings, heat treatments, drying, or freezing) [17].

In apples, like on other cultivated species, the development of a core list of passport descriptors was continuously undertaken by the International Plant Genetic Resources Institute—FAO/IPGRI, 2001 [18,19], the European Cooperative Programme for Crop Genetic Resources networks (ECP/GR), and other organizations in order to advance the conservation and use of genetic resources for the benefit of present and future generations [19]. The descriptors used for the apple were developed on the basis of the IBPGR *Descriptor List for Apple* [20] and the UPOV guidelines for the conduct of the DUS test—the test for distinctness, uniformity, and stability [21]. Among these descriptors, one part is represented by the particularities of the fruits and their use (i.e., dessert, cooking and processing, juice and cider, multipurpose) [22]. Frequently, for practical reasons and expeditiousness when working with a large number of accessions, descriptors are illustrative or evaluated on a grading scale that is not measurable and, in these cases, statistical analysis and models must be appropriate at different working scales, or when using three groups of adequate characteristics: qualitative, quantitative, and pseudo-qualitative [23]. For a better understanding of the variations of the important features of fruit quality, i.e., peel color, texture parameters, physico-chemical attributes, etc., among different apple genotypes, an in-depth study is required, especially for the promotion of new valuable cultivars, but also for apple breeding. Consequently, the current work aims to perform the chemometric comparison and classification of 22 apple genotypes based on a texture analysis and the physico-chemical quality attributes, allowing more complex distinctions to be drawn than the descriptors or rating scales used in the above-mentioned procedures. Apples with extremely different genotypes and provenances were used (i.e., some are ripening, origin, 'classic' or 'modern' cultivars, some are well known from the world assortment or are new autochthonous creations; some are old or ancestral forms of some modern cultivars, with varied destinations, and are consumed as fresh fruit, or suitable in the processing industry, etc.). As hypotheses, the variability of some important quality traits of fruits and the possibility of identifying and classifying the genotypes based on the physico-chemical attributes of apples were tested. In addition, because multivariate analysis was considered to be a useful tool in assessing the importance of individual descriptors in discriminating between *Malus* cultivars, indicating that some characteristics of fruits meet the criteria for ideal descriptors [24], we intended to analyze the studied parameters to identify possible links between the genotypes and their impact on apple breeding.

2. Materials and Methods

2.1. Materials

The experimental materials were harvested from the apple germplasm collection of the Research Institute for Fruit Growing Pitești-Mărăcineni (44.8992, 24.8596), Romania. In the area of RIFGPM, the climate is favorable for the growth of fruit species, the multiannual average temperature being 9.8 °C, and the annual amount of precipitation being 668 mm. The experimental apple collection of RIFGPM, comprising more than 600 apple genotypes, is situated near the headquarters of the institute, on colluvial and alluvial soil, with a medium humus content, 262 m above sea level. The apple collection was established in 2010, with all the genotypes being grafted on the rootstock MM106, the trees planted at a distance of 4 × 2.5 m (a density of 1000 trees/ha). Fertilization, phytosanitary treatments, and tree maintenance were of a standard type, similar to those applied in commercial orchards. Twenty-two apple genotypes with distinct differences in fruit texture, color, and chemical composition and possibilities for use (dessert, culinary, processing, juice, cider, multipurpose) were chosen for this study. The test materials included '*Malus floribunda* clone 821′, 'Greensleaves', 'T188′, 'Fuji Fenfu', 'Iris', 'Bērnu Prieks', 'Lobo', 'Gala Dicarli Fendeca', 'Judaine', 'Judeline', 'Golden Delicious Goldrosio', 'Golden Russet', 'Ananas Reinette', 'Cidor', 'Akane', 'Gala Brookfield', 'T97′, 'Gala Fenplus', 'Gala Venus Fengal', 'Jonagold', 'Priam', and 'T120′ (Figure 1).

At the phenological growth stage BBCH-87 [25], ripe fruit samples represented by 90 fruits per genotype, disease-free and without pest or mechanical damage, were picked homogenously and analyzed in the lab. For each studied genotype, each analysis was performed with five repetitions, each measurement repetition using a whole apple fruit, obtained by dividing the laboratory sample by the method of quartering; excepting the texture analysis where half fruits were used, as mentioned on Section 2.3.

Figure 1. The appearance of the fruits for the studied apple genotypes.

2.2. Physico-Chemical Quality Attributes

The determination of the fruit mass was done by weighing, using an analytical balance (Shimadzu, Kyoto, Japan), with five repetitions being performed for each studied apple genotype.

The actual volume of the fruit was measured by the method of immersing the fruit in a known volume of water. This method is one of the most common and simple means of measuring the volume of fruit. Each fruit is immersed in a graduated water vessel at which the volume of water is known. Five repetitions were performed for each apple genotype. The volume was calculated with the following equation:

$$V(mL) = V_2 - V_1,$$

where V is the volume of the individual apple (mL), V_1 is the initial volume of water (mL), and V_2 is the volume registered after the immersion of the apple fruit in the vessel (mL).

The fruit dimension measurements for the different apple genotypes studied was performed using a vernier caliper using the method reported by Mohsenin [26]. In order to assess the average size of the apple fruits, three linear dimensions were measured: length (L)—the equivalent distance of the stem to the calyx, width (W)—the longest dimension perpendicular to L, and thickness (T)—the longest dimension perpendicular to L and W. The geometric mean diameter (Dg) and arithmetic mean diameter (Da) were computed using the following Equations (1) and (2):

$$Dg = \sqrt[3]{LWT} \tag{1}$$

$$Da = (L + W + T)/3 \tag{2}$$

The moisture of the apple sample was determined using the oven drying method at 103 °C ± 2 °C, until it reached a constant weight. The mineral content was determined by ashing the apple samples at 600 °C in a muffle furnace.

The total soluble solids were assessed by the standard refractometric method ISO 2173:2003, while titratable acidity was measured following the ISO 750:1998 (E) method.

The color of the apple samples was measured using an NR200 portable colorimeter (3NH, Shenzhen, China) based on the CIE L* a* b* color system. The color value was expressed as L*, a*, and b* values, where L* is a measure of lightness and ranges from zero (the darkest black) to 100 (the brightest white). Positive values of a* indicate redness and negative values complement green, while positive values of b* are the vector for yellowness and negative for blueness. Measurements were performed using a D65 illuminant with an opening of 8 mm. The colorimeter was subjected to automatic black and white calibration. Background, covering (where appropriate) and overlapping (where appropriate) color parameters were determined depending on each apple genotype color characteristics, on the color corresponding part of the fruit, with five repetitions being taken for each apple genotype and color type, each color type repetition being performed on separate whole apple fruits.

2.3. Texture Analysis

The texture analysis was performed using a CT3 Brookfield Texture Analyzer equipped with the TA39 probe (2 mm Diameter Rod, Stainless Steel 5 g, 20 mm Length, Flat end). A compression test with a 5 mm target value was selected, the probe test speed being set to 0.5 mm/s, the trigger load at 4 g, and 10 points/second being registered. Each apple was cut in half, placed cut-side down and compressed on the middle upper region (unpeeled half apple sample), with five repetitions being performed for each studied apple genotype on apple halves obtained from five separate whole apple fruits. Peel hardness (N), toughness (mm), hardness work (mJ), and flesh hardness (N) were computed according to the methods reported by Qiu et al. [27] and Bejaei et al. [28], with some modifications, as shown in Figure 2 and Table 1.

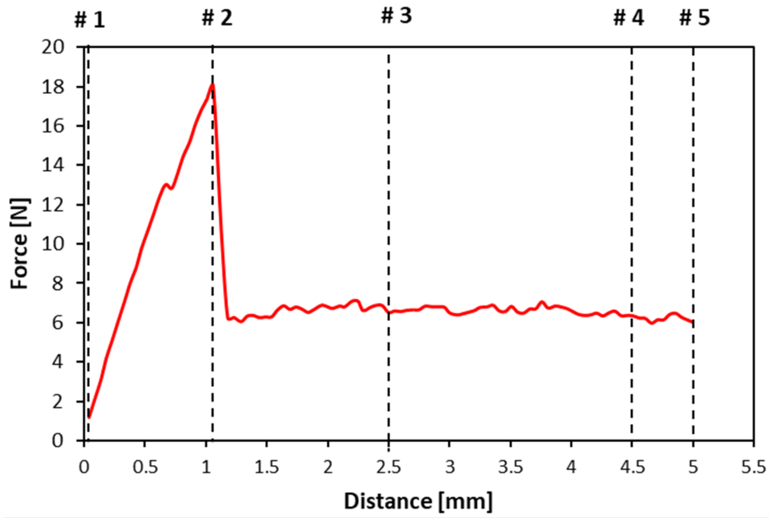

Figure 2. Example of force–distance curve obtained from CT3 Brookfield Texture Analyzer with results from a compression test of an unpeeled half apple sample. The computed textural parameters are described in Table 1, using the anchor numbers located on the upper edge of the curve.

Table 1. Parameter definition and calculation for texture analysis.

Parameters	Units	Definition	Method of Calculation and Location on the Force-Distance Textural Curve
Peel hardness	N	The force at the maximum peak during the puncture testing	Shown by anchor #2 on Figure 2
Toughness	mm	The displacement at the maximum force (peel hardness) during the puncture process	Measured from the distance between anchors #1 and #2 on the "Distance (mm)" x-axis of Figure 2
Hardness work	mJ	The mechanical work conducted to rupture the peel and flesh to the target distance value (5 mm)	Calculated from the total area under the red textural curve between anchors #1 and #5 on Figure 2. The hardness work is calculated to the target distance, even though the hardness point may occur at the fracture
Flesh hardness	N	The average force between 2.5 and 4.5 mm depth of the probe where the steady state force (plateau) is reached	Calculated by the average of force recorded between anchor #3 and #4 on Figure 2

2.4. Statistical Analyses

The registered data of the analyzed elements of fruit quality and indices were processed as the mean of the traits and standard deviation (SD), as well as the coefficient of variation. An analysis of variance (ANOVA) was applied to the analyzed traits, and when the test returned a significant F-statistic, the Tukey test ($\alpha < 0.05$) was used as a post hoc test for the analysis of differences. The data were subjected to multivariate statistical analysis, namely principal component analysis (PCA) and hierarchical cluster analysis (HCA) using the Unscrambler X v.10.5.1 software. This software was used also for the construction of a dendrogram, as Euclidean distances between cultivars.

3. Results and Discussion

3.1. Physico-Chemical Properties

The physico-chemical properties of horticultural crops are useful indices for designing the grading and the distribution in quality classes, conveying, processing, and packaging systems [15]. The total soluble solids (TSS) parameter is mainly based on the sugar content, followed by acids, vitamins, and some mineral substances that are soluble in water. TSS is pivotal for consumer acceptance, being an important integrated index to assess the quality and sweetness of fruits. In the current study, a TSS mean of 16.22% with a coefficient of variation (CV) of 17.78% indicates a slight difference between the analyzed genotypes. '*M. floribunda* clone 821′ had the highest TSS (24.03%), followed by 'Ananas Reinette' and 'Cidor', whereas 'Jonagold' (10.13%) and 'Fuji Fenfu' (12.80%) had the lowest TSS values (Table 2). In an earlier study, Jan et al. [29] reported a lower soluble solid content for the five apple cultivars studied, with values in the range of 11.24–11.79%; however, it has to be stressed that the cultivars were harvested in Pakistan, as compared to the current study of European-grown apples. Kumar et al. [30], also found genotype differences to be the main factor determining the soluble solid content in twenty-two apple genotypes. The most popular and widely grown apple cultivars in India, 'Golden Delicious' and 'Royal Delicious', recorded 13.5 °Brix and 13.2 °Brix, respectively.

The mean water content of the 22 apple genotypes was 85.05% with a CV as low as 2.74% (Table 2), indicating a relatively similar water content among the studied apple genotypes. The water content had the highest value in the 'Greensleaves', 'Akane', and 'T120′ fruits (88–87%) and the lowest in the '*M. floribunda* clone 821′, 'Golden Delicious Goldrosio', and 'Cidor' fruits (79–81%).

Titratable acidity governs the overall taste of the apple fruits [30], with the determined average value for the 22 apple genotypes being 0.55% malic acid with a CV as high as 54.3%. Thus, a wide variation in titratable acidity was observed, with higher values being recorded in 'Bērnu Prieks' (1.28%), 'T97′ (1.17%), and '*M. floribunda* clone 821′ (1.00%), while smaller values were registered in genotypes 'Gala Venus Fengal' (0.18%), 'Gala Dicarli Fendeca (0.20%), and 'Cidor' (0.23%) (Table 2). In an earlier study, Kumar et al. [30] reported a mean of 0.39% malic acid for 22 apple genotypes grown in India, with the maximum titratable acidity for non-red genotypes, 'Winter Banana' and 'Starkspur Golden' (0.67%), while the minimum was observed in red genotypes, 'Royal Delicious', 'Red Gold', 'Early Red-I', 'Spartan', and 'Red Delicious' (0.27%). As reported by Wu et al. [31], cultivars possessing high TSS and acidity can be considered to be good for apple juice concentrate production. A fruit's appearance is one of the most purchase-driving traits that influence the consumer's decision. Basically, it is manifested by different external characteristics of a fruit, such as size, shape, and color [32]. Dimensional attributes of the studied apple samples are useful for describing the fruit shape and genotype descriptions. The fruit weight average of the twenty-two genotypes studied was 119.52 g (Table 2).

The fruit weight of 'T97′ (199.94 g), 'T188′ (171.42 g), 'Golden Russet' (167.88 g), 'Greensleaves' (161.29 g), and 'Judaine' (142.14 g) registered the highest values for single fruit weight, while showing no statistically significant differences to each other; in contrast, '*M. floribunda* clone 821′ had the lowest value registered for single fruit weight (23.95 g). As expected, the same genotype recorded the lowest statistically significant values for fruit width (36.83 mm), length (36.35 mm), geometric mean (36.10 mm), and arithmetic mean diameter (36.11 mm) (Table 3).

3.2. Peel Color

Peel or skin color in the apple industry is fundamental as a sorting criterion for various genotypes. In the present study, background, covering, and overlapping colors were determined. As presented in Figure 1, and based on the instrumentally determined values given on Table 4, 'T97', 'T120', 'Greensleaves', 'T188', and 'Gala Fenplus' presented only a background color; 'Gala Dicarli Fendeca', 'Gala Venus Fengal', '*M. floribunda* clone 821', 'Bērnu Prieks', 'Golden Russet', and 'Jonagold' showed both background and covering colors, while 'Fuji Fenfu', 'Lobo', 'Judeline', 'Golden Delicious Goldrosio', and 'Gala Brookfield' showed both background and overlapping colors. Among the studied apple fruits, there were genotypes, such as 'Ananas Reinette', 'Cidor', 'Iris', 'Judaine', 'Akane', and 'Priam', which presented background, covering, and overlapping colors.

Table 2. Basic physico-chemical properties of 22 apple genotypes.

Genotype	Fruit Weight (g)	Volume (mL)	Water Content (%)	Ash Content (%)	Total Soluble Solids (%)	Titratable Acidity (% Malic Acid)
M. floribunda clone 821	23.95 ± 3.90 [f]	32.50 ± 5.00 [e]	79.069 ± 1.24 [h]	2.17 ± 0.94 [a]	24.03 ± 0.60 [a]	1.00 ± 0.02 [c]
Greensleaves	161.29 ± 46.53 [a,b]	237.50 ± 70.42 [a]	88.063 ± 0.09 [a]	1.55 ± 0.99 [a]	12.97 ± 0.76 [i,j]	0.40 ± 0.02 [g,h,i]
T188	171.42 ± 35.53 [a,b]	225.00 ± 52.60 [a,b]	85.980 ± 0.20 [b,c,d]	2.38 ± 0.87 [a]	14.63 ± 0.93 [g,h,i,j]	0.79 ± 0.02 [d]
Fuji Fenfu	100.52 ± 10.97 [c,d,e]	127.50 ± 15.00 [b,c,d,e]	85.315 ± 0.88 [c,d,e]	1.93 ± 0.42 [a]	12.80 ± 0.69 [j,k]	0.35 ± 0.01 [h,i]
Iris	127.75 ± 14.52 [b,c,d,e]	155.00 ± 38.73 [a,b,c]	86.454 ± 0.21 [a,b,c,d]	1.83 ± 0.36 [a]	16.80 ± 1.01 [c,d,e,f,g]	0.61 ± 0.04[e]
Bērnu Prieks	29.54 ± 5.69 [f]	45.00 ± 12.91 [d,e]	86.042 ± 0.07 [b,c,d]	2.69 ± 0.15 [a]	16.07 ± 1.33 [d,e,f,g,h]	1.28 ± 0.02 [a]
Lobo	112.92 ± 24.13 [b,c,d,e]	162.50 ± 45.73 [a,b,c]	86.671 ± 0.24 [a,b,c,d]	2.50 ± 0.18 [a]	16.63 ± 0.70 [c,d,e,f,g]	0.55 ± 0.01 [e,f]
Gala Dicarli Fendeca	134.48 ± 25.84 [b,c]	167.50 ± 33.04 [a,b,c]	86.657 ± 0.21 [a,b,c,d]	1.88 ± 0.24 [a]	16.63 ± 0.84 [c,d,e,f,g]	0.20 ± 0.01 [j,k]
Judaine	142.14 ± 24.38 [a,b,c]	177.50 ± 35.94 [a,b,c]	85.990 ± 0.92 [b,c,d]	1.87 ± 0.28 [a]	13.77 ± 0.12 [h,i,j]	0.56 ± 0.02 [e,f]
Judeline	75.16 ± 17.00d [e,f]	102.50 ± 26.30 [c,d,e]	85.102 ± 0.23 [d,e]	1.85 ± 0.59 [a]	15.07 ± 0.38 [f,g,h,i,j]	0.49 ± 0.02 [f,g]
Golden Delicious Goldrosio	127.81 ± 30.75 [b,c,d,e]	175.00 ± 42.03 [a,b,c]	81.339 ± 0.23 [g]	2.91 ± 0.95 [a]	15.63 ± 0.12 [e,f,g,h,i]	0.61 ± 0.07 [e]
Golden Russet	167.88 ± 39.97 [a,b]	220.00 ± 52.28 [a,b]	82.756 ± 0.81 [f,g]	2.68 ± 0.65 [a]	16.47 ± 2.16 [c,d,e,f,g]	0.65 ± 0.01 [e]
Ananas Reinette	127.70 ± 33.81 [b,c,d,e]	165.00 ± 61.91 [a,b,c]	82.173 ± 0.18 [f,g]	2.79 ± 0.36 [a]	19.73 ± 1.37 [b]	0.40 ± 0.02 [g,h,i]
Cidor	69.29 ± 18.65 [e,f]	97.50 ± 17.08 [c,d,e]	81.627 ± 0.17 [g]	2.66 ± 0.39 [a]	19.03 ± 0.29 [b,c]	0.23 ± 0.03 [j,k]
Akane	129.93 ± 16.65 [b,c,d]	150.00 ± 40.82 [a,b,c]	87.548 ± 0.07 [a,b]	3.09 ± 0.49 [a]	18.67 ± 0.45 [b,c,d]	0.24 ± 0.01 [j,k]
Gala Brookfield	119.01 ± 26.94 [b,c,d,e]	152.50 ± 28.72 [a,b,c]	85.180 ± 0.34 [c,d,e]	2.44 ± 0.21 [a]	16.40 ± 1.14 [c,d,e,f,g,h]	0.30 ± 0.02 [i,j]
T97	199.94 ± 29.81 [a]	247.50 ± 46.46 [a]	87.108 ± 0.49 [a,b,c]	2.08 ± 0.21 [a]	17.20 ± 0.95 [b,c,d,e,f,g]	1.17 ± 0.05 [b]
Gala Fenplus	125.51 ± 18.82 [b,c,d,e]	152.50 ± 26.30 [a,b,c]	83.630 ± 0.44 [e,f]	2.85 ± 0.20 [a]	13.17 ± 0.21 [i,j]	0.57 ± 0.01 [e,f]
Gala Venus Fengal	128.18 ± 11.70 [b,c,d]	152.50 ± 17.08 [a,b,c]	85.230 ± 0.13 [c,d,e]	1.47 ± 0.43 [a]	15.27 ± 0.31 [f,g,h,i,j]	0.18 ± 0.01 [k]
Jonagold	135.18 ± 20.07 [b,c]	170.00 ± 31.62 [a,b,c]	86.967 ± 0.50 [a,b,c,d]	3.38 ± 0.35 [a]	10.13 ± 0.12 [k]	0.77 ± 0.04 [d]
Priam	101.04 ± 15.46 [c,d,e]	135.00 ± 23.80 [b,c,d]	85.158 ± 0.08 [c,d,e]	1.98 ± 0.91 [a]	18.30 ± 0.85 [b,c,d,e]	0.42 ± 0.01 [g,h]
T120	118.85 ± 29.66 [b,c,d,e]	160.00 ± 43.20 [a,b,c]	87.139 ± 0.52 [a,b,c]	2.17 ± 0.45 [a]	17.40 ± 0.00 [b,c,d,e,f]	0.35 ± 0.01 [h,i]
Mean	**119.52**	**155.00**	**85.05**	**2.32**	**16.22**	**0.55**
Coefficient of Variation (%)	35.17	34.58	2.74	22.1	17.78	54.3

Identical lowercase superscripts within columns indicate no significant difference ($p > 0.05$).

Table 3. Dimensional attributes of different apple genotypes.

Genotype	Fruit Dimension (mm)			
	Width	Length	Geometric Mean Diameter	Arithmetic Mean Diameter
M. floribunda clone 821	36.83 ± 2.19 ^{e}	36.35 ± 2.66 ^{d}	36.10 ± 2.09 ^{e}	36.11 ± 0.86 ^{d}
Greensleaves	74.18 ± 10.15 ^{a,b}	59.60 ± 9.69 ^{a,b}	67.97 ± 9.89 ^{a,b,c,d}	68.27 ± 7.67 ^{a,b}
T188	75.84 ± 6.31 ^{a,b}	62.05 ± 6.99 ^{a,b}	70.06 ± 4.64 ^{a,b,c}	70.32 ± 7.29 ^{a,b}
Fuji Fenfu	63.40 ± 2.38 ^{b,c,d}	52.08 ± 4.71 ^{b}	58.81 ± 3.15 ^{b,c,d}	59.03 ± 6.09 ^{a,b}
Iris	68.29 ± 2.47 ^{a,b,c,d}	55.65 ± 5.21 ^{a,b}	62.40 ± 3.34 ^{a,b,c,d}	62.63 ± 6.42 ^{a,b}
Bērnu Prieks	38.80 ± 4.31 ^{e}	36.70 ± 3.03 ^{c,d}	37.52 ± 4.06 ^{e}	37.53 ± 1.12 ^{c,d}
Lobo	69.50 ± 3.94 ^{a,b,c,d}	58.50 ± 3.45 ^{a,b}	64.79 ± 3.09 ^{a,b,c,d}	64.97 ± 5.75 ^{a,b}
Gala Dicarli Fendeca	65.45 ± 3.90 ^{a,b,c,d}	56.18 ± 3.59 ^{a,b}	61.29 ± 3.85 ^{a,b,c,d}	61.42 ± 4.75 ^{a,b}
Judaine	73.60 ± 1.62 ^{a,b}	57.35 ± 2.70 ^{a,b}	66.16 ± 1.57 ^{a,b,c,d}	66.52 ± 8.32 ^{a,b}
Judeline	58.60 ± 5.75 ^{c,d}	56.30 ± 5.98 ^{a,b}	57.23 ± 6.64 ^{c,d}	57.24 ± 1.21 ^{a,b}
Golden Delicious Goldrosio	66.48 ± 7.61 ^{a,b,c,d}	58.48 ± 7.78 ^{a,b}	62.79 ± 7.68 ^{a,b,c,d}	62.88 ± 4.06 ^{a,b}
Golden Russet	78.90 ± 3.45 ^{a}	62.85 ± 1.35 ^{a,b}	71.48 ± 1.97 ^{a,b}	71.80 ± 8.18 ^{a,b}
Ananas Reinette	66.93 ± 7.73 ^{a,b,c,d}	54.79 ± 4.92 ^{a,b}	62.09 ± 6.67 ^{a,b,c,d}	62.33 ± 6.58 ^{a,b}
Cidor	57.58 ± 3.80 ^{d}	50.65 ± 5.46 ^{b,c}	54.65 ± 4.18 ^{d}	54.73 ± 3.63 ^{b,c}
Akane	71.10 ± 1.40 ^{a,b,c}	58.00 ± 2.90 ^{a,b}	65.90 ± 1.48 ^{a,b,c,d}	66.17 ± 7.12 ^{a,b}
Gala Brookfield	65.63 ± 2.23 ^{a,b,c,d}	57.40 ± 1.30 ^{a,b}	62.29 ± 1.75 ^{a,b,c,d}	62.40 ± 4.39 ^{a,b}
T97	76.78 ± 5.67 ^{a,b}	67.03 ± 6.30 ^{a}	72.76 ± 6.45 ^{a,b,c,d}	72.88 ± 5.16 ^{a,b}
Gala Fenplus	63.30 ± 4.84 ^{b,c,d}	55.88 ± 6.90 ^{a,b}	59.87 ± 6.12 ^{a,b,c,d}	59.95 ± 3.76 ^{a,b}
Gala Venus Fengal	64.78 ± 3.87 ^{b,c,d}	54.75 ± 4.49 ^{a,b}	60.60 ± 4.24 ^{a,b,c,d}	60.76 ± 5.30 ^{a}
Jonagold	69.30 ± 2.98 ^{a,b,c,d}	58.30 ± 2.37 ^{a,b}	64.64 ± 2.55 ^{a,b,c,d}	64.82 ± 5.78 ^{a,b}
Priam	58.43 ± 2.45 ^{c,d}	59.28 ± 2.23 ^{a,b}	58.13 ± 2.03 ^{b,c,d}	58.14 ± 1.30 ^{a,b}
T120	69.13 ± 9.46 ^{a,b,c,d}	54.43 ± 9.58 ^{a,b}	63.00 ± 9.61 ^{a}	63.33 ± 7.83 ^{a,b}

Identical lowercase superscripts within columns indicate no significant difference ($p > 0.05$).

Table 4. The color parameters of different apple genotypes.

Genotype	Background Color			Covering Color			Overlapping Color		
	L*	a*	b*	L*	a*	b*	L*	a*	b*
T97	66.55 ± 2.49	−6.11 ± 0.69	40.85 ± 1.65				-	-	-
T120	69.69 ± 2.02	−4.12 ± 0.78	39.56 ± 1.12	-	-	-	-	-	
Greensleaves	65.90 ± 1.15	−5.70 ± 0.45	42.08 ± 1.88	-	-	-	-	-	-
T188	70.00 ± 1.73	−4.66 ± 0.60	41.96 ± 1.30	-	-	-	-	-	-
Gala Fenplus	38.80 ± 2.78	34.75 ± 1.22	12.92 ± 1.29				-	-	-
Gala Dicarli Fendeca	42.76 ± 3.16	34.35 ± 2.56	14.85 ± 1.89	51.45 ± 5.22	30.09 ± 3.92	19.259 ± 1.4	-		
Gala Venus Fengal	50.89 ± 3.51	40.60 ± 2.13	19.31 ± 0.93	60.45 ± 5.93	23.63 ± 5.17	24.79 ± 3.46			
M. floribunda clone 821	68.04 ± 1.95	26.54 ± 2.05	35.24 ± 1.70	42.46 ± 2.79	39.88 ± 2.51	16.56 ± 2.96	-	-	-
Bērnu Prieks	53.54 ± 3.73	30.21 ± 3.19	14.039 ± 2.12	38.28 ± 2.76	34.47 ± 3.26	10.58 ± 1.41			
Golden Russet	65.30 ± 1.47	−7.63 ± 0.51	40.44 ± 1.29	65.24 ± 1.48	5.388 ± 1.87	39.28 ± 3.62	-	-	-
Jonagold	72.73 ± 1.84	1.68 ± 0.47	35.58 ± 1.54	46.52 ± 2.34	37.3 ± 1.30	17.87 ± 2.71	-	-	-
Fuji Fenfu	67.87 ± 1.79	0.82 ± 0.02	31.05 ± 1.03	-	-	-	57.14 ± 5.3	15.76 ± 6.37	22.18 ± 5.28
Lobo	77.44 ± 1.03	−0.45 ± 0.09	33.39 ± 2.14	-	-	-	65.34 ± 2.52	22.32 ± 3.7	25.21 ± 2.28
Judeline	73.14 ± 2.04	−6.51 ± 0.98	37.31 ± 1.47	-	-	-	60.95 ± 3.08	20.46 ± 6.75	25.38 ± 3.80
Golden Delicious Goldrosio	71.17 ± 2.43	−2.74 ± 0.16	39.56 ± 1.42	-	-	-	68.17 ± 0.61	12.32 ± 4.35	32.71 ± 0.98
Gala Brookfield	74.313.60	0.37 ± 0.48	33.68 ± 3.34				60.99 ± 7.95	22.33 ± 8.49	26.53 ± 3.26
Ananas Reinette	62.19 ± 1.55	−3.99 ± 0.17	42.04 ± 2.55	51.78 ± 1.76	11.83 ± 1.25	26.85 ± 1.77	58.12 ± 1.3	3.14 ± 3.06	35.55 ± 1.54
Cidor	70.37 ± 2.94	−0.13 ± 1.61	43.97 ± 1.40	59.14 ± 3.33	15.22 ± 2.27	34.00 ± 1.57	63.11 ± 3.93	12.1 ± 2.59	37.37 ± 2.77
Iris	74.84 ± 1.65	−0.74 ± 0.09	40.88 ± 3.62	41.81 ± 2.56	40.42 ± 1.65	18.73 ± 3.08	61.26 ± 6.64	24.17 ± 5.58	29.81 ± 2.97
Judaine	73.44 ± 1.71	1.17 ± 0.37	39.69 ± 1.44	58.02 ± 1.07	33.11 ± 4.27	24.75 ± 3.15	59.45 ± 5.96	25.29 ± 4.26	27.96 ± 3.26
Akane	74.74 ± 1.91	0.58 ± 0.67	31.07 ± 3.27	33.90 ± 1.51	30.18 ± 2.79	9.41 ± 1.35	50.04 ± 5.37	31.29 ± 2.67	15.98 ± 0.70
Priam	79.01 ± 1.09	0.77 ± 0.62	33.13 ± 1.23	46.83 ± 1.62	37.69 ± 0.91	16.71 ± 0.81	67.18 ± 1.46	13.84 ± 2.97	27.47 ± 2.21

The intensity of the background red peel color was higher in the Gala genotype, with the 'a*' value ranging from 34.35 to 40.60; the results are in line with the results obtained by Kumar et al. [30] for apple cultivars from the Gala cultivars, which obtained 'a*' values ranging from 27.45 to 30.59, giving them an edge in sensory appeal compared to other cultivars (Table 4). Some non-red apple cultivars, such as 'Cidor' ('b*' value = 43.97), 'Greensleaves' ('b*' value = 42.08), and 'Ananas Reinette' ('b*' value = 42.04), showed higher 'b*' values, indicating their yellow color; additionally, their 'a*' values were as low as −5.70. Such differences in the peel color of the studied apple samples may be due to genotypic variations and the composition of pigments [33].

3.3. Texture Profile

The main textural characteristics determined—peel hardness (N), toughness (mm), flesh hardness (N), and hardness work (mJ)—were significantly different among the 22 genotypes of apples fruits, as presented in Table 5.

The results showed that peel hardness varied between 3.80 and 13.69 N, the toughness between 0.2 and 1.07 mm, the flesh hardness between 0.97 and 4.76 N, while the hardness work was between 6.88 and 27.84 mJ. Peel hardness and flesh hardness reflect the overall compactness and firmness of the fruit. The average peel hardness of the 22 apples genotypes was 9.59 N. The 'Golden Delicious Goldrosio' (15.00 N), 'Fuji Fenfu' (13.69 N), and 'Jonagold' (13.22 N) registered the highest hardness values. The average flesh hardness of the 22 apples genotypes was 3.21 N, with 'Golden Delicious Goldrosio' (4.76 N), 'Fuji Fenfu' (4.47 N), and 'Gala Fenplus' (4.01 N) having the highest hardness values. There were indications of a possible relationship between the hardness of the peel and the hardness of the flesh. In contrast, 'Bērnu Prieks' and 'Lobo' recorded the lowest values for these two textural characteristics. Toughness represents the ability of the fruit to withstand the action of a force, such as a bite. It registered the highest value in 'Cidor' and 'Iris' apple fruits, with 1.87 and 1.49 mm, respectively, while the lowest values were measured for the 'T120′ (1.09 mm) and 'Gala Fenplus' (1.07 mm) apple fruits.

The largest hardness work was found in the 'Fuji Fenfu' and 'Gala Dicarli Fendeca' fruits, with values of 27.84 and 25.08 mJ, respectively, whereas it presented the lowest values in the fruits of 'Bērnu Prieks' (7.08 mJ) and 'Lobo' (6.88 mJ). The basic physico-chemical properties of apples contribute greatly to their textural characteristics. Genetic variability is the main source of the diversity of fruit physico-chemical properties [29,34–36]. As expected, we found significant differences for several physico-chemical indexes among the 22 apples genotypes studied, suggesting that genetic characteristics have a decisive effect on the physico-chemical properties of apples. The effect of genetic characteristics was also emphasized in other horticultural species [37,38].

However, unexpectedly, we found certain significant correlations between some physico-chemical indices and textural characteristics. Many studies performed on textural characteristics of fruit have focused, so far, only on the analysis of the texture indexes themselves and less on to the relationship between fruit quality and textural characteristics [27]. Nonetheless, the results of the current study showed that the apple fruit physico-chemical indices may have certain effects on the texture parameters (Table 6).

Table 5. Comparison of peel hardness, flesh hardness, toughness, and hardness work of 22 apples genotypes.

Genotype	Peel Hardness (N)	Toughness (mm)	Flesh Hardness (N)	Hardness Work (mJ)
M. floribunda clone 821	5.80 ± 0.52 f,g	1.17 ± 0.13 b	3.08 ± 0.39 b,c,d	16.26 ± 1.01 f
Greensleaves	7.90 ± 0.85 e,f	1.30 ± 0.26 b	2.79 ± 0.55 c,d	17.60 ± 1.65 d,e
T188	8.88 ± 1.19 d,e,f	1.29 ± 0.10 b	2.92 ± 0.45 b,c,d	18.33 ± 2.62 c,d,e
Fuji Fenfu	13.69 ± 1.36 a,b	1.23 ± 0.09 b	4.47 ± 0.52 a,b	27.84 ± 1.38 a,b
Iris	9.35 ± 2.78 d,e	1.49 ± 0.36 a,b	3.09 ± 0.83 b,c,d	18.36 ± 3.70 d,e
Bērnu Prieks	3.80 ± 0.39 g	1.16 ± 0.29 b	1.06 ± 0.30 e	7.08 ± 1.48 f
Lobo	3.98 ± 0.78 g	1.44 ± 0.22 a,b	0.97 ± 0.17 e	6.88 ± 0.87 f
Gala Dicarli Fendeca	11.76 ± 1.70 a,b,c,d	1.22 ± 0.09 b	4.20 ± 0.85 a,b,c	25.08 ± 2.14 a,b,c
Judaine	10.06 ± 1.36 c,d,e	1.29 ± 0.14 b	3.34 ± 0.43 a,b,c,d	21.42 ± 2.03 b,c,d,e
Judeline	10.19 ± 1.49 c,d,e	1.42 ± 0.14 a,b	3.70 ± 0.77 a,bc,d	22.62 ± 3.28 a,bc,d,e
Golden Delicious Goldrosio	15.00 ± 2.59 a	1.30 ± 0.16 b	4.76 ± 1.14 a	28.90 ± 5.15 a
Golden Russet	10.58 ± 1.42 b,cd,e	1.25 ± 0.27 b	3.07 ± 0.87 b,c,d	19.90 ± 4.71 c,d,e
Ananas Reinette	9.67 ± 1.20 d,e	1.26 ± 0.06 b	3.85 ± 1.05 a,b,c,d	21.90 ± 3.02 b,c,d,e
Cidor	7.58 ± 1.83 e,f	1.87 ± 0.22 a	2.86 ± 0.66 c,d	17.60 ± 3.91 d,e
Akane	8.51 ± 1.30 d,e,f	1.28 ± 0.31 b	2.36 ± 0.38 d,e	16.38 ± 1.39 e
Gala Brookfield	10.65 ± 1.36 b,c,d,e	1.16 ± 0.08 b	3.42 ± 0.38 a,b,c,d	22.12 ± 2.80 b,c,d,e
T97	10.95 ± 0.76 b,c,d,e	1.28 ± 0.19 b	3.46 ± 0.53 a,b,c,d	21.80 ± 2.45 b,c,d,e
Gala Fenplus	10.97 ± 0.73 b,c,d,e	1.07 ± 0.06 b	4.01 ± 0.86 a,b,c	23.72 ± 3.10 a,b,c,d
Gala Venus Fengal	11.44 ± 1.24 b,c,d	1.29 ± 0.32 b	3.72 ± 0.65 a,b,c,d	22.96 ± 3.06 a,b,c,d
Jonagold	13.22 ± 0.78 a,b,c	1.48 ± 0.23 a,b	3.04 ± 0.48 b,c,d	22.38 ± 2.47 b,c,d,e
Priam	8.51 ± 2.13 d,e,f	1.34 ± 0.13 b	3.69 ± 0.75 a,b,c,d	20.70 ± 1.65 c,d,e
T120	8.52 ± 0,94 d,e,f	1.09 ± 0.27 b	2.83 ± 0.44 c,d	17.50 ± 1.25 d,e

Identical lowercase superscripts within columns indicate no significant difference ($p > 0.05$).

Table 6. Pearson correlations between physico-chemical and textural attributes of the 22 studied apple genotypes.

Physico-Chemical Quality Attributes	Fruit Weight (g)	Volume (mL)	Water Content (%)	Ash Content (%)	Total Soluble Solids (%)	Titratable Acidity (% Malic Acid)	Width (mm)	Length (mm)	Geometric Mean Diameter (mm)	Arithmetic Mean Diameter (mm)	Peel Hardness (N)	Toughness (mm)	Hardness Work (mJ)
Volume (mL)	**0.981**												
Water Content (%)	**0.443**	**0.435**											
Ash Content (%)	−0.056 ^{NS}	−0.076 ^{NS}	−0.237 ^{NS}										
Total Soluble Solids (%)	−0.411 ^{NS}	−0.423 ^{NS}	**−0.524**	−0.012 ^{NS}									
Titratable Acidity (%Malic Acid)	−0.115 ^{NS}	−0.108 ^{NS}	−0.087 ^{NS}	0.205 ^{NS}	0.052 ^{NS}								
Width (mm)	**0.940**	**0.935**	**0.465**	−0.013 ^{NS}	**−0.441**	−0.298 ^{NS}							
Length (mm)	**0.899**	**0.895**	0.417 ^{NS}	−0.027 ^{NS}	−0.400 ^{NS}	−0.264 ^{NS}	**0.919**						
Geometric Mean Diameter (mm)	**0.943**	**0.938**	**0.463**	−0.011 ^{NS}	**−0.434**	−0.300 ^{NS}	**0.992**	**0.960**					
Arithmetic Mean Diameter (mm)	**0.943**	**0.938**	**0.464**	−0.011 ^{NS}	**−0.434**	−0.301 ^{NS}	**0.993**	**0.958**	**1.000**				
Peel Hardness (N)	**0.463**	0.395 ^{NS}	−0.042 ^{NS}	0.038 ^{NS}	**−0.476**	−0.283 ^{NS}	**0.429**	**0.471**	**0.452**	**0.449**			
Toughness (mm)	−0.085 ^{NS}	−0.054 ^{NS}	−0.075 ^{NS}	0.074 ^{NS}	0.009 ^{NS}	−0.182 ^{NS}	0.061 ^{NS}	0.116 ^{NS}	0.080 ^{NS}	0.078 ^{NS}	−0.077 ^{NS}		
Hardness Work (mJ)	0.345 ^{NS}	0.283 ^{NS}	−0.196 ^{NS}	−0.116 ^{NS}	−0.297 ^{NS}	−0.357 ^{NS}	0.291 ^{NS}	0.373 ^{NS}	0.323 ^{NS}	0.321 ^{NS}	**0.941**	−0.110 ^{NS}	
Flesh Hardness (N)	0.242 ^{NS}	0.187 ^{NS}	−0.318 ^{NS}	−0.198 ^{NS}	−0.134 ^{NS}	−0.343 ^{NS}	0.167 ^{NS}	0.271 ^{NS}	0.202 ^{NS}	0.199 ^{NS}	**0.849**	−0.148 ^{NS}	**0.972**

^{NS} Not statistically significant ($p > 0.05$).

3.4. Chemometric Comparison and Classification

The combined application of principal component analysis (PCA) and hierarchical cluster analysis (HCA) might be useful for the comparison and classification of the studied apples genotypes. In order to achieve quality classification, cluster analysis can manage large data to observe the degree of similarity among different apples genotypes. PCA could effectively analyze the quality differences of various apple genotypes and the screening of the characteristic trait factors, an approach already used on apricots and citrus fruits [34,37]. Moreover, PCA can compress the original information using dimensionality reduction data and present the screening of effective indicators. This has been effective in other studies for the comprehensive evaluation of apple quality [39]. In the present study, PCA (Figure 3) and HCA (Figure 4) classified the apple fruits' physico-chemical and textural attributes according to an accurate algorithm, and the 22 studied apples genotypes were divided into four distinct categories. Several clustering methods were also applied to other fruits, such as pomegranates and citrus fruits [40,41]. The results from the current study showed that using both chemometric techniques, PCA, and HCA, the apples' texture and physico-chemical quality attributes can be more comprehensively understood. On the basis of the 14 quality parameters determined in this experiment (fruit weight, volume, water content, ash content, total soluble solids, titratable acidity, width, length, geometric mean diameter, arithmetic mean diameter, peel hardness, toughness, flesh hardness, and hardness work), after a weighted standard deviation pre-treatment of the data, in order to apply a relative significance to each value in the set of value, a systematic cluster analysis of the 22 apples genotypes was performed (Figure 4). The results showed that with a relative distance of 10, all the genotypes were grouped into four main clusters. Cluster I contained the genotypes 'Bērnu Prieks' and '*M. floribunda* clone 821′, while Cluster II comprised the other two genotypes, namely 'Cidor′ and 'Lobo'. The main cluster, Cluster III, was divided in several sub-clusters, and included the 'Jonagold', 'Golden Russet', 'T188′, 'T97′, 'T120′, 'Gala Brookfield', 'Akane', 'Judaine', 'Iris', and 'Greensleaves' apple genotypes. The other main cluster, Cluster IV, is based on the 'Gala Fenplus', 'Ananas Reinette', 'Golden Delicious Goldrosio', 'Priam', 'Judeline', 'Fuji Fenfu', 'Gala Venus Fengal', and 'Gala Dicarli Fendeca' apple genotypes.

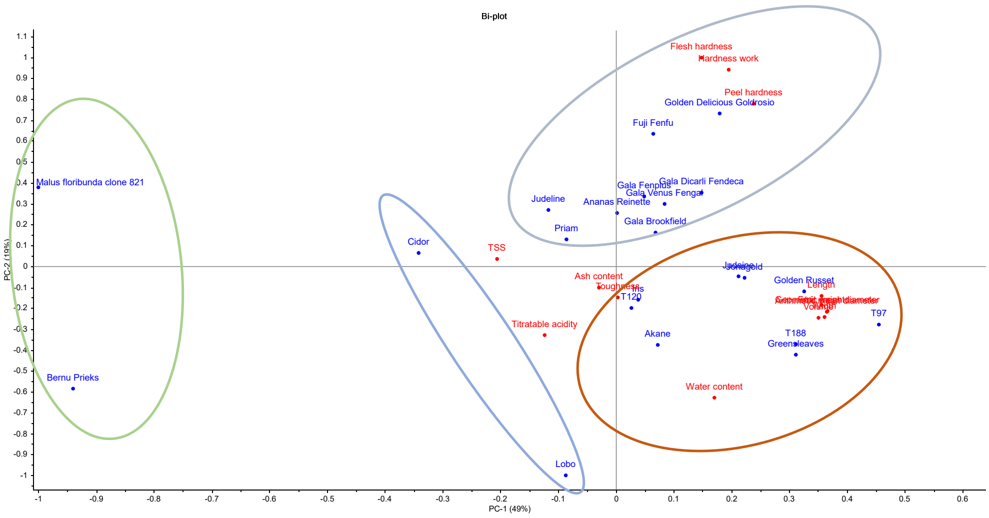

Figure 3. Principal component analysis (PCA) bi-plot for the 22 studied apple genotypes based on texture and physico-chemical quality attributes.

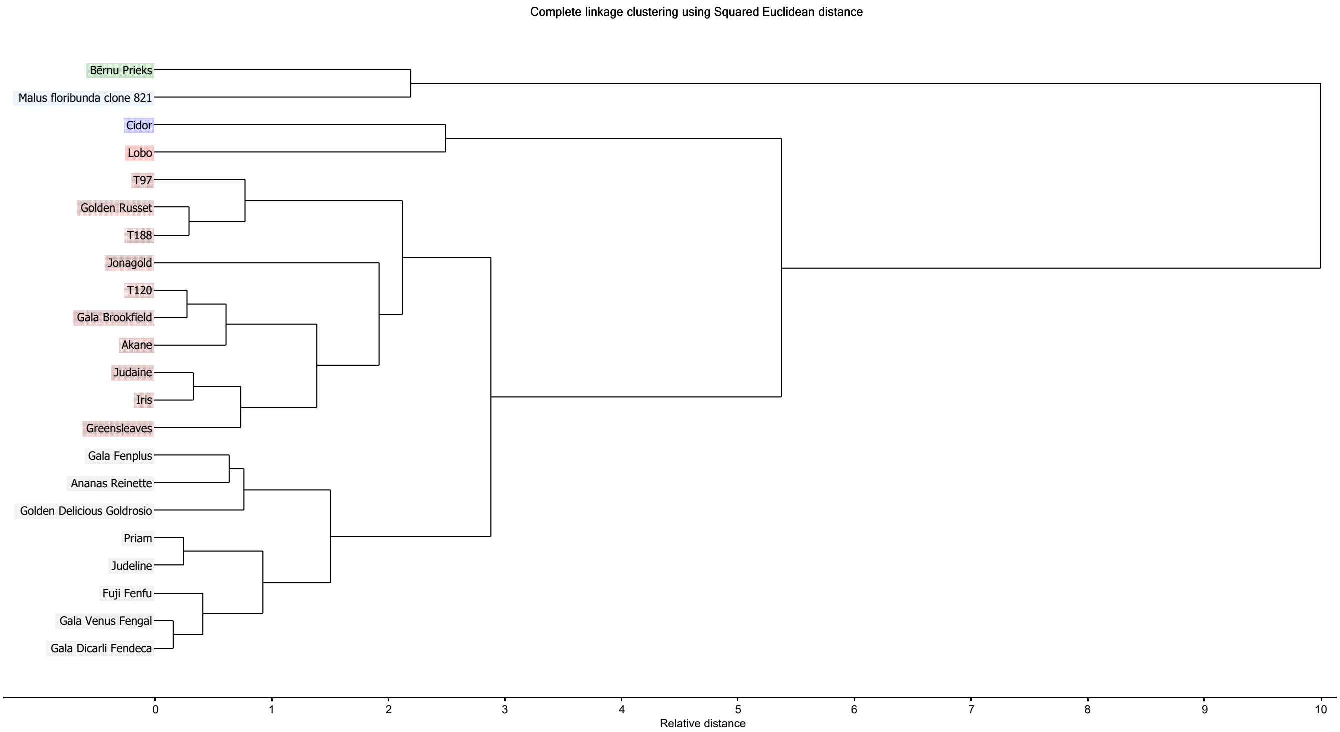

Figure 4. Hierarchical clustering diagram for the 22 studied apple genotypes.

From the cultivars in the 'Gala' group, only two ('Gala Venus Fengal' and 'Gala Dicarli Fendeca') were situated very close to each other, being located on a common sub-cluster in the dendrogram and belonging to Cluster IV. As showed above, in the same cluster was located 'Gala Fenplus', with only 'Gala Brookfield' appearing more distant from all three in Cluster III. However, the PCA analysis shows that all 'Gala' cultivars are placed in the same quadrant, and quite close to each other, forming practically a relatively homogeneous group. Consequently, the multivariate analysis also confirmed the close genetic kinship of these mutant varieties of 'Gala'. The 'Gala' group is close within the same quadrant of the PCA to the 'Golden Delicious Goldrosio' cultivar, probably reflecting not only the similarity based on the analyzed characteristics of the fruit, but also their similarity at the genetic level (all having one common parent, the 'Golden Delicious' cultivar) [42]. The arrangement of these cultivars in the quadrant, which also includes parameters that define pulp texture, can illustrate qualitative reference associations, as the respective cultivars are well appreciated organoleptically, but also as tasty apples. Finally, in the same quadrant, along with the cultivars originating in 'Gala' and 'Golden Delicious', there is also a cultivar originating in 'Fuji' ('Fuji Fenfu'). It is noteworthy that cultivars, such as 'Golden Delicious', 'Gala', and 'Fuji', known and widespread throughout the world, probably have this status also due to their high mutability, with many mutants (strains or sports) of these becoming in turn known and appreciated by the growers and consumers of apples. The perceived marketplace quality of such red or bicolored apples is determined by their visual appearance, and the intensity and quality of the red skin color and fruit size influence both consumer acceptance and sales [43]. 'Jonagold', which has a qualitative appreciation close to previous cultivars, and in addition comes from a cross between 'Golden Delicious' and the 'Jonathan', is positioned in another quadrant, with its triploidy probably influencing the variables quantified in the PCA. Because they are not negatively correlated (they are not positioned on opposite sides, in diagonally opposed quadrants), 'Jonagold' seems to differ from the other well-rated cultivars, especially on the basis of some parameters of fruit size. In fact, this result confirms that 'Jonagold', as a triploid cultivar, has large fruits [44].

3.5. Final Considerations and Verification of Hypotheses

The results of the study showed that within the analyzed genotypes, there is a wide variability for some traits (with the coefficient of variation CV% over 30% for some elements that contribute to fruit size), while for others, the variability is extremely small (e.g., water content in fruits). Wide variability is useful in apple breeding, with the choice of parents being focused on cultivars that have desired characteristics at high values [45,46]. However, the variability of all genotypes has been greatly influenced (increased) by crab apples, i.e., *M. floribunda* clone 821 and Bērnu Prieks (an early-autumn cultivar from Latvia, translated as Children's Joy, with small fruits and red pulp, being sweet and sour, and lingonberry flavored). For example, excluding these two genotypes from the calculation of the coefficient of variability for fruit weight, the value of the CV% would be reduced from 35.17% to 24.00%.

Although crab apples have the disadvantage of small fruits and other weak quality elements (revealed by the considerable distance in the PCA between them and the rest of the cultivars), many wild *Malus* species have been used in apple breeding, contributing to the diversification of the genetic background within the cultivated species, *M. domestica* Borkh [47–49]. *M. floribunda* clone 821 is well known for the *Vf* gene that confers resistance to apple scab disease, being the ancestor of many modern cultivars [50]. The process of obtaining the first cultivars of apple with genetic resistance to apple scab based on the *Vf* gene was long, from the first hybridization between *M. floribunda* clone 821 and Rome Beauty to obtaining the first cultivar with genetic resistance to apple scab conferred by the *Vf* gene (Prima cultivar) being necessary over sixty years [50]. In the present study, the physico-chemical attributes of the fruits reveal the closeness between this ancestor and some modern descendant cultivars, even after decades of modified backcross and selection. Thus, despite the distance that appears in the PCA, *M. floribunda* clones 821 and Priam (a distant descendant, after several generations of modified backcross), and Judeline (a descendant of Priam), are located in the same quadrant of the PCA. Only Judaine is in opposition to the distant parent, *M. floribunda*, and the direct one, Priam.

Similarly, Bērnu Prieks, which differs greatly in both the PCA and the dendrogram from 'noble' (improved) cultivars, could be introduced into a 'modified backcrossing' strategy, by which a simply inherited trait, such as red flesh, could be transferred into high-quality eating apple cultivars. Especially since Bērnu Prieks corresponds to a new trend in apple breeding, respectively obtaining cultivars with red pulp, it could be a potential parent for the rich content in suitable active chemical compounds [51]. A similar strategy can be used in order to obtain new cultivars, intended mainly for juice or cider. In the dendrogram, the Cidor and Lobo cultivars, suitable for cider, are positioned on the same subcluster, but in the PCA they are in different quadrants. The negative correlation of their physico-chemical elements with those of other cultivars recognized for the organoleptic quality of fruits can reflect not only their contrast but also can predict the possibilities of causing a wider phenotypic and genotypic variability in artificial hybridizations between such parental forms. Our study can emphasize the possibility of choosing the adequate apple cultivars to cross in the breeding process and how future strategies can help apple breeders select breeding parents, which are essential key steps in the breeding of new apple cultivars [13,52,53].

Such studies combined with those related to the organoleptic peculiarities of possible parental forms used in apple hybridization works can be extremely useful for the development of prospective breeding strategies, as in other horticultural species [46,54,55]. Consumer tastes and preferences for apples, as well as the needs of processors and industries, may change over time. As a result, the impact of fruit quality assessment studies and apple breeding targeting in line with fruit quality requirements will increase in the future.

4. Conclusions

Different texture and physico-chemical quality indexes were associated with each of the four clusters, especially fruit weight, volume, fruit dimensions, TSS, titratable acidity, peel hardness, flesh hardness, and hardness work, based on the PCA analysis (Figure 3, main clusters highlighted by the elliptical shapes). Cluster I was associated with the smallest values for fruit weight, volume, and diameters, Cluster II was based on medium-sized fruits, with low values for texture parameters, while Cluster III was mainly specific for the apple genotypes with the highest fruit size values, and medium values for texture indices. Cluster IV is mainly characterized by the apple genotypes with the fruits presenting the highest values for peel hardness, flesh hardness, and hardness work.

Our findings show that the combination of cluster analysis and principal component analysis could better classify the apple genotypes based on the physico-chemical and texture quality of apples fruits and extract the main features. In conclusion, combining basic physico-chemical index measures with apple fruit texture profiles enabled us to effectively characterize and compare the differences in apple fruits characteristics for 22 apples genotypes. Though there were significant differences in the basic physico-chemical properties and textural properties of the 22 apples genotypes, clustering analysis revealed trait similarities among the apple fruits from certain genotypes.

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