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A Decade-Long Quantitative–Qualitative Characterization of 18 Lemon Cultivars

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Abstract: Together with lime, lemon is recognized as the third most extensively cultivated citrus species worldwide, trailing only behind orange and mandarin. The enhancement in the economic value of lemons as a valuable resource in Southern Italy depends by the competitiveness of local lemon production in both domestic and international markets. This necessitates conducting a comprehensive study that thoroughly explores the available indigenous germplasm at the local and national levels. This study aims to identify the most promising Sicilian and Campanian cultivars that are well suited for both fresh fruit consumption and the production of processed goods. This re-study assumes even greater importance considering the ongoing climate changes, as environmental stresses significantly impact the ripening process and the timing of fruit development. Our study has highlighted a notable diversity among the 18 investigated lemon cultivars, particularly highlighting specific cultivars that possess desirable attributes for fresh consumption. The cultivars that showed the greatest cumulative production over the 10 years of the study were Erice with 467.89 kg/tree and Femminello Siracusano 2KR with 408.44 kg. Notably, cultivars like Segesta, Erice, and Kamarina have exhibited higher percentages of juice content ranging from 27.30% to 31.08%. These cultivars show great potential for abundant juice content and optimal acidity levels for direct consumption. On the other hand, cultivars characterized by enhanced yield, such as Femminello Siracusano 2KR, Femminello Fior d'Arancio m79, and Erice, may prove to be particularly well suited to produce processed goods. Overall, our findings provide valuable insights into some qualitative parameters of lemon cultivars, important either for fresh consumption or for transformed products.

Keywords: germplasm; lemon fruits; *Citrus limon* (L.) Burm. f.; cumulative production; fruits quality

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1. Introduction

Lemon (*Citrus limon* (L.) Burm. f.) is an evergreen tree crop belonging to the family *Rutaceae* and it is appreciated worldwide for the organoleptic and nutraceutical properties of both the juice and the peel of its fruits. Since commercially lemons and limes satisfy the same market share, they are considered as a single crop in the FAO (Food and Agriculture Organization) statistics, which reveal a world production of 20.8 million tons on 1.3 million hectares (www.fao.org/faostat/en/, accessed on December 2021). Actually, limes belong to the *Citrus* species *C. aurantiifolia* and *C. latifolia* and are mainly spread in semitropical areas, while lemons are widely cultivated in areas characterized by a Mediterranean-type climate with warm and dry summers and mild winters [1]. At the end of the 20th century, the global consumption of citrus fruits started to surge among the populace and lemon holds the third position as the world's most widely cultivated citrus species, ranking just after orange and mandarin [2,3]. India is the largest lemon producer in the world with 2,978,000 tons of annual production volume, followed by Mexico with 2,429,839 tons of annual production [4]. Lemon cultivation is widely spread in Italy and in other Mediterranean countries, like Spain, Egypt, and Turkey. In Italy, lemon cultivation spans approximately 26,000 hectares (ISTAT,2018), with production accounting for about 5.4% of the demand for fresh fruit, with a portion being utilized by the food industry for various purposes such as marmalades, beverages, ice cream, desserts, and essential oil extraction [5]. Another industrial application of lemon is the liquor's elaboration "limoncello" by means of maceration of lemon peels in ethanol, water, and sugar. This beverage has raised an evident interest in making further use of lemon [6]. The Southern Italian regions of Apulia, Campania, Calabria. and Sicily are among the main producers of lemon and seven PGIs (Protected Geographical Indications) have been awarded: Limone Femminello del Gargano in Apulia; Limone di Sorrento and Limone Costa d'Amalfi in Campania; Limone di Rocca Imperiale in Calabria; and Limone Interdonato di Messina, Limone dell'Etna, and Limone di Siracusa in Sicily [7,8]. Lemon is renowned in society for its valuable properties and wide range of applications in nutrition, medicine, pharmacology, industry, and cosmetics [9–11]. The versatility of lemon stems from its abundant content of bioactive compounds, including phenolic compounds, carotenoids, vitamins A, C, and B, minerals, citric acid, and essential oils, among others [12–14]. Lemon juice is recognized for its direct health benefits attributed to its antimicrobial, antioxidant, antiviral, and anti-inflammatory properties [13,15,16]. In general, lemons are rich in bioactive compounds, such as vitamins, phenolic compounds, fiber, organic acids, and mineral salts, which contribute to their beneficial health effects [8,17,18]. However, research indicates that the chemical composition of lemon juice, both qualitatively and quantitatively, is not constant and can be influenced by factors such as fruit maturity, lemon variety, and cultivation and management conditions [16,19]. Consumers' preferences extend beyond the external appearance of a fruit, such as its size, color, and firmness; they also seek internal quality, including flavor, volatile compounds, and functional components [3,19]. While citrus flavor and aroma play crucial roles in determining quality, consumers primarily base their lemon product purchase decisions on their perception of overall product quality and value for money [20]. Among the key indicators that express good commercial quality of lemon are fruit shape, fruit color, juice content, juice soluble solids, acids and soluble solid to acid ratio, seeds per fruits, peel thickness, and peel smoothness rating [3,19]. Numerous studies have highlighted the potential health benefits of lemons, ranging from their impact on various types of cancer, cardiovascular diseases, obesity, cholesterol levels, and more [12,21]. Enhancing the economic value of lemons as a significant resource in Southern Italy requires improving the competitiveness of indigenous lemon production both in domestic and international markets. Therefore, a comprehensive study is necessary to thoroughly examine the available local and national germplasm, with a specific focus on evaluating the agronomic performance of the trees, the morphological and physical characteristics of the fruit, and various analytical aspects. Such research gains even greater significance when considering the ongoing climate changes, as environmental stresses significantly impact the ripening process and timing of the fruits.

Currently, only a few lemon varieties have high commercial value. "Eureka" is the most widely spread lemon variety outside the Mediterranean Basin, in Argentina, California, Australia, South Africa, Chile, and Israel, and it is characterized by a good precocity and an ever-bearing fruiting habit. Also, "Lisbon" is a widespread lemon variety, appreciated for its cold tolerance and high productivity. "Fino" and "Verna" are the most cultivated lemon varieties in Spain. In Italy, most of the lemon varieties belong to the "Femminello" group, whose ever-blooming and ever-bearing nature allows at least three crops per year with different fruit characteristics and also different names according to their flowering period: *primofiore* are harvested in autumn (September–November), *limoni invernali* from December to May, and *bianchetti* in the summer (from June to September) [1]. Moreover, a fourth production is also possible in the summer through forcing, a technique consisting of a temporary suspension of irrigation, which induces flowering and the production of small fragrant green lemons called *verdelli* [22]. However, the Femminello lemon group is represented by several clones, mainly generated through bud mutation, which have been selected since the 1960s by growers and breeders looking for new lemon varieties coupling excellent fruit traits and resistance to mal secco disease, a tracheomycosis caused by the mitosporic fungus *Plenodomus tracheiphilus*, which represent the most limiting factor of lemon production in the Mediterranean Basin [23]. This has led to the enlargement of the existing Italian lemon germplasm, although the characterization of those traits linked with production, fruit quality, and breeding is lacking and even very dated, except for a few examples [24–31]. In fact, most of the varieties considered in the present research were identified in the framework of breeding activities conducted for selecting new varieties with enhanced tolerance to the disease, but most of them are not widely used by growers and only maintained in the germplasm collection at the University of Naples Federico II and in the University of Catania experimental farms. In this regard, our work had the objective of evaluating 18 cultivars of different origins, many from Sicily and Campania, all grown in the same environmental conditions, evaluating the vegetative–productive parameters of the plants, the physical–chemical characteristics of the fruits, and the time necessary for each cultivar to enter regular production.

2. Materials and Methods

2.1. Plant Material and Experimental Design

The lemon genotypes included in the experimental trial were sourced from the germplasm collection present at the University of Naples Federico II, situated in Portici, Italy (40°48′67″ north, 14°19′91″ east, elevation 60 m above sea level). The lemon plants were planted in 2006 and all were grafted onto bitter orange (*Citrus aurantium* (L.)) and trained to the globe system at a distance of 5 × 5 m. For irrigation, a self-compensating drip system with two nozzles per tree, delivering 4 L per hour, was employed. The amount of water given to plants through irrigation was established based on the water balance equation starting from the month of May. The climatic parameters (ETo and rainfall) (Table 1) were obtained from a meteorological station located near the experimental orchard, while the Kc varied between 0.6 and 0.8, according to FAO, for various crop stages, changing with time [32]. Pruning was carried out annually, and fertilization and pest management were carried out according to local standard practices. The soil at the site had a sandy loam texture. More details of the soil analysis are shown in Table 1 and details of the sampling site are reported in Ruggiero et al. [7]. The climate exhibited typical Mediterranean characteristics with hot and dry summers and mild winters, in particular during the trial, the lowest average annual temperature was recorded in 2010 at 16.1 °C, while the highest was reported in the last year of the trial 2018 at 17.3 °C, confirming a substantial increase in temperatures over the years (Table 2). Their vegetative–productive behavior was closely monitored over a span of 10 years (2009–2018).

Table 1. Chemical and physical characteristics of the soil at 40–50 cm depth. All the data are expressed as the mean ± SD (standard deviation).

Proprieties	
pH (H_2O)	8.1 ± 0.1
C.E.C (cmol (+)/kg)	10.0 ± 3.2
tot. Carb. (g/kg)	14.7 ± 1.6
O.C. (g/kg)	9.2 ± 1.7
N (g/kg)	1.07 ± 0.12
P (mg/kg)	1.0 ± 0.01
K (mg/kg)	1313 ± 823
Ca (mg/kg)	4085 ± 805
Mg (mg/kg)	161 ± 2
Na (mg/kg)	171 ± 18
sand (g/kg)	847 ± 43
silt (g/kg)	146 ± 43
clay (g/kg)	7 ± 1

Table 2. Average annual maximum, minimum, and mean temperatures (°C) recorded during the period of trial.

	Years									
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
T° max (°C)	20.7	20.3	21	21.1	21	21.3	21.5	21.4	21.4	21.7
T° means (°C)	16.5	16.1	16.5	16.7	16.6	16.9	17.1	17	16.8	17.3
T° min (°C)	12.7	12.4	12.7	12.9	12.9	13.3	13.4	13.2	12.7	13.6

The studied lemon genotypes consisted of 18 cultivars (Figure 1): *Sfusato Amalfitano, Ovale di Sorrento, Femminello Fior d'Arancio m 79, Femminello Siracusano m 296, Femminello Dosaco, Femminello S, Femminello Siracusano 2KR, Femminello Scandurra, Fino Iniasel 95, Femminello Continella m84, CNR L58, Femminello Adamo, Femminello Cerza, Akragas, Selinunte, Segesta, Erice,* and *Kamarina,* whose provenance is mainly Sicilian and Neapolitan with the exception of only the Spanish Fino Iniasel 95, as indicated in Table 3. Before planting, the plants were subjected to health checks. Negative results were obtained regarding the CTV (citrus tristeza virus), CPsV (citrus psorosis virus), and CVV (citrus variegation virus).

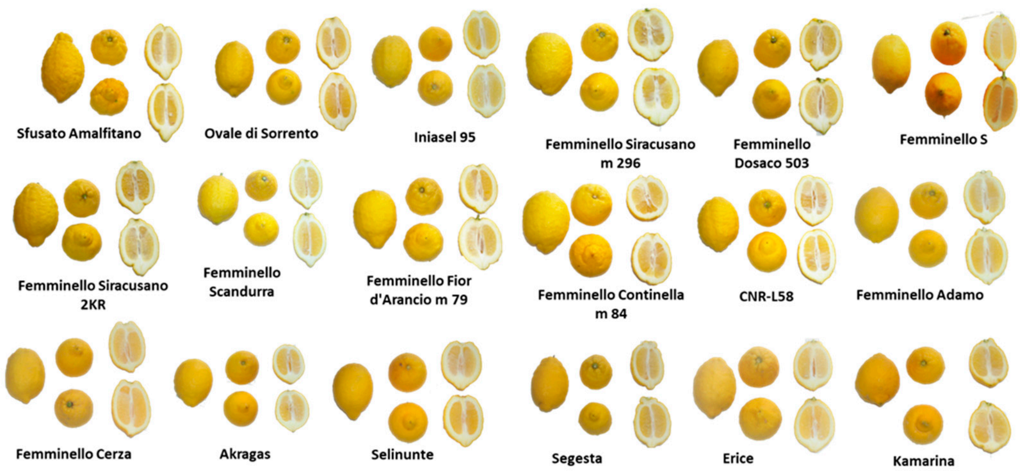

Figure 1. Photos of the 18 Campanian and Sicilian lemon cultivars analyzed in this study.

Table 3. Description of the place of origin and references of the 18 lemon cultivars analyzed in this study.

Cultivars	Provenance	References
Sfusato Amalfitano	clonal selection identified near Amalfi (SA)	Capparelli et al. [33]
Ovale di Sorrento	clonal selection identified near Sorrento (NA)	Capparelli et al. [33]
Fino Iniasel 95	seedless clonal selection of Fino from Spain	
Femminello Siracusano m 296	shoot-tip-grafted clonal selection of Femminello	
Femminello Dosaco M503	shoot-tip-grafted clonal selection of Femminello	Damigella and Continella [24]
Femminello S	in vitro mutation regenerated after selection with mal secco toxin	Gentile et al., 1992 [34]
Femminello Siracusano 2Kr	irradiation-induced nucellar selection	Starrantino et al. [35]
Femminello Scandurra	clonal selection identified in Aci Castello (CT)	
Femminello Fior d'Arancio m 79	shoot-tip-grafted clonal selection of Femminello identified in Acireale (CT)	Damigella and Continella [24]
Femminello Continella m84	shoot-tip-grafted clonal selection of Femminello identified in Giarre (CT)	Damigella and Continella [24]
CNR L58	clonal selection Lascari (PA)	Abbate et al. [36]
Femminello Adamo	clonal selection identified in Giarre (CT)	Reforgiato Recupero et al. [37]
Femminello Cerza	clonal selection identified in San Gregorio (CT)	Reforgiato Recupero et al. [37]
Akragas	clonal selection identified in Partitico (PA)	Calabrese et al. [38]
Selinunte	clonal selection	Calabrese et al. [38]
Segesta	clonal selection identified in Misilmeri (PA)	Calabrese et al. [38]
Erice	clonal selection	Calabrese et al. [38]
Kamarina	clonal selection identified in Syracuse (PA)	Calabrese et al. [38]

2.2. Vegetative and Productive Parameters of Plants

The tree yield and the diameter of the trunk were measured above the graft point at a height of 30 cm from the ground for three plants per cultivar. Based on these measurements, the cross-sectional area of the trunk (TCSA) calculated using the standard formula ($girth^2/4\pi$) was determined and it was measured at the beginning of the growing seasons of all ten years. The yield efficiency (YE) (plant production/TCSA), which represents the cumulative yield per tree/trunk cross-sectional area, was calculated.

2.3. Morphological and Chemical Parameters of Fruits

On a sample of 60 fruits per cultivar (20 from 3 plants), collected from the winter production (the sole production in the evaluation area), the following parameters were determined: mean fruit weight, polar and equatorial diameters, skin thickness, seed number, juice percentage, titratable acidity, and juice pH. The weight of the whole fruits was measured with an electronic digital balance (Precisa Instruments AG, model XB220A, Dietikon, Switzerland); the equatorial (mm), the polar diameters of the fruit (mm), and skin thickness (mm) were determined using a digital vernier caliper (Mitutoyo, Kawasaki, Japan). Lemon seeds were separated during squeezing and counted, and juice yield was measured and expressed as a percentage. Titratable acidity (TA) was determined through a titration of the juice, diluted with distilled water to a 1:1 ratio, with NaOH 0.1 N and expressed as citric acid (in grams per liter) and the pH was measured with a digital pH meter (Crison Instruments, model GLP 21, Barcelona, Spain). Morphological and chemical parameters of fruits behavior were closely monitored over the span of 10 years (2009–2018).

2.4. Statistical Analysis

The collected data underwent analysis of variance (ANOVA) to assess their statistical significance. Subsequently, Duncan's multiple range test (DMRT) was employed to separate the means of the measured variables at a significance level of $p = 0.05$. ANOVA was performed using SPSS (Statistical Package for Social Sciences) Package 6, version 23. Additionally, a principal component analysis (PCA) was conducted on both the agronomic parameters of the plants and the quali–quantitative parameters of the fruits. For these analyses, the statistical software package XLStat Version 2013 (New York, NY, USA) was utilized.

3. Results and Discussion

3.1. Vegetative and Productive Parameters of Plants

The environmental conditions in which plants are grown can have a substantial influence on their physiological functions and on the vegetative and productive parameters of the plants [39]. The cumulative and final TCSA results are shown in Figure 2.

At the beginning of the test, all the plants had a fairly homogeneous TSCA, reporting minimum values of 9 cm^2 (*Femminello Scandurra*) with a maximum of 15.70 cm^2 (*Femminello Siracusano 2 KR*). In all cultivars there was a clear increase starting from the sixth year of experimentation. Our study showed that the *Segesta* and *Femminello Cerza* cultivars had a greater cumulative TCSA equal to 1591.78 cm^2 and 1642.20 cm^2, respectively; in particular, the cultivar that showed a higher TSCA (*Femminello Cerza*) saw an increase of 976% over the 10 years. Expressing the vegetative annual growth of plants showed that CNR L58 was a cultivar with less vigor than other cultivars, with values equal to 812.42 cm^2. TCSA is usually considered to be highly correlated with cumulative yield and canopy volume [40]. As reported in some studies, we made a correlation between cumulative yield and the final TCSA, and in agreement with Rosati et al., 2017 [41], on olive cultivars, we did not find any correlation ($R^2 = 0.009$), as previously reported also by Connor et al., 2014 [42].

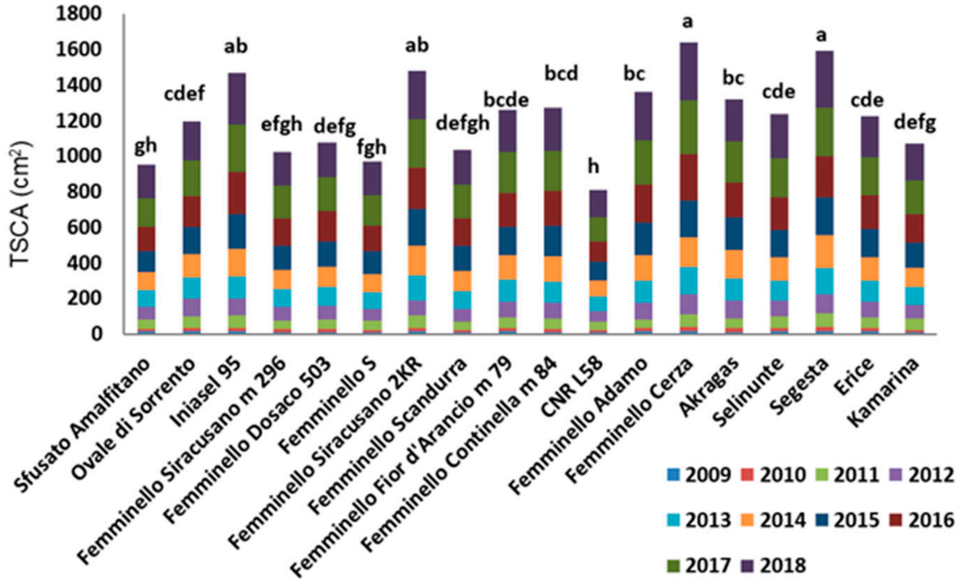

Figure 2. Cumulative TSCA (cm^2) values over the 10 years of testing (2009–2018) of the 18 lemon cultivars analyzed. Different letters indicate significant differences based on Duncan's test (p = 0.05).

Figure 3 shows the cumulative values of the cumulative production per plant of the 18 lemon cultivars analyzed over the 10-year trial.

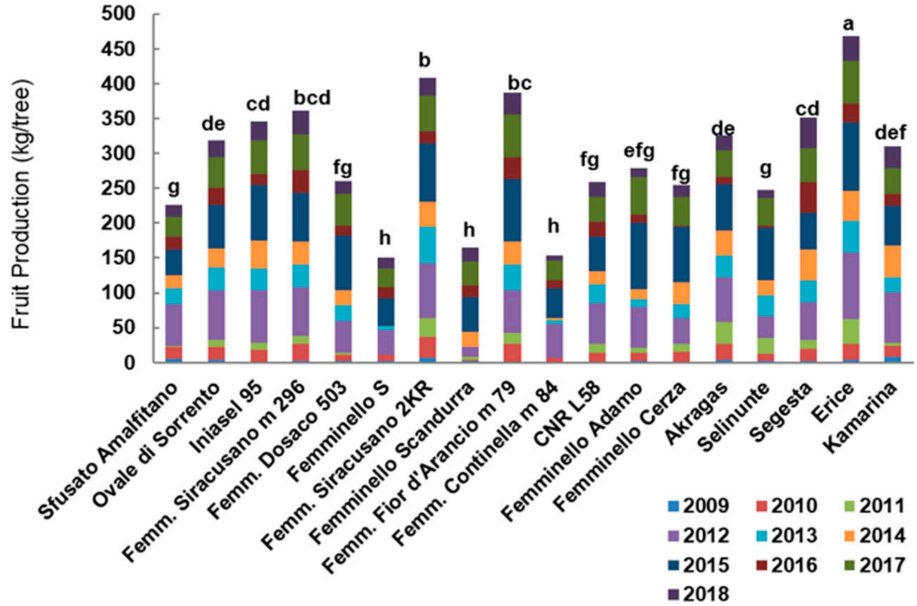

Figure 3. Cumulative production/pt (kg) values over the 10 years of testing (2009–2018) of the 18 lemon cultivars analyzed. Different letters indicate significant differences based on Duncan's test (p = 0.05).

The Sicilian cultivar Erice showed a significantly higher cumulative production than the others analyzed, with cumulative production values in 10 years equal to 467.89 (kg/tree), while among the least productive cultivars with a cumulative production of 156 (kg/tree) per plant there were the following cultivars: Femminello S, Femminello Scandurra, and Femminello Continella m84. During the test, it was evident that there were alternations in production; in particular, for all the cultivars in the years 2012 and 2015, an increase in production is shown, and in the first three years of the trial instead all the cultivars showed a lower production trend. It is quite common for fruit trees to exhibit a biennial cycle, wherein a year of abundant yields, known as an "on-year", is followed by a year of minimal or no yield, known as an "off-year". This alternating pattern can persist for several years. Even within a relatively regular biennial sequence, it is possible to observe consecutive on-years or off-years [43]. Another cultivar that exhibited a greater cumulative production was *Femminello Siracusano 2KR*, further substantiating a higher production during the years 2012 and 2015. In addition to impacting crop load, alternate bearing diminishes the commercial value of the yield. During an "on-year" the trees yield a high quantity of small fruits. In contrast, in the "off-years", the trees yield a limited number of large, unappealing fruits, posing challenges in orchard management and resulting in adverse economic consequences. Hence, alternate bearing poses a significant global challenge for citrus production [44].

In the bibliography, there are not many studies related to a varietal characterization of the different Italian lemon cultivars, but studies have mainly been performed on the interactions *variety* × *rootstock* or *variety* × *cultivation substrate* [14]. According to Perez-Perez et al. [45], during a six-year study on different Spanish lemon cultivars, the Fino 77 cultivar demonstrated a cumulative production of approximately 879 kg, which is nearly double the production observed in our study for the *Erice* cultivar. The variation in production between different lemon cultivars can be attributed to several factors, including genetic characteristics, age of trees, tree vigor, disease resistance, and environmental factors [46].

The same production trend is also shown in terms of yield efficiency (kg/cm^2) (Figure 4).

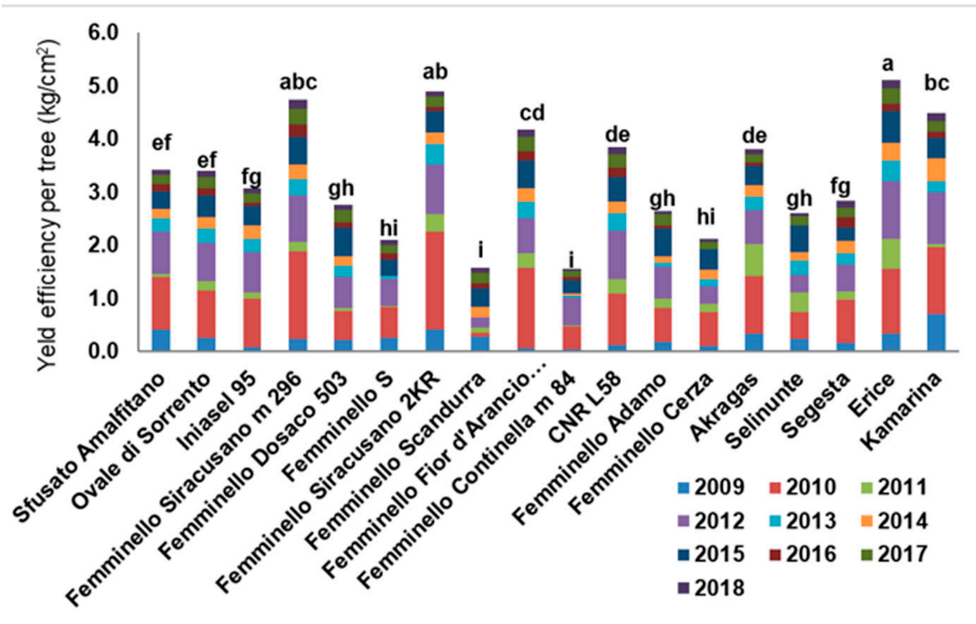

Figure 4. Cumulative yield efficiency per tree (kg/cm^2) values over the 10 years of testing (2009–2018) of the 18 lemon cultivars analyzed. Different letters indicated significant differences based on Duncan's test ($p = 0.05$).

In fact, the highest cumulative yield of lemon varieties over the 10 years from 2009 to 2018 was obtained with the cultivars *Erice* and *Femminello Siracusano 2KR*, respectively, with values equal to 5.11 kg/cm^2 and 4.89 kg/cm^2; on the other hand, *Femminello Scandurra* and *Femminello Continella m84* were the cultivars that showed a lower yield efficiency with an average of about 1.55, thus reporting a production efficiency about 70.64% lower than the *Erice* cultivar. The years 2010 and 2012 stand out as having the highest yield efficiency. In the bibliography, it is reported that different cultivars present a significant difference in production efficiency thanks to the effect of the different rootstocks used [47–49], but in our study all the cultivars were grafted on the same rootstock (*C. aurantium* (L.));

therefore, the differences observed are only due to the cultivars analyzed. In a study conducted by Continella and Tribulato [25], some of the cultivars considered in our study were analyzed, *namely Femminello Siracusano, Femminello Dosaco, Femminello Fior d'Arancio,* and *Femminello Continella*. This study considered a cumulative production over 2 years, showing higher values for *Femminello Siracusano* with 34.07 kg and lower values for *Femminello Fior d'Arancio* with 6.98 kg. These results, despite being based on a shorter number of years, are in agreement with ours, as they also report a higher cumulative production for *Femminello Siracusano*. The higher cumulative production that we reported for *the Femminello Siracusano* cultivar in our work is further confirmed by Continella [26], reporting values of 203.1 kg over the period from 1977/78 to 1981/82. Also, in another study by Continella [27], he reported even higher cumulative production, amounting to 358.6 kg for *Femminello Siracusano* thanks to the rapid onset of production from the beginning.

3.2. Morphological and Chemical Parameters of Fruits

The results of the chemical–physical analyses are shown in Table 4. In general, there were significant differences in fruit morphology and in juice content in the 18 cultivars studied, while minimal differences were highlighted in terms of titratable acidity and pH.

From the results obtained in our study, it is evident that there is a clear difference in terms of sizes among the various cultivars; in fact, the fruit diameters analyzed have shown a high variability in terms of size among different cultivars, with the polar diameter ranging from 82.81 mm to 103.77 mm, while the equatorial diameter ranged from 59.97 mm to 73.62 mm. The cultivars that reported a higher fruit weight were *FemminelloSiracusano 2KR* (229.55 g), *Femminello Fior d'Arancio m 79* (231.50 g), *Femminello Cerza* (229.74 g), and *Akragas* (231.75 g); on the contrary the *Kamarina* cultivar reported a lower fruit weight equal to 137.78. Therefore, the *Akargas* cultivar showed a higher weight by about 40.55% compared to *Kamarina.* The cultivar *Iniasel 95* showed a major polar diameter of 103.77 mm and an equatorial diameter of 71.27 mm, while the *Kamarina* cultivar instead, in addition to a lower weight, also showed a lower polar diameter equal to 82.81 mm and an equatorial diameter equal to 63.16 mm, showing itself as the cultivar characterized by smaller fruits. Overall, dimensioning fruits plays a vital role in the agricultural industry, supply chain management, and consumer satisfaction. It enables standardization, quality assessment, efficient packaging, and better decision-making throughout the fruit production and distribution process [50]. A large fruit size is most often preferred in the fresh fruit market and brings higher prices. In a particular year, the ultimate size a citrus fruit achieves is the result of many complex factors including nutrition and irrigation programs, rainfall distribution, pruning, fruit load, and the rootstock/scion combination; however, it is important to note that the primary determinant of fruit size is the genotype or genetic makeup of the citrus variety [51]. Continella [26] analyzed some of the same cultivars present in our study. Specifically, they reported an average fruit weight of 124 g for *Femminello Siracusano, Femminello Dosaco,* and *Femminello Fior d'Arancio*. However, the same cultivars analyzed in the current study exhibited significantly higher weights, approximately 85.48% greater.

Table 4. Fruit weight (g), polar diameter (mm), equatorial diameter (mm), skin thickness (mm), seed number, juice percentage (%), titratable acidity (g/L citric acid), and pH of lemon fruits of the 18 cultivars analyzed in this study.

Cultivar	Fruit Weight (g)	Polar Diameter (mm)	Equatorial Diameter (mm)	Skin Thickness (mm)	Seed Number	Juice Percentage (%)	Titrabele Acidity (g/L Citric Acid)	pH
Sfusato Amalfitano	198.56 ± 23.30 abcd	101.12 ± 10.04 ab	67.52 ± 1.97 bcdef	8.73 ± 1.67 bcd	6.43 ± 3.01 de	23.20 ± 3.99 de	53.73 ± 7.49 b	2.45 ± 0.32 ab
Ovale di Sorrento	223.48 ± 32.63 ab	95.77 ± 6.35 abcd	71.55 ± 3.26 abc	8.77 ± 2.03 bcd	6.15 ± 3.16 de	27.78 ± 1.45 abc	57.96 ± 5.04 ab	2.46 ± 0.28 ab
Iniasel 95	219.64 ± 22.27 abc	103.77 ± 9.65 a	71.27 ± 5.11 abcd	8.18 ± 3.71 cde	7.47 ± 1.79 cde	26.47 ± 4.11 bcd	54.76 ± 2.91 ab	2.42 ± 0.26 b
Femminello Siracusano m 296	221.25 ± 25.78 abc	96.54 ± 7.80 abcd	71.21 ± 3.61 abcd	9.82 ± 4.51 ab	21.70 ± 1.55 a	24.17 ± 2.54 cde	56.20 ± 4.15 ab	2.45 ± 0.26 ab
Femminello Dosaco 503	221.90 ± 45.85 abc	96.07 ± 8.82 abcd	70.32 ± 5.32 abcde	7.78 ± 5.78 cdef	1.80 ± 0.59 fg	22.30 ± 4.41 e	58.46 ± 3.30 ab	2.41 ± 0.30 b
Femminello S	177.45 ± 33.12 bcde	86.73 ± 6.65 de	66.76 ± 4.06 cdef	7.35 ± 6.29 defg	4.63 ± 5.38 ef	25.90 ± 1.96 bcde	58.88 ± 3.78 ab	2.44 ± 0.28 ab
Femminello Siracusano 2KR	229.55 ± 25.17 a	95.95 ± 6.97 abcd	73.62 ± 3.57 a	9.26 ± 7.90 abc	11.82 ± 4.23 b	25.33 ± 1.22 bcde	60.01 ± 6.44 ab	2.44 ± 0.26 ab
Femminello Scandurra	164.96 ± 36.14 de	82.35 ± 9.60 e	65.37 ± 5.29 defg	8.16 ± 8.72 cde	0.57 ± 0.36 g	27.08 ± 1.64 bcd	57.54 ± 4.46 ab	2.48 ± 0.33 ab
Femminello Fior d'Arancio m 79	231.50 ± 31.84 a	99.19 ± 9.23 abc	72.99 ± 4.06 ab	9.83 ± 9.67 ab	9.78 ± 1.83 bc	24.69 ± 1.85 bcde	68.12 ± 18.35 a	2.48 ± 0.28 ab
Femminello Continella m84	177.04 ± 14.47 cde	83.71 ± 5.07 e	68.24 ± 2.23 abcdef	6.60 ± 10.09 fg	1.45 ± 1.06 fg	27.32 ± 2.47 abc	59.35 ± 5.44 ab	2.40 ± 0.30 b
CNR L58	194.88 ± 29.72 abcd	91.23 ± 6.98 bcde	67.63 ± 3.48 bcdef	9.17 ± 11.80 abc	9.17 ± 2.89 bcd	24.92 ± 3.78 bcde	68.76 ± 18.60 a	2.42 ± 0.25 b
Femminello Adamo	211.71 ± 23.36 abc	93.13 ± 6.67 abcde	70.92 ± 3.42 abcde	8.68 ± 12.94 bcde	0.68 ± 0.61 g	28.02 ± 1.99 abc	60.55 ± 7.24 ab	2.41 ± 0.26 b
Femminello Cerza	229.74 ± 45.22 a	97.87 ± 10.94 abcd	71.84 ± 5.75 abc	7.81 ± 13.27 cdef	0.00 ± 0.00 g	27.60 ± 1.09 abc	59.76 ± 6.01 ab	2.39 ± 0.26 b
Akragas	231.75 ± 34.01 a	99.10 ± 8.46 abc	72.24 ± 3.14 abc	10.61 ± 14.44 a	2.60 ± 0.40 fg	22.30 ± 1.24 e	59.84 ± 9.44 ab	2.45 ± 0.26 ab
Selinunte	188.01 ± 45.06 abcd	88.35 ± 9.48 cde	67.46 ± 5.16 bcdef	8.91 ± 15.69 bcd	1.58 ± 0.62 fg	25.50 ± 2.95 bcde	61.22 ± 7.77 ab	2.42 ± 0.26 b
Segesta	157.57 ± 25.01 de	91.54 ± 6.38 bcde	59.97 ± 3.45 g	6.30 ± 16.47 fg	0.20 ± 0.00 g	28.66 ± 1.22 ab	67.64 ± 17.99 ab	2.76 ± 0.22 ab
Erice	178.48 ± 23.89 bcde	92.24 ± 6.67 abcde	65.15 ± 3.25 efg	7.15 ± 17.47 efg	3.20 ± 1.70 fg	27.29 ± 4.24 abc	61.72 ± 6.19 ab	2.83 ± 0.17 a
Kamarina	137.78 ± 15.92 e	82.81 ± 4.39 e	63.16 ± 2.95 fg	6.22 ± 18.67 g	1.50 ± 0.52 fg	31.08 ± 1.97 a	56.87 ± 4.83 ab	2.80 ± 0.20 ab
Significance	***	***	***	***	***	***	ns	ns

All the data are expressed as the mean ± SD (standard deviation). For each parameter, the same letter indicates not significant differences according to Duncan's multiple range test ($p < 0.05$). Level of significance per the ANOVA is indicated as *** ($p < 0.001$).

As regards the skin thickness (Table 2), the *Akragas* cultivar showed higher values equal to 10.61 mm. The determination of this parameter is important because the skin of lemon fruits contains essential oils that contribute to its distinct aroma and flavor. In fact, in the bibliography there are several studies on the content of essential oils in lemon skin [52,53] and a quantification of the lemon peel oil components was described in the study of Chamblee et al. [54]. In one of our previous studies, we carried out analyses of the essential oil content on the same 18 cultivars [8]. The average seed number determined on the 18 cultivars analyzed is shown in Table 2. The cultivar *Femminello Siracusano m 296* reported a significantly higher average than the others, equal to 21.70 seeds; conversely, an average number of seeds equal to 0.00 was shown in the *Femminello Cerza* cultivar. Moreover, as in previous work, *Femminello Adamo, Femminello Cerza, Femminello Dosaco 503, Femminello Scandurra, Femminello Continella m84, Akragas, Selinunte, Segesta, Erice*, and *Kamarina* are confirmed to be generally seedless [55]. Obviously, this parameter is strongly correlated with the characteristics of the various genotypes analyzed and each genotype can have specific characteristics in terms of appearance, flavor, and adaptability to different climates and soils [56]. Another important parameter for determining the quality of lemon fruits is the juice content (Table 2). The juicier the fruit, the better is its acceptance not only for the juice market but also as a fresh fruit [51]. Lemon juice has various beneficial properties due to its natural composition. It is rich in vitamin C, acting as an antioxidant that protects the body against oxidative stress and supports the immune system. The acidic nature of lemon juice provides antimicrobial effects, inhibiting the growth of certain bacteria and fungi. In moderate amounts, lemon juice can aid digestion by stimulating stomach acid production and relieving symptoms of indigestion [12,21,57]. Our findings are partially consistent with those of Continella and Tribulato [25], where higher juice yield in both cases is shown for the *Femminello Continella* cultivar. The cultivars that showed the lowest juice content were *Femminello Dosaco 503* and *Akragas* with values of 22.30% of juice; the *Kamarina* cultivar instead showed a higher content equal to 31.08% of juice. Our results agree with those of Al-Jaleel et al. [51], who stated that fruits with thick rinds are usually low in juice, in agreement with our results where the cultivar *Kamarina* showed the lowest skin thickness but the highest juice percentage. Our results have highlighted an inverse relationship between juice content and fruit size, as the *Kamarina* cultivar exhibited smaller-sized fruits compared to others but had a higher juice content; this was confirmed by the correlation between juice percentage and fruit weight, which showed an R^2 of 0.013. The relationship between lemon fruit weight and juice content can vary depending on various factors such as the specific variety of lemon, the growing conditions, and cultural practices, which can also influence juice content independently of fruit weight [18]. The titratable acidity (g/L of citric acid) and pH results did show significant differences between some of the cultivars. Those that showed higher acidity were *Femminello D'Arancio m 79* and *CNR L 58*, with values of 68.12 g/L of citric acid and 68.76 g/L of citric acid, respectively. Higher pH values were reported in the *Erice* cultivar (2.83), while lower values were observed in the *Femminello Continella mc84* cultivar (2.40).

3.3. Principal Component Analysis (PCA)

To gain a comprehensive understanding of the agronomic aspects of lemon trees and the physico-chemical parameters of lemon fruits from various cultivars, a principal component analysis (PCA) was performed (Figure 5). This analysis allowed us to examine and summarize the key characteristics and variables associated with lemon tree cultivation and the chemical composition of the fruits across different varieties. The principal components disclosed 63.88% of the cumulative variance, with PC1 detailing 36.92% and PC2 26.96%.

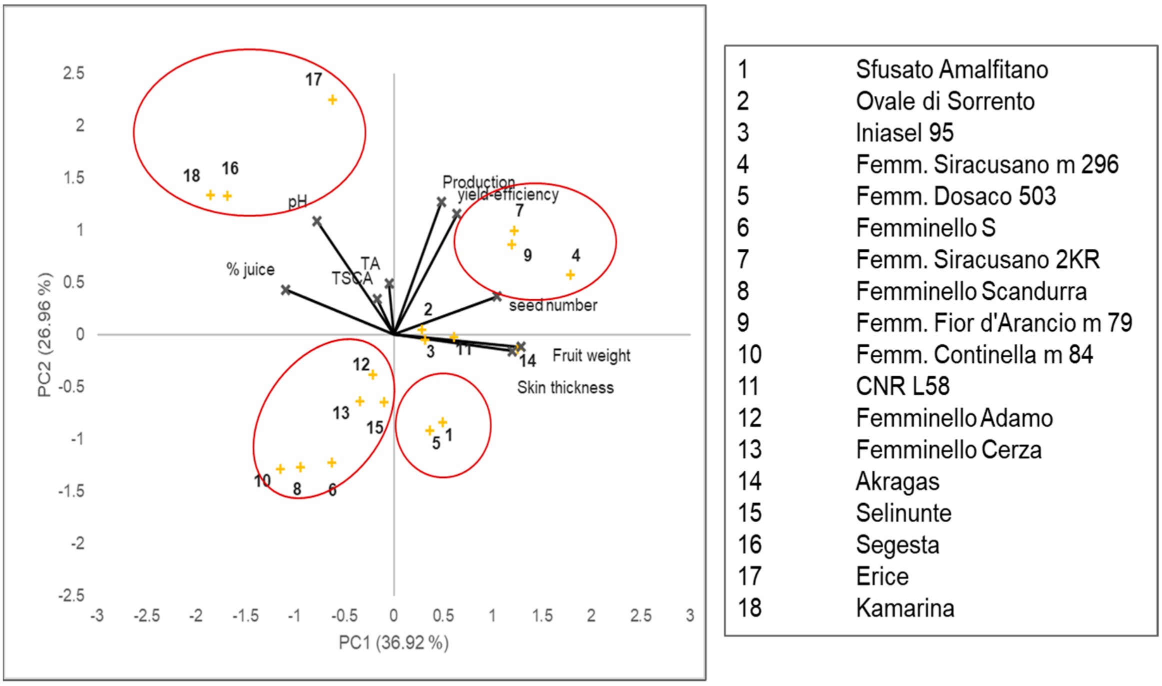

Figure 5. Principal component analysis (PCA) of agronomic parameters of plants and quali–quantitative parameters of fruits of 18 cultivars of lemon analyzed: production/pt (kg), yield efficiency (kg/cm^2), TSCA, fruit weight (g), skin thickness (mm), seed number, % juice, pH, and titratable acidity (g/L citric acid).

PC1 is positively correlated with the physicochemical parameters of lemon fruits (fruit weight, skin thickness, seed number, and % juice), while PC2 is positively correlated with the agronomic parameters of plants (production/pt and yield efficiency). Specifically, when analyzing the different lemon cultivars, it was observed that *Segesta*, *Erice*, and *Kamarina* exhibited a higher juice content percentage accompanied by increased acidity levels, pH, and TSCA. On the other hand, cultivars such as *Sfusato Amalfitano*, *Iniasel 95*, *Femminello Dosaco 503*, and *CNR L58* were positioned in the opposite quadrant, indicating lower juice content but higher fruit weight and skin thickness. The *Ovale di Sorrento*, *Femminello Siracusano m 296*, and *Femminello Fior d'arancio m 79* cultivars demonstrated a notable positive correlation with agronomic parameters: production/pt, yield efficiency, and number of seeds. On the contrary, these parameters exhibited a negative correlation with the remaining cultivars: *Femmniello S., Femmniello Scandurra, Femm. Continella m84, Femminello Adamo, Femminello Cerza*, and *Selinunte.*

4. Conclusions

This study encompasses the evaluation of different cultivars, mainly from Sicilian and Campanian germplasms, to ensure a broad and representative assessment. Based on this research, it was possible to identify the most suitable lemon cultivars for both fresh fruit consumption and processing through evaluating the agronomic performance of the trees, as well as the physical and morphological characteristics of the fruits. The findings of our study have revealed a significant biodiversity among the lemon cultivars examined, particularly highlighting the presence of certain cultivars that exhibit qualities well suited for fresh consumption or transformation. In the 10 years of the trial, all lemon cultivars exhibited fruit production starting as early as 3 years after planting, with a peak in production around 7 years after planting. Specifically, the cultivars that showed the highest cumulative production were *Erice* with 467.89 kg and *Femminello Siracusano 2KR* with 408.44 kg. The different cultivars showed significant differences in terms of fruit shape. Those characterized by a high percentage of juice content and acidity, and a low number of seeds (*Segesta*, *Erice*, and *Kamarina*), stand out as promising options for seeking lemons with abundant juice content and desirable levels of acidity for direct consumption, while the cultivars exhibiting enhanced yield (such as *Femminello Siracusano 2KR*, *Femminello Fior d'Arancio m79*, and *Erice*) might present a greater aptitude for the manufacturing of processed goods. Through a comprehensive multiyear investigation, this research has allowed for a meticulous description of various cultivars from the Sicilian and Campanian germplasms. Particularly, based on the agronomic plant data and fruit quality, it is possible to say that among the cultivars studied, those that showed the best qualitative and quantitative performance in the area where the test was carried out are *Erice* and *Femminello Siracusano 2KR.*

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