Physicochemical Diversity and Relationships among Sweet Cherry Cultivars from the Moroccan National Fruit GenBank

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Summary

In Morocco, cherries have acquired significant importance among fruit species and are one of the main species in high altitude areas. However, there is no exhaustive study that has highlighted the genetic diversity level of this species according to the varietal effect over several years under Moroccan climatic conditions. In the present study, twenty sweet cherry varieties were characterized using pomological and physicochemical traits over three years (2019, 2021, and 2022). Analysis of variance revealed that the majority of fruit traits were significantly affected by the variety, year, and their interaction. Fruits average weight for three years presented a high variation, ranging from 3.01g to 7.75g. Fruit length varied from 16.15 mm to 23.06 mm, and width ranged from 15.51mm to 22.52 mm. For chemical parameters, according to the variety, the pH ranged from 3.32 to 4.03 and the total soluble content among 17.17 and 23.24. Differences between the three years were highly significant for all the pomological parameters, highlighting the annual influence on the fruit parameters. Most of the pomological traits (fruit weight, dimensions, etc.) were relatively higher in 2019. For the physicochemical traits, pH and titratable acidity showed a strong variation over the three years, whereas total soluble content did not show any variation. The study showed a great diversity of Moroccan sweet cherry and physicochemical parameters variation is highly significant according to the variety and the harvest year. This study provides a basis for the breeding programs of sweet cherries in Morocco.

Key words

cherry tree, *ex-situ* collection, diversity, multivariate analysis, physicochemical, pomology

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Introduction

Prunus avium L., known as the sweet cherry, is a member of the Rosaceae family, and the Prunus genus is an important horticultural crop in temperate regions. It is a species of high economic value due to the nutritional quality, technological potential, and commercial relevance of its fruits (Dosba et al., 1994; Li et al., 2010). Sweet cherries are widely appreciated for their organoleptic characteristics (firmness, texture, taste and aroma), color, nutritional value and health benefits (Gonçalves et al., 2019). With their sweet and juicy taste, they are highly valued in the food industry directly as fresh fruit or by its use in the production of jams, jellies, compote, syrup, and a variety of non-alcoholic beverages (Gonçalves et al., 2019; Pérez-Sánchez et al., 2010).

Sweet cherry tree (*Prunus avium* L.) was disseminated across Europe and Asia by birds from which it takes its name from the Latin (Avis = bird). The Roman armies also transported it during various campaigns (Breton et al., 1972; Watkins, 1976).

Cherry production remains dominated by Turkey as the world's largest producer with 656041 tons (24% of world production) followed by the chili with 434067.19 tons (16% of world production) (FAOSTAT, 2022). In Morocco, harvested area in 2012-2022 increased from 1437 to 3553 hectares and the production was fluctuating between 7.196 and 15915.18 thousand tons. In 2019, the main production regions were Fez-Meknes with 18 thousand tons, Marrakech-Safi with 1.3 thousand tons and Béni Mellal-Khenifra with 513 tons ((MAPMDREF, 2019). In Morocco, the range of cherry varieties is relatively limited and is essentially limited to the bigarrel groups ('Burlat', 'Moreau', 'Van', 'Hedelingen', 'Napoléon'). However, the dominance belongs to the varieties 'B. Burlat' and 'B. Van', named respectively 'Bigaro' and 'Hajjari' in reference to their size and the firmness of the fruit (Kodad et al., 2016; MAPMDREF, 2019; Oukabli, 2004).

The physicochemical characteristics of fruits constitute the first elements which attract the consumer, and they are the basis of varietal selection. The success of the variety is ensured by fruit with an attractive color, large size, firm, tasty flesh and resistance to transport (Oukabli, 2004; Pérez-Sánchez et al., 2010). These characteristics generally depend on the genetic profile and are also strongly influenced by the environment. Finally, sweet cherry quality and consumer preferences are influenced by chemical profiles such as titratable acidity (TA) and total solid soluble (TSS) which are very important parameters for determining harvest date (Fazzari et al., 2008; Hansche et al., 1966; Pérez-Sánchez et al., 2010).

In Morocco there have been very limited studies related to the evaluation of the genetic diversity of cherry trees (*Prunus avium* L.), especially phenotypic variations under local environmental conditions. Likewise, climate change and accelerated warming in Morocco, including the Middle Atlas region, could have a negative impact on the agronomic behavior of cherry trees and on the quality of fruit (Legave, 2009). The objective of this study is therefore a characterization of 20 cherry accessions belonging to the *ex-situ* collection of the National Institute for Agricultural Research of Morocco (INRA) (experimental station of Annouceur), using pomological and physicochemical characteristics. This is the first study in Morocco which characterizes trees on the same site and over several years, minimizing the effect of environment and climate. The database obtained is essential for the development of sweet cherries cultivation in Morocco and would constitute a basis for genetic breeding programs.

Material and Methods

Plant Material

The plant material was composed of twenty varieties of sweet cherry (Table1) belonging to the *ex-situ* collection installed at the experimental field of Annoceur relevant to the National Institute for Agronomic Research INRA (33°41'05.2"N 4°51'19.9"W). The trees were planted at 5 × 4 m spacing, with 4 replicates for each variety, each replicate corresponding to one tree. Fifteen fruits were randomly collected from each replicate tree for pomological and physicochemical analyses. All trees were grown under the same cultural practices. Trees of uniform age (16 years) were grafted onto the same rootstocks (Sainte-Lucie). Fruits were harvested between mid-May and June in the years 2019, 2021, and 2022, at full maturity. In 2020, the study was not carried out due to the worldwide COVID-19 pandemic.

Table 1. List of the 20 sweet cherry varieties studied

Varieties	
Newstar	Lapins
INRAL4A21	Rainier
Stela	Van
INRAL5A21	Vista
Guillaume	Tragana d'Edessa
Burlat	Napoléon
INRAL1A17	Revérchon
Moreau	Marmotte
Stark Hardy Giant	Géant d'Hedelfingen
Précoce De Bernard	Noire De Meched

Characterization Parameters

For the pomological characterization, several parameters according to descriptors defined by International Union for The Protection of New Varieties of Plants (UPOV, 2019) were considered. The stone weight and fruit weight were measured with a precision balance and expressed in grams. The dimensions of the fruit and stone, such as length, width, and diameter, as well as the measurements of the stalk length and diameter, were determined using a digital caliper and expressed in millimeters.

The coloration of the fruit skin was measured using a NH310 colorimeter (Shenzhen 3NH Technology, China) and the color measurements were performed using the L * a * b * indices. The L * value represents lightness, ranging from 0 (black) to 100 (white).

Reddening or greening is expressed by the value of a coordinate a*, positive if red and negative if green. Yellowing or blueness is represented by a b* coordinate, which is positive for yellow and negative for blue. The color of the cherry skin was measured in 10 fruits.

The chemical analysis was performed in triplicates and concerned citric acid by titrating sweet cherry juice with 0.1 M NaOH (recommended by international federation of fruit juice producer (IFU) and total soluble solids were measured as °Brix using digital refractometer (PR101 ATAGO, Norfolk, VA, USA). The measurement of pH was performed by a pH meter (Thermo Scientific™ ECPH70042S).

Statistical Analysis

Statistical analysis was performed using SPSS software version 21. A one-way analysis of variance (ANOVA) was first conducted to evaluate the variability among varieties for each pomological and physicochemical trait. Mean comparisons were performed using Duncan's post hoc test ($P < 0.05$, $P < 0.01$), Subsequently, a multivariate analysis of variance (MANOVA) was applied to assess the effects of cultivar, harvest year, and their interaction (variety × year) on the studied traits. In addition, correlation indices by Person's index were carried out to determine the relationships between pomological and physicochemical parameters. The average of the tree years was used to perform cluster analysis, principal component analysis and discriminant factor analysis on physicochemical and pomological parameters. For cluster analysis, a similarity matrix based on Euclidian coefficient was calculated.

Results and Discussion

Fruits Pomological Characteristics

Analysis of variance (ANOVA; $P < 0.01$, $P < 0.05$) showed high variability among all the traits studied. Average weight for three years varied between 3.010 g (INRAL1A17) and 7.75 g ('Burlat') (Table 2) with 5.78 g as the average of all varieties. Our values are similar to those of (El Baji et al., 2021) and (Benková et al., 2017), who reported weight ranges from 3.60 to 7.52 g and from 3.70 to 8.90 g respectively, whereas our findings are greater than those observed by (Bandi et al., 2010) who found values that varied between 3.45 g and 4.63 g. Regarding dimensions, 'Burlat' is the largest variety with length of 23.07 mm, width 22.53 mm and thickness 21.42 mm, while the INRAL1A17 recorded the lowest values with length 16.15 mm, width 15.51 mm and thickness 15.85 mm. Concerning fruit, stalk length ranged from 24,45 mm ('Noire de Meched') to 40.73 mm (INRA L4A21) with an average of 34.68 mm. Our values are lower than those of Portuguese sweet cherry whose values are from to 33.4 to 49 mm (Rodrigues et al., 2008). Fruit stalk thickness ranged from 0.71 (Van) to 1.02 mm (INRAL4A21).

For stone weight, the values varied from 0.166 ('Stark Hardy Giant') to 0.575 g ('Moreau'). This finding aligns with those of (Khadivi et al., 2019) and (Karaat et al., 2019) (with value ranging from 0.38 to 0.57 g and 0.22 to 0.34 g respectively). Fruit stone length was from 8.46 ('Stark Hardy Giant') to 12.35 mm ('Van'). Fruit stone width was from 7.37 ('Géant d'Hedelfingen') to 11.15 mm ('Stark Hardy Giant'). Fruit stone thickness was from 5.42 (INRA L5 A21) to 7.54 mm ("Moreau").

The analysis of variance showed that variety, year, and their interaction had significant effects on all pomological traits examined (Table 3). Firstly, the differences between the three years were highly significant ($P < 0.01$ $P < 0.05$) for all pomological parameters, indicating the annual influence on fruit parameters. Most pomological characteristics (fruit weight, dimensions, etc.) were relatively higher in 2019 (Table 4). For the fruit weight, the difference between 2019 and those of 2021 and 2022 is 1.14% and 15.95%, respectively. For the length and thickness of the fruit, the differences between 2019 and 2021 and between 2019 and 2022, respectively, are 3.28% and 14.13%; 9.39% and 19.39%. The length of the stone and the thickness of stalk differences are 2.88% and 16.65% of 2021 and for 2022 the differences are 8.27% and 5.75 respectively. These results agree with the finding obtained by (Khadivi-Khub, 2014; Rodrigues et al., 2008; Sánchez et al., 2008).

In agreement with our results (Blažková et al., 2002), (Sánchez et al., 2008) and (Khadivi-Khub, 2014) reported that fruit characteristic, such as stalk length, fruit size (weight, length, width and diameter) and stone weigh, were affected by interannual climatic variations.

Picking cherries for fresh consumption or for the food industry is very dependent on the coloration level of cherries. Significant variation in color traits was observed among the sweet cherry varieties (table 5). The skin color of sampled fruits varied from a clear reddish yellow to a very dark reddish-brown color.

The highest L* was recorded by "Napoléon" followed by 'Burlat' (37.91 and 26.36, respectively), whereas the lowest values were recorded by 'Newstar' and 'Vista' (1.38 and 6.10 respectively). The highest a* was recorded by 'Lapins' and 'Newstar' (54.66 and 46.67 respectively), whereas the lowest values were recorded by 'Revérchon' and 'INRAL5A21' (12.09 and 15.71, respectively). The highest b* was recorded by 'Napoléon' and 'Lapins' (48.65 and 40.97 respectively), whereas the lowest values were recorded by 'Revérchon' and 'Tragana d'Edessa' (2.86 and 5.18 respectively).

For the C* values the sampled fruit showed a variation of the saturation from a less vivid and muted colors to a color with more vividness and saturated. The highest C* was recorded by 'Lapins' and 'Napoléon' (66.35 and 60.77 respectively), whereas the lowest values were recorded by 'Revérchon' and 'Géant d'Hedelfingen' (12.56 and 17.48 respectively).

The Hue angle (h*) ranged from 12.74 to 54.52 suggesting a red to reddish-brown color variation.

The darkest cherries (red- darkest) have low values for the lightness index (L*) and for the red (a*) and yellow (b*) color indices. The varieties which have these indices with high values have light skin colors. The 'Napoléon' variety is lighter; 'Noire de Meched', 'Van' and 'Tragana d'Edessa' have intermediate colors, while 'Vista' and 'Newstar' are the darkest cherries. The maturation process from the green color of the skin to the final color causes a constant change in the a* values and the h* angle (Barrelt and Gonzalez, 1994). However, the results show high correlations among L*, a* and b* indices compared to the hue angle (0.90, 0.99 and 0.97 against 0.01, -0.28 and - 0.472, respectively), which provides an explanation for the color differences among matured

Table 2. Average of pomological traits of the varieties studied

Varieties	WFr	LgFr	WidFr	ThicFr	LgSta	ThicSta	Wsto	LgSto	WidSto	ThicSto
Newstar	6.39±1.62^{cd}	20.51±2.19^{def}	21.02±2.04^{cde}	20.45±3.44^{bc}	31.66±4.42^{hi}	0.85±0.19^{de}	0.27±0.07^{e}	9.84±0.61^{f}	8.68±0.62^{fgh}	6.82±0.5^{ef}
INRAL4A21	3.68±0.44^{i}	17.39±2.05^{i}	16.32±1.96^{i}	17.25±2.69^{h}	40.73±5.16^{a}	1.02±0.34^{a}	0.25±0.13^{e}	10.52±0.45^{f}	8.48±0.42^{hi}	6.44±0.45^{gh}
Stela	4.63±1.38^{h}	17.31±2.11^{i}	18.42±3.52^{h}	16.8±2.06^{h}	36.23±5.42^{de}	0.75±0.18^{fg}	0.28±0.1^{de}	9.67±1.01^{g}	8.38±1.16^{hi}	6.65±1.04^{fg}
INRAL5A21	5.03±1.59^{g}	18.28±2.13^{h}	19.12±2.19^{gh}	18.37±2.62^{fg}	33.48±4.56^{fgh}	0.81±0.16^{def}	0.19±0.07^{fg}	9.11±1.12^{de}	8.89±1.22^{ehg}	5.42±0.85^{k}
Guillaume	6.25±1.18^{d}	21.66±1.61^{b}	20.53±2.41^{def}	19.57±2.66^{de}	37.88±6.14^{cd}	0.87±0.59^{cd}	0.39±0.07^{b}	12.34±0.77^{a}	8.58±0.64^{fgh}	7.18±0.42^{bcd}
Burlat	7.75±1.03^{a}	23.07±2.17^{a}	22.53±1.77^{a}	21.42±2.89^{a}	39.11±9.34^{abc}	0.72±0.22^{g}	0.25±0.05^{e}	10.79±1.19^{cd}	9.14±0.9^{de}	5.66±0.87^{j}
INRAL1A17	3.01±0.48^{j}	16.15±1.57^{j}	15.51±1.06^{j}	15.85±1.65^{i}	37.97±5.98^{bcd}	0.82±0.2^{def}	0.2±0.06^{f}	10.26±0.99^{e}	8.19±0.57^{i}	6.16±0.42^{i}
Moreau	6.66±1.13^{bc}	20.82±1.68^{cde}	21.55±2.23^{bc}	20.42±2.2^{bc}	33.21±6.24^{fgh}	0.82±0.18^{def}	0.58±0.32^{a}	11.58±0.71^{b}	9.47±0.68^{cd}	7.54±0.55^{a}
Stark Hardy Giant	5.69±1.5^{f}	19.41±1.94^{g}	20.09±2.85^{f}	19.54±2.12^{de}	32.64±5.76^{ghi}	0.77±0.15^{efg}	0.17±0.07^{g}	8.46±2.29^{h}	11.15±2.67^{a}	7.33±1.12^{abc}
Précoce De Bernard	5.26±1.07^{g}	18.29±2.08^{h}	19.17±2.51^{g}	18.32±2.43^{fg}	34.91±6.15^{ef}	0.94±0.15^{bc}	0.33±0.09^{c}	9.89±1.15^{f}	8.99±0.99^{ef}	7.35±0.81^{ab}
Lapins	6.65±1.67^{bc}	20.97±2.44^{cd}	20.9±3.41c^{de}	20.9±3.25^{ab}	30.86±5.43^{ij}	0.76±0.17^{fg}	0.3±0.07^{cd}	10.35±0.73^{e}	9.77±1.11^{c}	6.76±0.99^{f}
Rainier	6.11±0.73^{de}	20.01±1.48^{f}	20.5±1.59^{def}	19.65±2.24^{de}	29.21±4.21^{j}	1±0.17^{ab}	0.25±0.04^{e}	8.8±0.77^{gh}	9.66±1.36^{c}	6.19±0.77^{i}
Van	6.04±0.69^{def}	20.96±1.37^{cd}	20.32±3.19^{ef}	19.44±1.59^{e}	40.15±6.12^{ab}	0.71±0.2^{g}	0.37±0.21^{b}	12.35±0.91^{a}	10.45±1.66^{b}	6.41±0.58^{h}
Vista	6.84±1.09^{b}	21.07±1.75^{cd}	21.05±1.95^{cde}	20.33±2.89^{bc}	29.39±4.44^{j}	0.85±0.19^{de}	0.32±0.07^{c}	10.27±0.9^{e}	8.67±0.79^{fgh}	7.01±0.56^{de}
Tragana D'Edessa	5.28±0.83^{g}	18.49±1.1^{h}	20.07±1.98^{f}	18.82±1.99^{f}	38.98±3.35^{abc}	0.72±0.15^{g}	0.21±0.04^{f}	9.05±0.74^{g}	8.66±1.02^{fgh}	5.65±0.67^{j}
Napoléon	6.19±0.84^{de}	20.83±1.69^{cde}	21.09±2.31^{cde}	20.13±2.27^{cd}	33.41±5.36^{fgh}	0.87±0.13^{cd}	0.21±0.04^{f}	10.62±0.88^{de}	8.98±1.02^{ef}	5.67±0.65^{j}
Revérchon	6.68±1.64^{bc}	20.31±2.36^{ef}	21.84±1.28^{b}	20.84±2.96^{b}	36.41±8.19^{de}	0.77±0.3^{efg}	0.33±0.08^{c}	10.46±1.06^{de}	8.92±0.86^{efg}	7.12±0.69^{cd}
Marmotte	6.62±1.34^{bc}	21.31±1.96^{bc}	21.56±2.25^{bc}	20.62±2.49^{bc}	34.62±5.65^{efg}	0.79±0.13^{defg}	0.22±0.05^{f}	10.29±1.05^{e}	8.77±1^{efgh}	5.7±0.74^{j}
Géant d'Hedelfingen	4.98±1.63^{g}	19.34±2.5^{g}	18.55±2.41^{gh}	18.05±2.78g	38.14±7.32^{bcd}	0.75±0.17^{fg}	0.26±0.04^{e}	10.97±1.23^{c}	7.37±0.56^{j}	6.37±0.67^{hi}
Noire De Meched	5.87±1.41^{ef}	19.45±1.59^{g}	21.18±2.33^{bcd}	19.65±2.28^{de}	24.45±3.81^{k}	0.85±0.11^{de}	0.26±0.09^{e}	8.67±0.73^{h}	8.12±0.9^{i}	6.45±0.57^{gh}

Note: All data were expressed as means ± SD (n = 3), letters mean statistically significant differences ($P < 0.05$). WFr: Fruit Weight (g); LgFr: Fruit Length (mm); WidFr: Fruit Width(mm); ThicFr: Fruit Thickness (mm); LgSta: Stalk Length (mm); ThicSta: Stalk thickness (mm); Wsto Stone Weight (g); LgSto: stone length (mm); WidSto: stone width (mm); ThicSto: stone thickness (mm).

Table 3. Analysis of variance of the varietal and harvest year effect on sweet cherry fruit

	WFr	LgFr	WidFr	ThicFr	LgSta	ThicSta	Wsto	LgSto	WidSto	ThicSto	L*	a*	b*	C*	°Hue	pH	TA	°Brix
V	1085.11*	2506.88*	2714.78*	1881.65*	15203.57*	6.51*	7.1*	1027*	595.85*	358.38*	51100.45*	86512.57*	146831.47*	198129.37*	105189.69*	8.22*	88.81*	457.41*
Y	177.83*	580.6*	1223.61*	2994.72*	3667.45*	3.35*	0.7*	118.72*	181.71*	45.55*	8153.93*	3689.83*	4304.87*	7858.76*	1076.2NFS	6.36*	51.53*	2.16NFS
Y*V	568.58*	1254.33*	1393.47*	1153.91*	7185.78*	14.7*	5.57*	295.11*	349.17*	199.96*	24193.04*	45990.57*	58584.46*	95598.71*	65040.9*	5.12*	29.46*	312.65*
Error	572.853	1411.723	2182.340	1428.416	18946.444	27.886	4.437	519.737	563.032	212.703	16437.553	98395.045	112520.941	178319.792	334437.818	0.307	2.365	448.524

Note: NS: not significant; *: indicate a significant at $P < 0.05$ and $P < 0.01$

sweet cherry varieties. However, studies have indicated that concentration and distribution of anthocyanins and colorless phenolic compounds as well as pH influence the coloring of cherries (Gao and Mazza, 1995).

The differences between the three years were highly significant ($P < 0.01$, $P < 0.05$) for all color index, except for the Hue° index, highlighting the annual influence on fruit parameters. The skin color (Table 6) of the fruits harvested in 2022 has the highest a*, b* and C* with a significant difference of 17.28%, 20.87% and 18.41% respectively compared to 2019 and 7.81%, 23.25% and 10.18% respectively compared to 2021. The highest L* was recorded by the fruit harvested in 2019 with a difference of 8.99% compared to 2021 and 42.25% compared to 2022, while there were minor differences between the three years for the Hue° index. The colors of the fruits harvested in 2022 are the darkest with moderate red slightly less yellow undertones, while the fruits harvested in 2019 are the lightest with a milder red shift and slightly less pronounced yellow undertones.

Chemical Attributes

In addition to morphological traits, the parameters like °Brix, titratable acidity and pH are also constitute elements of selection for the breeder and of choice for the consumer. Thus, they are indicators of the maturity level of cherries (Pruthi et al., 1980). Significant variability was found between varieties for all the studied parameters (table 5). The highest pH values are recorded by the variety 'Géant d'Hedelfingen' and INRAL1A17 (4.03 and 3.98, respectively), whereas the lowest values are recoded by 'Revérchon' and 'Burlat' (3.32 and 3.35 respectively). The average pH value is 3,71. According to (Brouillard et al., 1991) who reported that a pH among 3.0 and 5.0 favored copigmentation reactions, the pH values of our varieties are favorable for strengthening the color of cherries. Similar values (3.56 to 3.80) were shown in varieties grown in Turkey (Hayaloglu and Demir, 2015) and with results (3.81 to 3.96) reported by (Vavoura et al., 2015) for 'Canada giant', 'Ferrovia', 'Lapins' and 'Skeena' varieties.

For the Titratable acidity (TA), the greatest values are found in the varieties 'Marmotte' and 'Revérchon' (3.70 and 3.65 $g{\cdot}100\ g^{-1}$ respectively), whereas the lowest values are recoded by "Burlat" and "Lapins" (0.79 and 1.48 $g{\cdot}100\ g^{-1}$ respectively). Our values are greater than those published by Vavoura et al. (2015) for 'Canada giant', 'Ferrovia', 'Lapins' and 'Skeena' varieties.

Sugars are the main element in determining the taste of cherries and are the factor that involves consumer preferences (Crisosto et al., 2003; Usenik et al., 2008). They are the main component of total soluble solids (TSS) with a percentage of 90%. The refractometer constitutes the simplest, most precise, and reproducible tool for determining the SSC content using °Brix (Girard and Kopp, 1998). The highest values of SSC for varieties studied are recorded by the varieties 'Stark Hardy Giant' and 'INRAL4A21' (23.27 and 21.25 °Brix respectively), whereas the lowest values are recoded by the varieties 'Newstar' and 'Lapins' (17.18 and 17.23 °Brix, respectively). The average value is 20.51 °Brix, with most varieties exhibiting TSS levels above 19 °Brix. Compared to results published for sweet cherry varieties from other countries, the SSC content of our varieties is higher (Hayaloglu and Demir, 2015; Kelebek and Selli, 2011).

Table 4. Average of pomological traits of the varieties studied for different harvest years

Varieties	Year	WFr	LgFr	WidFr	ThicFr	LgSta	ThicSta	Wsto	LgSto	WidSto	ThicSto
Newstar	2019	7.76 ± 1.01	22.65 ± 1.08	20.12 ± 0.99	24.45 ± 1.4	32.76 ± 3.28	1.02 ± 0.08	0.23 ± 0.03	10.36 ± 0.42	8.78 ± 0.43	6.98 ± 0.46
	2021	6.86 ± 0.59	20.6 ± 0.68	23.25 ± 0.95	19.89 ± 1.31	33.7 ± 3.72	0.64 ± 0.12	0.35 ± 0.04	9.82 ± 0.44	9.15 ± 0.43	7.12 ± 0.37
	2022	4.57 ± 1.06	18.29 ± 1.81	19.7 ± 1.78	17 ± 1.81	28.52 ± 4.53	0.9 ± 0.12	0.22 ± 0.02	9.33 ± 0.5	8.12 ± 0.49	6.38 ± 0.33
INRAL4A21	2019	3.84 ± 0.35	17.73 ± 0.62	15.72 ± 0.52	18.51 ± 0.95	38.53 ± 4.38	0.69 ± 0.08	0.15 ± 0.03	10.56 ± 0.55	8.43 ± 0.27	6.51 ± 0.27
	2021	3.81 ± 0.36	18.27 ± 0.62	16.89 ± 0.99	18.69 ± 1.53	43.57 ± 3.08	1.35 ± 0.31	0.37 ± 0.16	10.69 ± 0.34	8.76 ± 0.42	6.82 ± 0.31
	2022	3.39 ± 0.47	16.17 ± 3.14	16.36 ± 3.17	14.54 ± 2.77	40.09 ± 6.37	1 ± 0.17	0.23 ± 0.06	10.33 ± 0.36	8.26 ± 0.39	5.98 ± 0.26
Stela	2019	3.4 ± 1.22	15.6 ± 1.69	15.17 ± 2.85	16.1 ± 1.48	36.42 ± 5.45	0.72 ± 0.2	0.18 ± 0.1	9.15 ± 0.87	7.6 ± 0.79	5.8 ± 0.63
	2021	6.08 ± 0.61	19.15 ± 0.93	22.3 ± 1.93	18.7 ± 1.58	40.48 ± 5.85	0.54 ± 0.12	0.24 ± 0.03	9.38 ± 0.3	9.63 ± 0.41	5.61 ± 0.33
	2022	4.38 ± 0.34	16.6 ± 0.48	17.97 ± 0.87	15.34 ± 0.88	36.08 ± 5.31	0.85 ± 0.18	0.28 ± 0.04	9.09 ± 0.6	7.89 ± 0.91	6.36 ± 0.79
INRAL5 A21	2019	5.34 ± 0.59	19.57 ± 0.65	18.08 ± 0.77	21.05 ± 0.89	32.55 ± 2.64	0.87 ± 0.07	0.2 ± 0.02	9.75 ± 0.3	8.38 ± 0.27	6.2 ± 0.16
	2021	5.45 ± 2.54	17.66 ± 3	19.65 ± 3.35	17.28 ± 2.89	32.47 ± 5.85	0.65 ± 0.11	0.21 ± 0.12	8.81 ± 1.63	9.17 ± 1.95	5.12 ± 1.07
	2022	4.3 ± 0.59	17.6 ± 0.61	19.63 ± 0.99	16.78 ± 0.88	35.43 ± 5.39	0.92 ± 0.11	0.16 ± 0.04	8.77 ± 0.54	9.1 ± 0.3	4.95 ± 0.31
Guillaume	2019	6.79 ± 1.2	22.37 ± 1.52	18.42 ± 1.03	22.76 ± 1.22	37.53 ± 8.16	0.9 ± 0.09	0.33 ± 0.04	12.78 ± 0.83	8.83 ± 0.31	7.24 ± 0.33
	2021	6.23 ± 0.98	22.19 ± 0.94	22.72 ± 1.61	18.5 ± 1.01	40.44 ± 3.33	0.53 ± 0.13	0.44 ± 0.05	12.39 ± 0.41	9.01 ± 0.54	7.34 ± 0.48
	2022	5.75 ± 1.19	20.42 ± 1.59	20.45 ± 2.17	17.46 ± 1.66	35.67 ± 5.35	1.18 ± 0.91	0.41 ± 0.06	11.85 ± 0.73	7.92 ± 0.42	6.98 ± 0.39
Burlat	2019	8.16 ± 0.88	25.06 ± 1.55	20.63 ± 0.78	24.74 ± 1.08	43.26 ± 7.43	0.96 ± 0.12	0.26 ± 0.03	11.68 ± 0.41	8.36 ± 0.32	6.53 ± 0.43
	2021	8.32 ± 0.47	23.28 ± 1.19	24.34 ± 0.82	19.55 ± 2.54	44.86 ± 4.83	0.54 ± 0.1	0.27 ± 0.05	10.91 ± 1.14	9.89 ± 0.79	5.16 ± 0.79
	2022	6.77 ± 0.87	20.87 ± 1.25	22.62 ± 1.06	19.97 ± 0.92	29.2 ± 6.04	0.66 ± 0.18	0.22 ± 0.05	9.78 ± 1.01	9.18 ± 0.77	5.29 ± 0.58
INRAL1A17	2019	3.36 ± 0.34	17.12 ± 1.01	15.25 ± 0.96	17.41 ± 0.95	34.07 ± 4.9	0.66 ± 0.09	0.14 ± 0.02	10.16 ± 0.34	8.17 ± 0.36	6.27 ± 0.24
	2021	2.51 ± 0.3	15.27 ± 2.07	15.43 ± 1.31	14.48 ± 1.25	38.42 ± 4.79	1.05 ± 0.05	0.21 ± 0.04	10.08 ± 1.63	8.1 ± 0.87	5.87 ± 0.49
	2022	3.16 ± 0.31	16.07 ± 0.77	15.87 ± 0.8	15.66 ± 1.2	41.43 ± 6	0.75 ± 0.14	0.26 ± 0.03	10.55 ± 0.45	8.31 ± 0.33	6.34 ± 0.35
Moreau	2019	6.83 ± 0.65	21.5 ± 1.26	19.49 ± 0.65	23.2 ± 0.97	28.42 ± 6.51	1 ± 0.14	0.29 ± 0.03	12.19 ± 0.54	9.42 ± 0.29	7.54 ± 0.28
	2021	5.5 ± 0.74	19.02 ± 1.27	21.15 ± 1.57	18.57 ± 0.97	33.67 ± 4.53	0.78 ± 0.13	0.44 ± 0.07	11.43 ± 0.56	9.89 ± 0.85	8.06 ± 0.42
	2022	7.66 ± 0.67	21.95 ± 0.55	24.02 ± 1.2	19.5 ± 0.66	37.53 ± 3.82	0.7 ± 0.11	1 ± 0.15	11.12 ± 0.56	9.08 ± 0.56	7.03 ± 0.36

Continued. Table 4

Varieties	Year	WFr	LgFr	WidFr	ThicFr	LgSta	ThicSta	Wsto	LgSto	WidSto	ThicSto
Stark Hardy Giant	2019	5.52 ± 0.73	20.01 ± 0.95	18.15 ± 0.93	20.79 ± 1.03	27.07 ± 4.32	0.89 ± 0.08	0.23 ± 0.03	11.18 ± 0.46	8.67 ± 0.66	6.83 ± 0.57
	2021	7.17 ± 0.94	20.88 ± 1.07	23.53 ± 1.38	20.57 ± 1.03	36.42 ± 4.58	0.61 ± 0.09	0.16 ± 0.04	7.69 ± 1.33	13.91 ± 2.26	8.27 ± 1.19
	2022	4.39 ± 1.21	17.35 ± 1.59	18.59 ± 1.89	17.27 ± 1.92	34.44 ± 3.57	0.83 ± 0.12	0.1 ± 0.04	6.5 ± 1.32	10.88 ± 1.42	6.89 ± 0.86
Précoce De Bernard	2019	5.25 ± 0.66	18.51 ± 1.71	18.61 ± 2.28	19.95 ± 2.45	37.02 ± 7.43	0.96 ± 0.1	0.3 ± 0.08	10.27 ± 1.38	9.21 ± 1.26	7.57 ± 1.01
	2021	6.33 ± 0.63	20.22 ± 0.88	21.77 ± 0.99	19.27 ± 0.72	34.82 ± 4.3	1.02 ± 0.12	0.4 ± 0.08	10.5 ± 0.44	9.48 ± 0.48	7.75 ± 0.45
	2022	4.2 ± 0.57	16.14 ± 0.94	17.14 ± 1.25	15.75 ± 1.09	32.9 ± 5.99	0.83 ± 0.16	0.28 ± 0.05	8.88 ± 0.6	8.26 ± 0.63	6.74 ± 0.49
Lapins	2019	8.37 ± 0.62	23.68 ± 1	21.68 ± 0.66	25.09 ± 0.63	27.97 ± 3.75	0.92 ± 0.11	0.3 ± 0.01	10.57 ± 0.35	9.33 ± 0.26	7.29 ± 0.23
	2021	4.79 ± 0.92	18.37 ± 1.14	19.71 ± 1.74	17.69 ± 1.32	35.53 ± 2.5	0.7 ± 0.09	0.25 ± 0.08	9.9 ± 0.72	10.63 ± 1.6	5.5 ± 0.63
	2022	6.77 ± 0.87	20.87 ± 1.25	21.28 ± 5.44	19.97 ± 0.92	29.2 ± 6.04	0.66 ± 0.18	0.36 ± 0.05	10.56 ± 0.85	9.38 ± 0.36	7.45 ± 0.39
Rainier	2019	6.59 ± 0.58	20.86 ± 1.29	19.05 ± 0.76	22.24 ± 0.88	29.19 ± 3.66	1.09 ± 0.11	0.27 ± 0.03	9.13 ± 0.35	8.93 ± 0.86	7.01 ± 0.38
	2021	6.17 ± 0.65	20.56 ± 0.9	21.93 ± 0.97	19.19 ± 0.83	30.62 ± 4.61	1.03 ± 0.15	0.26 ± 0.05	9.08 ± 0.78	10.38 ± 1.47	6.03 ± 0.49
	2022	5.57 ± 0.61	18.62 ± 1.14	20.5 ± 1.39	17.51 ± 1.44	27.8 ± 4.09	0.87 ± 0.18	0.23 ± 0.03	8.18 ± 0.73	9.66 ± 1.35	5.52 ± 0.47
Van	2019	5.67 ± 0.4	20.3 ± 0.71	16.95 ± 0.45	21.31 ± 1	36.23 ± 5.35	0.88 ± 0.12	0.34 ± 0.18	12.02 ± 0.63	8.71 ± 0.24	7.02 ± 0.25
	2021	6.33 ± 0.8	21.71 ± 1.99	21.51 ± 2.17	18.16 ± 0.8	42.55 ± 6.49	0.49 ± 0.17	0.38 ± 0.22	12.67 ± 1.25	11.07 ± 1.12	6 ± 0.42
	2022	6.1 ± 0.69	20.87 ± 0.63	22.51 ± 2.87	18.84 ± 0.66	41.67 ± 4.7	0.75 ± 0.08	0.38 ± 0.24	12.36 ± 0.64	11.57 ± 1.52	6.22 ± 0.43
Vista	2019	7.29 ± 0.82	21.22 ± 1.1	20.22 ± 0.72	23.88 ± 1.3	28.41 ± 4.14	0.93 ± 0.09	0.26 ± 0.02	10.26 ± 0.38	9.06 ± 0.26	7.2 ± 0.39
	2021	5.78 ± 0.6	19.38 ± 1.06	20.06 ± 1.77	17.68 ± 1.22	31.71 ± 3.71	0.68 ± 0.1	0.3 ± 0.04	9.5 ± 0.82	7.93 ± 0.89	6.59 ± 0.62
	2022	7.45 ± 0.92	22.59 ± 1.32	22.88 ± 1.72	19.41 ± 1.07	28.04 ± 4.72	0.95 ± 0.2	0.39 ± 0.05	11.05 ± 0.66	9.01 ± 0.45	7.22 ± 0.4
Tragana D'Edessa	2019	5.23 ± 0.43	18.93 ± 0.96	18.11 ± 0.62	21.07 ± 0.64	38.3 ± 2.53	0.8 ± 0.08	0.21 ± 0.03	9.24 ± 0.45	7.81 ± 0.5	6.32 ± 0.33
	2021	6.08 ± 0.53	19.15 ± 0.65	22.3 ± 0.89	18.7 ± 0.73	40.48 ± 4.41	0.54 ± 0.08	0.24 ± 0.04	9.38 ± 0.74	9.63 ± 0.76	5.61 ± 0.41
	2022	4.53 ± 0.61	17.39 ± 0.67	19.8 ± 1.23	16.68 ± 1.04	38.18 ± 2.42	0.8 ± 0.08	0.18 ± 0.04	8.52 ± 0.73	8.55 ± 0.81	5.01 ± 0.48
Napoléon	2019	6.48 ± 0.87	21.86 ± 1	18.7 ± 0.86	22.55 ± 1.21	29.88 ± 3.59	0.94 ± 0.1	0.22 ± 0.02	11.13 ± 0.33	7.96 ± 0.22	6.34 ± 0.22
	2021	6.33 ± 0.89	19.91 ± 0.86	22.98 ± 1.28	19.35 ± 1.16	34.77 ± 3.28	0.76 ± 0.09	0.22 ± 0.06	10.15 ± 0.61	9.8 ± 0.8	5.46 ± 0.44
	2022	5.76 ± 0.6	20.73 ± 2.29	21.57 ± 2.06	18.5 ± 1.89	35.57 ± 6.81	0.92 ± 0.12	0.2 ± 0.03	10.57 ± 1.21	9.18 ± 0.85	5.21 ± 0.57

Continued. Table 4

Varieties	Year	WFr	LgFr	WidFr	ThicFr	LgSta	ThicSta	Wsto	LgSto	WidSto	ThicSto
Revérchon	2019	8.34 ± 0.78	22.99 ± 1.21	21.96 ± 0.78	24.59 ± 0.82	27.04 ± 4.01	0.88 ± 0.09	0.26 ± 0.03	11.01 ± 0.56	8.21 ± 0.34	6.56 ± 0.25
	2021	5.93 ± 1.59	19.15 ± 1.65	21.99 ± 1.68	18.79 ± 1.39	44.91 ± 4.14	0.63 ± 0.13	0.35 ± 0.03	10.23 ± 0.64	9.34 ± 0.45	7.37 ± 0.33
	2022	5.76 ± 0.92	18.8 ± 1.34	21.57 ± 1.26	19.13 ± 1.49	37.28 ± 2.26	0.82 ± 0.47	0.37 ± 0.12	10.15 ± 1.53	9.22 ± 1.09	7.43 ± 0.91
Marmotte	2019	6.97 ± 0.74	21.95 ± 1.17	19.66 ± 0.72	23.41 ± 1.24	31.27 ± 3.46	0.84 ± 0.08	0.23 ± 0.02	10.59 ± 0.5	7.99 ± 0.29	6.46 ± 0.32
	2021	7.71 ± 0.89	22.86 ± 1.13	24.16 ± 1.33	20.34 ± 1.26	40.39 ± 3.87	0.76 ± 0.09	0.25 ± 0.05	11.05 ± 0.85	9.84 ± 0.79	5.63 ± 0.55
	2022	5.19 ± 0.83	19.13 ± 1.13	20.85 ± 1.41	18.11 ± 1.05	32.2 ± 4.39	0.78 ± 0.18	0.17 ± 0.04	9.25 ± 0.79	8.48 ± 0.71	5.01 ± 0.43
Géant d'Hedelfingen	2019	5.7 ± 0.53	21.38 ± 0.89	18.54 ± 0.64	20.82 ± 0.79	34.8 ± 4.84	0.93 ± 0.07	0.27 ± 0.03	11.25 ± 0.91	7.98 ± 0.19	6.34 ± 0.24
	2021	6.33 ± 0.87	20.53 ± 1.12	21.15 ± 1.55	18.71 ± 1.24	45.77 ± 4.69	0.64 ± 0.13	0.24 ± 0.04	11.76 ± 1.29	7.03 ± 0.5	7.07 ± 0.49
	2022	2.9 ± 0.41	16.11 ± 0.61	15.96 ± 0.99	14.61 ± 0.88	33.85 ± 5.39	0.67 ± 0.11	0.27 ± 0.04	9.92 ± 0.54	7.11 ± 0.3	5.7 ± 0.31
Noire De Meched	2019	5.69 ± 0.52	19.8 ± 0.96	19.06 ± 0.58	22.04 ± 1.05	22.38 ± 2.76	0.89 ± 0.08	0.19 ± 0.02	8.88 ± 0.24	8.06 ± 0.65	6.28 ± 0.23
	2021	7.46 ± 0.9	20.81 ± 0.95	24.07 ± 1.15	20 ± 0.64	27.47 ± 3.38	0.75 ± 0.07	0.37 ± 0.05	9.23 ± 0.46	8.82 ± 0.7	7.08 ± 0.31
	2022	4.46 ± 0.55	17.73 ± 0.91	20.39 ± 1.02	16.91 ± 0.74	23.5 ± 3.37	0.89 ± 0.11	0.23 ± 0.05	7.88 ± 0.6	7.49 ± 0.83	5.99 ± 0.45

Note: All data were expressed as means ± SD (n = 3). WFr: Fruit Weight (g) LgFr: Fruit Length (mm); WidFr: Fruit Width (mm), ThicFr: Fruit Thickness (mm), LgSta: Stalk Length (mm) ThicSta: Stalk thickness (mm), Wsto Stone Weight (g), LgSto: stone length (mm) WidSto: stone width (mm) ThicSto: stone thickness (mm).

Table 5. Average of physicochemical traits of the varieties studied

Varieties	L*	a*	b*	C*	°Hue	pH	TA	TSS (°Brix)	MI
Newstar	1.38±7.37^{k}	46.67±17.73^{ab}	34.83±20.14^{b}	59.07±24.89^{a}	40.77±45.61^{bcd}	3.75±0.3^{ef}	2.31±0.35^{efg}	17.18±1.49^{c}	7.68±1.8^{defg}
INRAL4A21	10.55±11.84^{ghi}	23.55±6.35^{hij}	8.16±16.95^{ef}	23.72±17.37^{fghi}	12.74±15.96^{a}	3.84±0.24^{cd}	2.24±0.71^{fg}	23.25±2.84^{a}	11.11±3.08^{c}
Stela	16.19±11.7^{cde}	31.04±16.07^{defg}	15.39±10.46^{cde}	37.52±12.46^{cde}	32.02±51.66^{cdef}	3.91±0.28^{bc}	2.16±0.75^{fg}	18.77±1.52^{bc}	9.99±4.42^{cde}
INRAL5A21	8.45±4.99^{ij}	15.7±13.91^{ij}	10.34±15.45^{def}	19.99±19.62^{ghi}	35.53±24.26^{bcdef}	3.41±0.06^{hi}	3.26±0.29^{b}	21.03±2.3^{ab}	6.47±0.72^{fg}
Guillaume	8.52±6.18^{ij}	28.79±16.53^{efgh}	21.87±10.78^{c}	36.85±18.38^{cde}	45.95±37.97^{bc}	3.45±0.15^{h}	2.92±0.49^{c}	19.52±1.26^{bc}	6.86±1.37^{fg}
Burlat	26.36±3.49^{b}	39.82±5.16^{bcd}	23.59±4.81^{c}	46.32±6.81^{bc}	30.27±2.7^{cdef}	3.35±0.07^{ij}	0.78±0.03^{j}	18.88±1.17^{bc}	24.15±1.89^{a}
INRAL1a17	14.87±8.94^{def}	28.39±19.74^{efgh}	18.04±23.54^{cd}	34.88±29.28^{cdef}	20.49±15.66^{ef}	3.98±0.39^{ab}	2.2±0.79^{fg}	20.78±2^{ab}	10.34±3.11^{cd}
Moreau	17.88±9.62^{cd}	28.72±7.17^{efgh}	11.7±5.32^{def}	31.12±8.51^{defg}	21.09±5.2^{ef}	3.9±0.34^{bc}	2.79±0.6^{c}	21.48±1.94^{ab}	7.97±1.65^{defg}
Stark Hardy Giant	10.94±5.22^{ghi}	32.81±10.33^{cdef}	18.37±9.56^{cd}	37.81±13.51^{cd}	27.06±6.84^{cdef}	3.89±0.33^{cd}	2.71±0.64^{cd}	23.27±1.02^{a}	9.01±2.07^{cdef}
Précoce De Bernard	15.71±11.1^{cde}	27.01±8.16^{efgh}	9.47±7^{def}	28.82±10.1^{defgh}	17.63±8.64^{f}	3.72±0.48^{fg}	3.22±0.85^{b}	21.1±1.67^{ab}	6.92±1.62^{fg}
Lapins	13.88±9.89^{efg}	51.66±13.93^{a}	40.97±18.22^{ab}	66.35±21.67^{a}	37.53±6.53^{bcde}	3.66±0.09^{fg}	1.48±0.78^{i}	17.23±1.91^{c}	15.55±8.95^{d}
Rainier	9.02±6.6^{hij}	23.74±16.59^{fghi}	12.05±15.97^{def}	28.19±21.03^{defgh}	31.01±24.37^{cdef}	3.73±0.41^{efg}	2.92±1.23^{c}	21.3±2.74^{ab}	8.88±4.46^{cdef}
Van	12.53±2.77^{ehgh}	41.55±20.14^{bc}	39.97±30.22^{ab}	58.61±34.71^{ab}	35.93±14.92^{bcdef}	3.81±0.42^{dc}	1.78±1.21^{h}	19.57±3.85^{bc}	22.97±21.33^{a}
Vista	6.1±4.45^{j}	20.34±9.5^{hij}	6.43±4.81^{f}	21.71±9.81^{ghi}	19.63±14.69^{a}	3.84±0.36^{cd}	2.49±0.62^{de}	20.91±2.17	9.09±3.37^{cdef}
Tragana d'Edessa	11.19±7.37^{fghi}	23.34±14.27^{ghi}	5.18±6.81^{f}	25.33±16.23^{efgh}	14.78±15.23^{a}	3.66±0.14^{fg}	2.3±0.68^{efg}	18.5±2.13^{bc}	8.65±2.62^{cdef}
Napoléon	37.91±10.95^{a}	35.03±18.44^{cde}	48.65±21.15^{a}	60.77±26.19^{a}	54.52±11.68^{b}	3.4±0.04^{hij}	3.23±1.25^{b}	20.3±0.97^{abc}	7.6±3.89^{efg}
Revérchon	10.55±2.73^{ghi}	12.09±8.3^{i}	2.86±2.17^{f}	12.56±8.37^{i}	17.46±12.81^{f}	3.32±0.02^{i}	3.65±0.46^{a}	19.18±3.85^{bc}	5.27±0.9^{g}
Marmotte	19.02±3.97^{c}	31.54±6.15^{defg}	14.78±5.68^{cde}	34.94±7.9^{cdef}	24.16±4.89^{def}	3.66±0.31^{g}	3.7±0.56^{a}	20.32±1.85^{abc}	5.64±1.19^{g}
Géant d'Hedelfingen	10.58±2.31^{ghi}	16.48±2.89^{ij}	5.72±1.98^{ef}	17.48±3.34^{hi}	18.75±3.45^{ef}	4.03±0.03^{a}	2.39±0.3^{ef}	19.89±2.05^{bc}	8.41±1.32^{cdef}
Noire de Meched	13.11±3.43^{efg}	30.51±5.54^{efg}	14.81±6.39^{cde}	34.06±7.82^{cdef}	24.79±5.16^{def}	3.92±0.09^{bc}	2.12±0.42^{g}	20.75±2.11^{ab}	10.13±2.11^{cde}

Note: L* indicates lightness or darkness, and ranges from black (0) to white (100) a*—color direction from red (a* > 0) to green (a* 0) to blue (b* < 0); Chroma (saturation or vividness) higher the chromaticity more the vividness, lower the chromaticity more the dullness; Hue—angular measurement in which 0° = red and 90° yellow, total soluble solids (°Brix); Titratable acidity (TA, g·100 g^{-1}); Maturity index (MI = TSS/TA).

Table 6. Average of physicochemical traits of the varieties studied for different harvest years

Varieties	Year	L*	a*	b*	c*	Hue°	pH	AT	°Brix	MI
Newstar	2019	1.46 ± 5.95	46.721 ± 12.213	34.989 ± 13.33	58.664 ± 17.027	36.058 ± 6.336	3.747 ±0.016	2.306 ±0.035	17.176±0.688	7.45±0.4
	2021	-0.02 ± 11.44	51.026 ± 12.528	40.979 ± 22.164	66.25 ± 23.119	35.901 ± 9.676	4.09 ±0.01	1.907 ±0.026	18.751±0.753	9.83±0.46
	2022	2.68 ± 0.66	42.249 ± 25.31	28.514 ± 22.862	52.284 ± 31.906	50.357 ± 79.1	3.403 ±0.023	2.705 ±0.052	15.6 ±0.624	5.77±0.33
INRAL4A21	2019	22.16 ± 1.21	17.628 ± 1.378	0.53 ± 0.447	7.665 ± 1.34	1.803 ± 1.626	3.837 ±0.078	1.907 ±0.111	23.245±2.115	12.26±1.85
	2021	13.28 ± 3.66	24.086 ± 5.853	19.32 ± 26.163	34.084 ± 22.261	27.762 ± 19.683	4.097 ±0.137	1.653 ±0	21.991 ±4.76	13.3±2.88
	2022	-3.79 ± 7.28	28.939 ± 4.661	4.642 ± 3.08	29.407 ± 5.007	8.642 ± 4.727	3.577 ±0.037	3.162 ±0.222	24.5 ±0.557	7.77±0.38
Stela	2019	30.11 ± 2.97	30.691 ± 7.409	12.122 ± 5.008	33.08 ± 8.61	20.312 ± 5.369	3.908 ±0.05	2.163 ±0.017	18.768±0.831	8.68±0.43
	2021	15.84 ± 4.03	35.585 ± 7.763	21.661 ± 8.805	41.842 ± 11.018	29.875 ± 6.15	4.227 ±0.051	1.301 ±0.039	20.303±0.949	15.61±0.73
	2022	2.62 ± 0.06	26.852 ± 25.595	12.389 ± 13.333	37.646 ± 15.856	45.863 ± 89.249	3.588 ±0.056	3.025 ±0.032	17.233±0.723	5.7±0.29
INRAL5 A21	2019	8.57 ± 0.911	9.558 ± 10.32	9.695 ± 11.423	14.434 ± 14.572	51.789 ± 24.122	3.411 ±0.015	3.264 ±0.034	21.033 ±1.96	6.44±0.53
	2021	14.14 ± 2.55	20.295 ± 16.995	11.747 ± 24.335	24.561 ± 28.703	18.541 ± 11.262	3.475 ±0.024	2.935 ±0.052	20.367±2.501	6.93±0.79
	2022	2.63 ± 0.03	17.261 ± 12.123	9.567 ± 4.98	20.984 ± 10.829	36.253 ± 23.408	3.347 ±0.006	3.592 ±0.087	21.7 ±3.124	6.03±0.74
Guillaume	2019	8.12 ± 2.59	25.766 ± 14.284	22.168 ± 8.009	34.596 ± 14.952	56.784 ± 61.225	3.452 ±0.011	2.925 ±0.062	19.517±0.551	6.67±0.08
	2021	14.84 ± 5.71	40.509 ± 5.321	27.656 ± 9.46	49.251 ± 9.831	33.432 ± 4.977	3.62 ±0.028	2.368 ±0.1	20 ±2.042	8.45±0.79
	2022	2.59 ± 0.08	20.109 ± 19.715	15.785 ± 11.673	26.706 ± 21.471	47.641 ± 21.498	3.283 ±0.006	3.482 ±0.122	19.033±1.079	5.47±0.43
Burlat	2019	26.61 ± 2.54	40.276 ± 3.046	23.907 ± 3.098	46.851 ± 4.171	30.583 ± 1.467	3.353 ±0.06	0.783 ±0.013	18.883±1.127	24.14±1.86
	2021	25.51 ± 4.62	39.173 ± 8.01	23.353 ± 7.093	45.675 ± 10.378	29.955 ± 4.108	3.327 ±0.121	0.806 ±0.026	18.7 ±0.854	23.22±1.63
	2022	26.97 ± 3.04	40.017 ± 3.081	23.508 ± 3.574	46.436 ± 4.441	30.277 ± 1.924	3.38 ±0	0.759 ±0.008	19.067±1.834	25.11±2.37
INRAL1A17	2019	23.03 ± 1.73	16.221 ± 6.251	2.175 ± 2.339	16.421 ± 6.526	5.948 ± 4.688	3.98 ±0.008	1.871 ±0.039	20.783±2.006	11.11±1.07
	2021	8.04 ± 10.09	15.977 ± 11.323	6.059 ± 9.685	17.403 ± 14.504	16.889 ± 7.781	4.43 ±0.01	1.508 ±0.027	19.9 ±2.8	13.22±2.02
	2022	13.56 ± 4.83	52.975 ± 9.278	45.899 ± 19.691	70.807 ± 19.134	38.625 ± 9.784	3.53 ±0.008	3.234 ±0.063	21.667 ±1.32	6.7±0.41
Moreau	2019	30.14 ± 3.82	32.628 ± 6.463	12.285 ± 5.657	34.993 ± 8.009	19.511 ± 5.313	3.904 ±0.002	2.125 ±0.035	21.483±0.506	10.12±0.4
	2021	14.25 ± 2.44	30.743 ± 5.163	14.368 ± 4.805	34.014 ± 6.628	24.409 ± 4.012	4.297 ±0.025	2.742 ±0.056	19.367 ±1.05	7.07±0.52
	2022	9.26 ± 3.93	22.78 ± 5.869	8.453 ± 3.8	24.364 ± 6.743	19.348 ± 4.773	3.511 ±0.023	3.507 ±0.039	23.6 ±0.458	6.73±0.19

Continued. Table 6

Varieties	Year	L*	a*	b*	c*	Hue°	pH	AT	°Brix	MI
Stark Hardy Giant	2019	11.18 ± 4.47	32.646 ± 9.313	18.288 ± 8.779	37.586 ± 12.264	27.45 ± 6.366	3.886 ±0.041	2.041 ±0.034	23.267±0.833	11.4±0.43
	2021	13.67 ± 5.38	32.545 ± 5.304	16.605 ± 6.964	36.742 ± 7.776	25.844 ± 6.466	4.26 ±0.066	2.576 ±0.046	22.933±1.704	8.91±0.71
	2022	7.97± 4.40	33.252 ± 14.846	20.226 ± 12.439	39.107 ± 18.962	27.887 ± 7.897	3.511 ±0.023	3.507 ±0.039	23.6 ±0.458	6.73±0.19
Précoce De Bernard	2019	28.156 ± 2.55	29.314 ± 3.823	9.15 ± 3.27	30.767 ± 4.63	16.833 ± 3.648	3.722 ±0.075	2.551 ±0.013	21.1 ±1.441	8.27±0.53
	2021	16.34 ± 5.63	30.983 ± 6.381	16.015 ± 7.302	35.096 ± 8.812	25.959 ± 7.021	4.263 ±0.159	2.755 ±0.013	21.033±0.153	7.63±0.02
	2022	2.64 ± 0.02	20.736 ± 9.448	3.255 ± 1.626	20.586 ± 10.118	10.092 ± 6.028	3.181 ±0.115	4.348 ±0.032	21.167±3.001	4.86±0.66
Lapins	2019	14.08 ± 2.86	52.613 ± 8.415	41.575 ± 12.384	67.276 ± 13.869	37.686 ± 4.556	3.661 ±0.074	1.481 ±0.035	17.228±1.164	11.65±0.96
	2021	25.23 ± 5.70	46.876 ± 7.413	39.322 ± 18.971	61.664 ± 18.749	38.444 ± 6.091	3.683 ±0.006	0.576 ±0.026	15.567±1.484	27.08±3.09
	2022	3.08 ± 1.40	55.239 ± 20.675	41.945 ± 22.695	69.859 ± 29.463	36.537 ± 8.491	3.637 ±0.151	2.385 ±0.073	18.89 ±1.65	7.92±0.61
Rainier	2019	9.30 ± 4.10	9.095 ± 13.408	10.51 ± 7.867	15.013 ± 14.392	57.37 ± 22.153	3.73 ±0.013	2.584 ±0.01	21.303±0.482	8.25±0.16
	2021	14.92 ± 6.42	32.122 ± 14.152	18.961 ± 23.974	38.381 ± 26.22	24.267 ± 10.605	4.207 ±0.038	1.696 ±0.027	24.2 ±1.8	14.28±1.13
	2022	2.83 ± 0.67	29.989 ± 11.757	6.679 ± 8.935	31.168 ± 13.735	11.389 ± 7.599	3.254 ±0.017	4.472 ±0.039	18.407±1.166	4.12±0.27
Van	2019	12.70 ± 2.24	42.684 ± 1.951	42.071 ± 5.472	60.011 ± 4.855	44.396 ± 3.018	3.815 ±0.042	0.386 ±0.026	19.567±1.953	50.78±5.19
	2021	12.77 ± 3.58	63.845 ± 11.923	72.495 ± 20.42	96.907 ± 22.26	46.82 ± 8.452	4.297 ±0.083	1.772 ±0.052	23.2 ±1.539	13.11±1.21
	2022	12.11 ± 2.45	18.107 ± 2.583	5.357 ± 1.118	18.915 ± 2.575	16.575 ± 3.747	3.333 ±0.009	3.18 ±0.02	15.933±3.667	5.01±1.18
Vista	2019	5.92 ± 2.29	17.839 ± 8.524	4.323 ± 3.104	18.567 ± 8.595	15.586 ± 10.712	3.843 ±0.016	2.381 ±0.042	20.906±0.691	8.78±0.34
	2021	9.84 ± 5.31	27.332 ± 5.512	11.207 ± 4.772	29.646 ± 6.805	21.437 ± 5.474	4.263 ±0.015	1.946 ±0.644	21.556±2.693	12.06±4.5
	2022	2.53 ± 0.07	15.835 ± 9.977	3.746 ± 1.797	16.918 ± 8.934	21.867 ± 22.523	3.421 ±0.017	3.149 ±0.034	20.257±3.124	6.43±0.98
Tragana D'Edessa	2019	10.94 ± 0.98	14.801 ± 7.488	3.563 ± 5.054	15.796 ± 7.91	17.215 ± 14.136	3.665 ±0.002	1.969 ±0.109	18.503±2.082	9.45±1.52
	2021	19.99 ± 2.88	20.741 ± 11.162	2.049 ± 1.106	22.684 ± 17.531	7.384 ± 5.932	3.507 ±0.006	1.764 ±0.06	19.173±3.424	10.85±1.75
	2022	2.63 ± 0.05	34.475 ± 15.531	9.933 ± 9.038	37.51 ± 13.948	19.744 ± 20.054	3.823 ±0.01	3.175 ±0.255	17.833 ±0.85	5.65±0.67
Napoléon	2019	38.25 ± 8.70	36.088 ± 16.432	49.938 ± 17.818	62.047 ± 23.019	55.14 ± 7.607	3.396 ±0.028	3.9 ±0.1	20.3 ±0.173	5.21±0.15
	2021	32.48 ± 11.92	37.659 ± 20.013	45.581 ± 27.162	59.752 ± 32.534	48.352 ± 12.313	3.36 ±0.007	1.588 ±0.104	20.267 ±1.32	12.77±0.46
	2022	43.02 ± 9.97	31.343 ± 19.373	50.426 ± 18.329	60.512 ± 23.769	60.053 ± 12.049	3.431 ±0.059	4.211 ±0.305	20.333±1.422	4.83±0.26

Continued. Table 6

Varieties	Year	L*	a*	b*	c*	Hue°	pH	AT	°Brix	MI
Revérchon	2019	8.01± 2.02	5.927 ± 3.729	2.096 ± 1.455	6.485 ± 3.647	26.323 ± 17.653	3.32 ±0.012	3.981 ±0.129	19.183±2.937	4.82±0.69
	2021	13.03 ± 2.39	13.695 ± 5.385	3.956 ± 2.787	14.296 ± 5.959	15.149 ± 4.284	3.333 ±0.009	3.07 ±0.026	15.933±3.667	5.19±1.23
	2022	10.62 ± 0.02	16.634 ± 10.402	2.53 ± 1.703	16.896 ± 10.418	10.911 ± 7.065	3.306 ±0.017	3.891 ±0.283	22.433±2.371	5.78±0.72
Marmotte	2019	19.04 ± 1.72	31.72 ± 2.565	14.891 ± 2.519	35.07 ± 3.281	25.001 ± 2.399	3.656 ±0.005	3.369 ±0.055	20.323±0.772	6.03±0.18
	2021	15.04 ± 1.47	25.284 ± 4.019	9.496 ± 3.691	27.104 ± 4.921	19.903 ± 5.068	4.013 ±0.006	3.295 ±0.099	22.312±0.843	6.77±0.18
	2022	22.98 ± 3.26	37.622 ± 3.83	19.96 ± 4.784	42.656 ± 5.605	27.565 ± 3.315	3.298 ±0.011	4.442 ±0.013	18.333±0.702	4.13±0.15
Géant d'Hedelfingen	2019	10.50 ± 1.94	16.712 ± 3.084	5.862 ± 1.979	17.733 ± 3.545	18.96 ± 2.896	4.03 ±0.004	2.283 ±0.052	19.886±2.366	8.73±1.17
	2021	10.65 ± 2.86	16.252 ± 2.958	5.585 ± 2.168	17.23 ± 3.436	18.491 ± 4.287	4.06 ±0.01	2.33 ±0.522	20.038±2.424	8.81±1.81
	2022	10.58 ± 2.18	16.482 ± 2.794	5.723 ± 1.913	17.475 ± 3.232	18.794 ± 3.247	4 ±0.015	2.569 ±0.06	19.733±2.307	7.7±1.06
Noire De Meched	2019	12.91 ± 2.44	30.428 ± 4.108	14.692 ± 4.619	33.874 ± 5.665	25.16 ± 4.17	3.916 ±0.01	1.784 ±0.103	20.75 ±1.984	11.7±1.81
	2021	12.51 ± 4.31	33.988 ± 6.109	18.629 ± 7.829	38.942 ± 9.132	27.544 ± 5.618	4.023 ±0.021	1.905 ±0.045	20.3 ±1.539	10.67±0.94
	2022	13.93 ± 3.36	27.103 ± 4.095	11.097 ± 3.923	29.36 ± 5.247	21.679 ± 4.004	3.808 ±0.008	2.662 ±0.16	21.2 ±3.305	8.03±1.73

Note: All data were expressed as means ± SD (n = 3). WFr: Fruit Weight (g) LgFr: Fruit Length (mm); WidFr: Fruit Width (mm), ThicFr: Fruit Thickness (mm), LgSta: Stalk Length (mm) ThicSta: Stalk thickness (mm), Wsto Stone Weight (g), LgSto: stone length (mm) WidSto: stone width (mm) ThicSto: stone thickness (mm).

For Poland Sweet cherry cultivars, the reported contents vary among 14.3% and 20.9% (Skrzyński et al., 2016). In Spanish environmental conditions, the characterization of 12 cultivars, including 'Van', 'Summit' and 'Sweetheart', showed SSC values of 13.5 to 25.5% (González-Gómez et al., 2010). Generally, chemical characteristics can be affected by a number of factors such as temperature, degree of ripeness, cultural practices and rootstock (Díaz-Mula et al., 2009; Serradilla et al., 2012). Since the varieties studied have the same rootstock and were installed in the same experimental field and exposed to the same cultural practices, physicochemical variations are probably due to the varietal profile, and the environmental effect is minimized as much as possible.

Maturity index (MI), expressed as the ratio of TSS to TA indicates sweetness and consequently, fruit maturity (Chockchaisawasdee et al., 2016; Romano et al., 2006). "Revérchon" recorded the lowest value 5.26 while "Burlat" recorded the higher value 24.12. These values are similar to those of (Girard and Kopp, 1998).

For chemical parameters the differences between the three years were highly significant ($P < 0.01$, $P < 0.05$) for all chemical parameters, except for the TSS content which is not significant (Table 3), highlighting the annual influence on fruit parameters. In 2022, the fruits harvested have the highest titratable acidity with a significant difference of 29.61% compared to 2019 and 38.34% compared to 2021, while the highest pH was recorded by the fruits harvested in 2021 with a significant difference of 5.97% compared to 2019 and 11.96% compared to 2022. The °Brix values recorded over the three years showed no significant difference.

It is well established that cherry fruit quality is strongly influenced by environmental conditions and orchard management practices, such as rootstock selection, pruning, fertilization and irrigation, leading to variations in pomological parameters and nutrient concentrations (Gonçalves et al., 2006; Khadivi-Khub, 2014). Nevertheless, in the present study, all sweet cherry varieties were cultivated under uniform conditions in the same experimental field, with trees of the same age (16 years) grafted onto identical rootstocks (Sainte-Lucie). Additionally, the variation in variety traits may result from environmental factors such as temperature and humidity. The development of fruit, quality and physiological disorders of sweet cherries are affected by a range of environmental factors (Engin et al., 2009; Montiel et al., 2010; Usenik and Stampar, 2011). On the other hand, our results based on climatic data (Fig.1), show that 2019 was characterized by lower average temperatures and higher rainfall, whereas 2021 and 2022 were warmer and drier, particularly during fruit development. This climatic variability explains the significant year effect observed in the analysis.

Regarding the variety factor, the variation is highly significant for all parameters. Consequently, any observed differences in study parameters among varieties can be ascribed to the inherent genetic characteristics of each variety. Khadivi et al. (2019) and Reim et al. (2023) demonstrated that the variability of most pomological and physicochemical parameters was mainly due to the genotypic characteristic. Other studies on sweet cherries have shown that variation between varieties is mainly attributed to genetic profiles, although it also depends on environmental factors and cultivation practices (Gonçalves et al., 2006; Salazar-Gutiérrez et al., 2014).

Finally, for the year*variety interaction, all the parameters showed highly significant variation, indicating that the degree of variation from year to year depends on the variety (Neilsen et al., 2014) confirming the existence of a cultivar-year interaction effect on color, titratable acidity and the size of the fruit, whereas the °Brix recorded showed no significant difference.

Correlation Coefficients

The correlation coefficients among all examined variables are shown in Table 7. The results revealed a strong positive correlation between fruit and dimensions (fruit length r = 0.940**; fruit width r = 0.970**; fruit thickness r = 0.965**). In addition, a significant positive correlation was found between fruit length and fruit width r = 0.874**; fruit thickness r = 0.912**. However, fruit width is positively and strongly correlated with fruit thickness r = 0.950**, suggesting that the weight of the fruit depends on its dimensions. These findings are in line with those reported in several studies (Ganopoulos et al., 2015; Khadivi-Khub, 2014; Sánchez et al., 2008). Stone length is positively correlated with stalk length r = 0.530* and strongly correlated with stone weight r = 0.635**. Thickness stone is positively and strongly correlated with stone weight r = 0.625** similar results were reported by El Baji et al. (2021) and Khadivi-Khub (2014). L* index is positively correlated with b* index r = 0.444* and °Hue index r = 0.582**. A* index is positively and strongly correlated with b* index r = 0.801**, C*index r = 0.872**, °Hue index r = 0.816** and negatively with TA r = -0.515*. b* index is positively and strongly correlated with C*index r = 0.961 and °Hue index r = 0.874**.

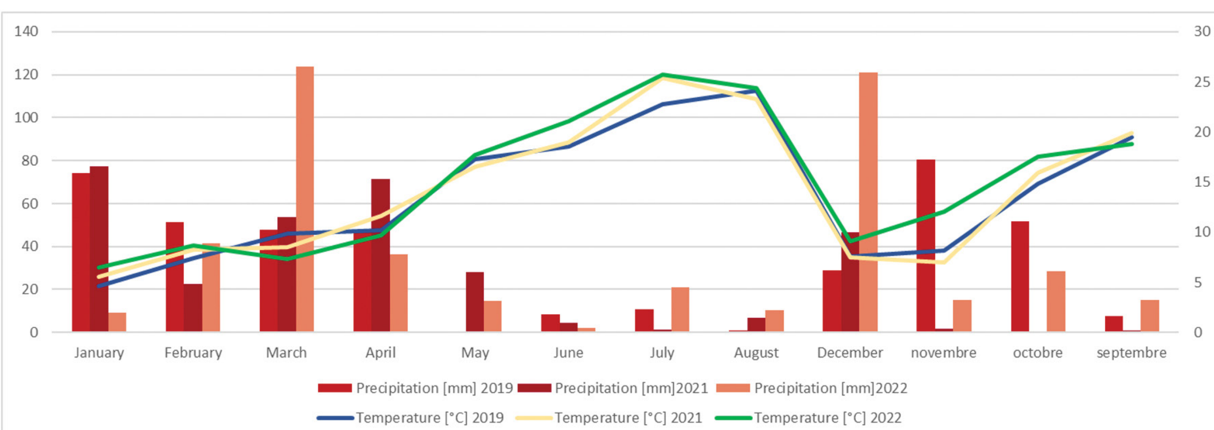

Figure 1. Meteorological data of "Laanaceur" experimental field

Table 7. Matrix of correlation coefficients between the pomological and physicochemical characteristics studied

	Correlations																	
	WFr	LgFr	WidFr	ThicFr	LgSta	ThicSta	Wsto	LgSto	WidSto	ThicSto	L*	a*	b*	C*	°Hue	pH	TA	°Brix
WFr	1																	
LgFr	**0.940****	1																
WidFr	**0.970****	**0.874****	1															
ThicFr	**0.965****	**0.912****	**0.950****	1														
LgSta	-0.326	-0.152	-0.391	-0.359	1													
ThicSta	-0.238	-0.213	-0.271	-0.168	-0.268	1												
Wsto	0.342	0.341	0.295	0.269	0.009	0.022	1											
LgSto	0.199	0.423	0.084	0.142	**0.530***	-0.149	**0.635****	1										
WidSto	0.348	0.306	0.327	0.385	-0.090	-0.111	0.093	-0.047	1									
ThicSto	0.125	0.053	0.078	0.104	-0.184	0.163	**0.625****	0.197	0.244	1								
L*	0.153	0.212	0.173	0.131	0.116	-0.107	-0.068	0.174	0.055	-0.374	1							
a*	0.286	0.413	0.212	0.321	-0.104	-0.200	0.100	0.312	0.293	0.085	0.295	1						
b*	0.251	0.371	0.222	0.284	-0.046	-0.137	-0.020	0.301	0.363	-0.127	**0.444***	**0.801****	1					
C*	0.288	0.373	0.252	0.308	-0.079	-0.184	0.013	0.233	0.389	-0.063	0.390	**0.872****	0.961**	1				
°hue	0.358	0.470*	0.339	0.392	-0.128	-0.186	0.005	0.275	0.285	-0.051	**0.582****	**0.816****	**0.874****	**0.865****	1			
pH	**-0.485***	**-0.472***	**-0.492***	**-0.504***	-0.135	0.050	0.089	-0.131	-0.118	0.306	-0.282	0.118	-0.201	-0.096	-0.023	1		
TA	-0.043	-0.114	0.051	0.007	-0.161	0.343	-0.005	-0.124	-0.048	0.107	-0.064	**-0.515***	-0.309	-0.439	-0.316	-0.225	1	
°Brix	-0.357	-0.320	-0.352	-0.305	-0.065	0.507*	-0.081	-0.201	0.197	0.126	0.035	-0.283	-0.388	**-0.456***	-0.283	0.292	0.337	1

Note : *, **- significant at $P < 0.05$ and $P < 0.01$, respectively

C* index is positively and strongly correlated with °Hue index r = 0.865** and negatively with the °Brix r= -0.456*. °Hue index is positively correlated with fruit length r=0.470*. pH is negatively correlated with all fruit sizes (Fruit weight r = -0.485*, fruit length r =-0.472*, fruit width r = -0.492* and fruit thickness r = -0.504*). °Brix is positively correlated with stalk thickness r = 0.507*.

Principal Components Analysis

Principal component analysis (PCA) was conducted based on 18 morphological and physicochemical traits. The first three components explain 53.45% of the total variation, with respective contributions of 27.78%, 15.75% and 9.93% respectively. The first two components are constituted by 14 variables that express more than 50% of all the variables and explain 43.52% of the total variance. Fruit color index (b*, C*, °Hue, a* and L*), titratable acidity and stalk thickness were mainly responsible for the separation on PC1. While fruit characteristics (weight, length, width, thickness) and stone characteristics (weight, length, width, thickness) were strongly correlated with PC2 PC3 was associated with peduncle length, physicochemical characteristics (pH, °Brix) and stone thickness (table 8).

Table 8. Eigenvector of principal component axes from PCA analysis

	Componte		
	1	2	3
b*	**0.890**	0.123	0.015
C*	**0.884**	0.102	0.028
°Hue	**0.859**	0.225	0.116
a*	**0.840**	0.218	0.274
L*	**0.548**	0.013	-0.153
TA	**-0.464**	-0.062	-0.402
ThicSta	**-0.282**	-0.015	0.046
WFr	0.121	**0.944**	-0.184
LgFr	0.201	**0.922**	-0.108
ThicFr	0.091	**0.773**	-0.116
WidFr	0.129	**0.731**	-0.207
Wsto	-0.131	**0.517**	0.387
LgSto	0.170	**0.484**	0.327
WidSto	0.239	**0.336**	0.071
pH	0.139	-0.083	**0.772**
ThicSto	-0.190	0.502	**0.569**
°Brix	-0.171	-0.062	**0.456**
ThicSto	0.089	-0.085	**0.277**

Our results confirm that pomological characteristics are the main factors explaining the diversity and similarity between sweet cherries.

Fig. 2 reveals variations in the relationships among the valuated varieties across different harvest years. Generally, variety dispersal is independent of harvest year for most varieties, and they are distributed into four homogeneous groups. The first group (1) comprises 6 varieties ('Lapins', 'Burlat' and 'Napoléon' within three years, 'Newstar' and 'Van' in 2019 and 2021, and 'Guillaume' in 2021) characterized by a large size and a range of colors from yellowish to orange red. The second group (2) comprises 15 varieties ('Newstar' in 2021, 'Stela' in 2021 and 2022, INRAL5A21 in 2021, 'Guillaume' in 2019 and 2022, 'Moreau' in 2019, 2021 and 2022, 'Stark Hardy Giant' in 2019 and 2021, 'Précoce De Bernard' in 2019 and 2021, and 'Rainier' in 2019, 2021 and 2022, 'Van' in 2022, 'Vista' in 2019, 20121 and 2022, 'Tragana d'Edessa' in 2019 and 2021, 'Revérchon' in 2019, 2021 and 2022, 'Marmotte' in 2021 and 2021, 'Géant d'Hedelfingen' in 2019 and 2021, and 'Noire de Meched' in 2019 and 2021). The members of the second group have a medium size. The third group (3) consists of four varieties ('Newstar' (2022), 'Stela' (2019), INRAL1A17 (2019), and 'Marmotte' (2022)). These varieties are characterized by a medium size and have a medium acidity. Finaly, the fourth group (4) includes 9 varieties ('Précoce De Bernard' in 2022, INRAL5A21 in 2019 and 2022, INRAL4A21 in 2019, 2021, and 2022, INRAL1A17 in 2019 and 20221, 'Noire de Meched' in 2022, 'Stark Hardy Giant' in 2022, 'Tragana d'Edessa' in 2022, 'Stela' in 2022 and 'Géant d'Hedelfingen' in 2022). These varieties are characterized by a medium size and a moderate sweetness.

These results show that the varieties 'Napoléon', 'Burlat', INRAL4A21, 'Lapins', 'Moreau', 'Vista' and 'Revérchon' have kept the same group despite the change in harvest year, which means that they are the least affected by the effect of the harvest year, which makes them the most stable varieties.

Cluster Analysis

Cluster analysis was performed using pomological and physicochemical traits that revealed considerable genetic diversity among the varieties studied (Fig. 3). The dendrogram grouped the accessions into two main clusters (A and B), each of which was further divided into several subclusters. The distinction into these major clusters shows that the collection varieties belong to two distinct genetic pools. The three local varieties (INRAL1A17; INRAL1A21 and INRAL5A21) are dispersed over three different subgroups which show that their pedigrees do not belong to the same genetic background.

Cluster A is distinguished into two. The first subcluster A-1 is made up of 8 varieties ('Burlat", 'Guillaume', 'Stela', INRAL1A17, 'Noire de Meched', 'Stark Hardy Giant', 'Moreau', 'Marmotte') characterized by the same stone length, stone width and L* index. The second Subcluster A-2 consists of 8 varieties 'Vista', 'Géant d'Hedelfingen', 'Précoce De Bernard', INRAL1A21, 'Rainier', 'Tragana d'Edessa Revérchon', INRAL5A21 which are characterized by similar titratable acidity, stone weight and stone thickness.

Cluster B is composed of 4 varieties: 'Napoléon', 'Newstar', 'Lapins', 'Van' which are characterized by same L* index.

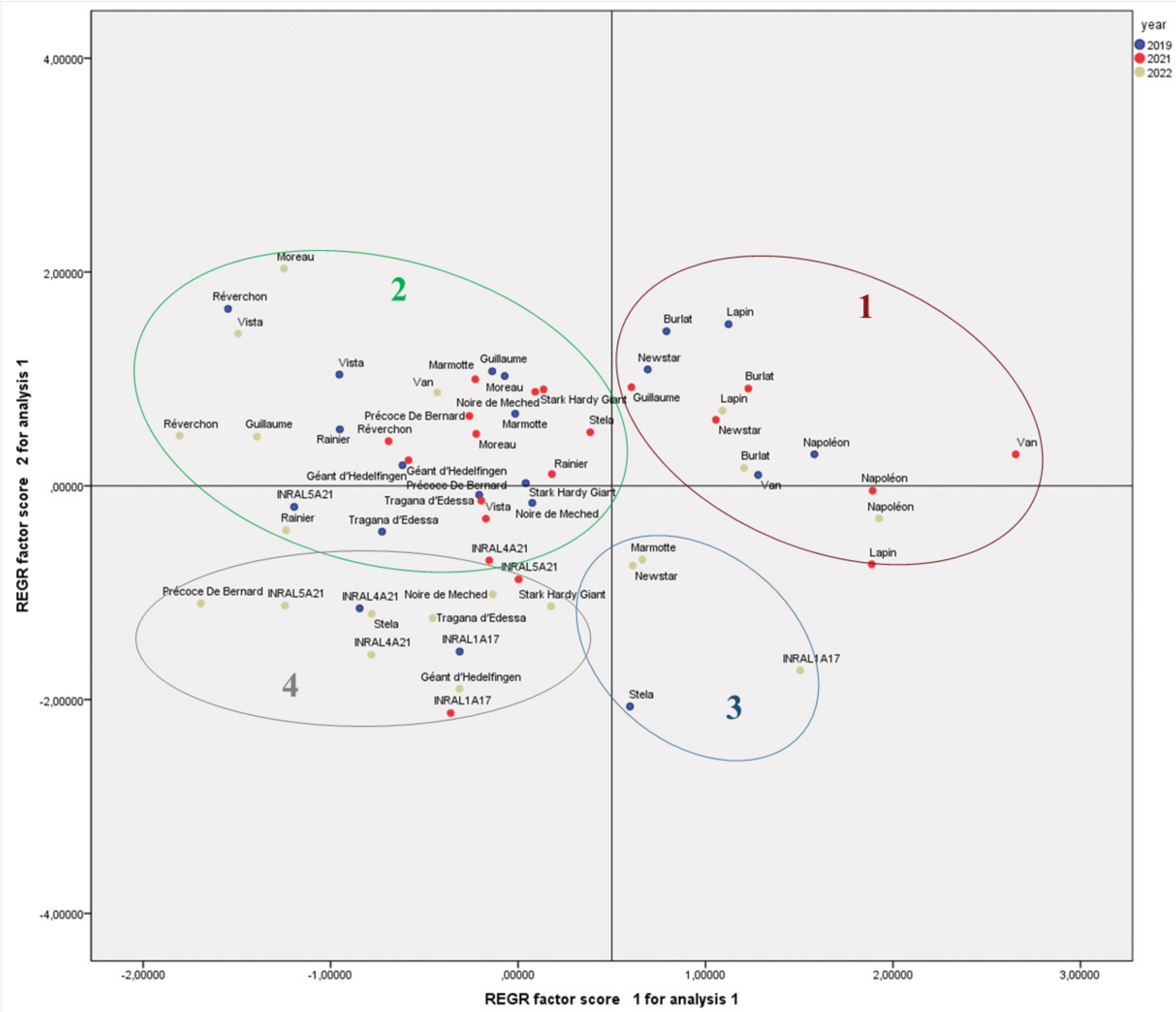

Figure 2. Scatterplot of the first two principal components (PC1/PC2, 53.43% of total variance) that discriminate between varieties according to harvest year

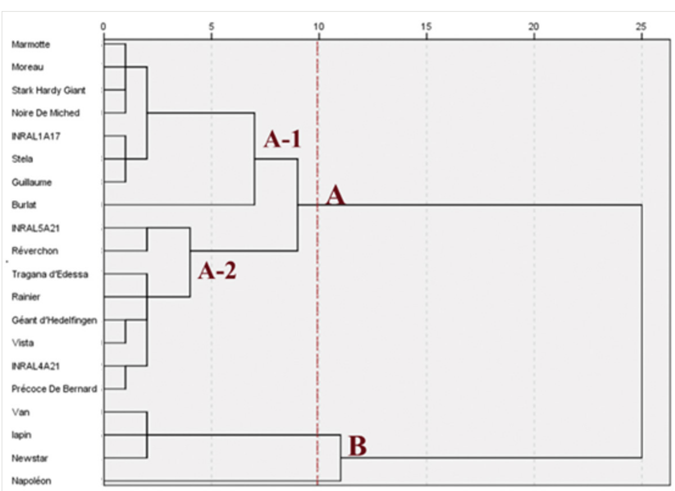

Figure 3. Cluster analysis of 20 varieties of sweet cherry based on physico-chemical and pomological traits

Conclusion

This first pomological and physicochemical characterization of the Moroccan sweet cherry collection allowed to obtain an interesting dataset. The findings revealed substantial variability among varieties across all evaluated traits. Analysis of variance revealed that variety, year, and their interaction significantly influenced most pomological and physicochemical traits. Furthermore, principal component analysis demonstrated that, for the majority of accessions, variety distribution was largely independent of harvest year. Furthermore, the hierarchical analysis illustrated the presence of different genetic pools and that the Moroccan varieties did not belong to the same pedigrees. The results of this study provide a basis for the breeding programs and the selection of sweet cherry varieties that are more suitable for climate change.

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CRediT Authorship Contribution Statement

Zahra El Kettabi: Conducting experiments and laboratory analysis and writing the original draft. **Kaoutar El Fazazi** and **Abdelmajid Haddioui:** Conceptualization, Visualization and review. **Abdelaziz Alaoui:** performed statistical analysis and review. **Chaimae El-Rhouttais** and **Kamal El Fallah**: provided technical support. **Jamal Charafi**: Funding acquisition, designed the methodology, provided technical support, conducting research and performed review of manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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