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# Quality and Flavor of 'Aliza' Fruit: A Unique Pomelo × Mandarin Hybrid

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**Abstract:** 'Aliza' is a new pomelo × mandarin hybrid (*Citrus maxima*, cv. Red Chandler × *Citrus reticulata*, cv. Ora) developed by the Israeli citrus breeding program at the Volcani Institute. Here, we aimed to characterize the quality and flavor of 'Aliza' fruit as compared to other commercial citrus fruit, specifically pomelo (*C. maxima*), grapefruit (*Citrus paradisi*), orange (*Citrus sinensis*) and mandarin (*C. reticulata*). 'Aliza' fruits have a similar size as grapefruits, but have a thinner peel and a unique yellowish/golden color. 'Aliza' fruits are completely seedless and have especially high juice contents. They also have a unique, highly preferred flavor, characterized by high sweetness and moderate bitterness and acidity, with strong citrusy and tropical fruity aromas. Sensory analyses conducted with the aid of a trained panel and an electronic tongue revealed that the flavor of 'Aliza' fruits is different from the flavors of other citrus species. Consumer acceptance and preference tests revealed that 'Aliza' fruit are highly appreciated and favored. The aroma volatile profile of 'Aliza' fruit was somewhat similar to those of pomelo and grapefruit, but very different from those of orange and mandarin. Overall, 'Aliza' fruits can be distinguished from other citrus fruits by their unique color, high juice content and exceptional, unique flavor.

**Keywords:** citrus; intelligent logistics; modelling; orange; postharvest



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## 1. Introduction

Citrus is the most important fruit tree crop in terms of cultivation and production values and is grown in the tropical and subtropical regions of the world, in more than 140 countries, with a total annual production of over 100 million tons [1,2]. The most important commercial citrus species are sweet orange (*Citrus sinensis*), mandarin (*C. reticulata*), grapefruit (*C. paradisi*), pomelo (*C. maxima*), lemon (*C. limon*) and lime (*C. aurantifolia*) [3]. Some commercial varieties are hybrids of different citrus species. For example, the 'Murcott' tangerine is a hybrid of orange and mandarin (*C. sinensis* × *C. reticulata*), the 'Minneola' tangerine is a hybrid of grapefruit and mandarin (*C. paradisi* × *C. reticulata*) and 'Oroblanco' is a hybrid of grapefruit and pomelo (*C. paradisi* × *C. grandis*) [4,5].

It is worth noting that pomelo (*C. maxima*), mandarin (*C. reticulata*) and citron (*C. medica*) are considered to be the three true original citrus ancestors, from which all other citrus species have evolved [3,6]. For example, sweet orange (*C. sinensis*) evolved from a hybridization between an early admixture mandarin and pomelo, and grapefruit (*C. paradisi*) evolved from a hybridization between pomelo and sweet orange [7,8]. In the current study, we characterized the quality of the 'Aliza' fruit, which is a new and unique pomelo × mandarin hybrid (*Citrus maxima* cv. Red Chandler × *Citrus reticulata* cv. Ora) developed by the

Israeli citrus breeding program at the Volcani Institute. 'Aliza' is a new commercial variety currently grown in several countries, including Israel, Spain and South Africa.

In a previous study, we demonstrated that the juice of 'Aliza' fruit differs in its sensory quality from orange and grapefruit juices [9]. In addition, 'Aliza' fruit contains low levels of furanocoumarins responsible for the grapefruit–drug interaction phenomenon, also known as the grapefruit effect, which is caused by the inhibition of the CYP3A4 drug-metabolism enzyme. This means that 'Aliza' fruit have a nutritional advantage as they can also be consumed by people who cannot consume grapefruit due to particular medications they are taking [10,11].

The quality of citrus fruit is determined by a combination of various factors, including external appearance, biochemical composition and flavor. The external appearance of fruit is determined by several physical traits, such as size, shape and weight, peel thickness, ease of peeling, amount of seeds and peel and pulp color. The biochemical and nutritional composition of citrus fruits is determined by the amounts of total soluble solids (TSS), acids, vitamin C and carotenoids that they contain among other nutrients [12,13]. The perceived flavor of citrus fruit is due to the combination of various taste, aroma and mouth-feel sensations. The taste of citrus fruit mainly results from sensations of sweetness, sourness and bitterness; the aroma of citrus fruit is due to the presence of dozens of aroma volatiles that belong to several chemical classes, including terpenes, aldehydes, alcohols, esters and ketones; and mouthfeel sensation is mainly determined by the juiciness and/or dryness of the fruit segments [14,15].

In the present study, we analyzed the quality and flavor of 'Aliza' fruit, and compared it with other common commercial citrus fruits, particularly pomelo, grapefruit, orange and mandarin that ripen at the same period.

## 2. Materials and Methods

### *2.1. Plant Material*

'Aliza', 'Newhall' navel orange, 'Star Ruby' red grapefruit, 'Goliath' pomelo and 'Nova' mandarin (Figure 1) were harvested from the Citrus Breeding Collection orchard at the Volcani Institute, Israel. All trees were grown on 'Troyer' rootstocks and harvested in December 2019. The harvesting maturity criteria included full color development and withstanding the minimum TSS and acidity levels (Figure 1, Table 1).

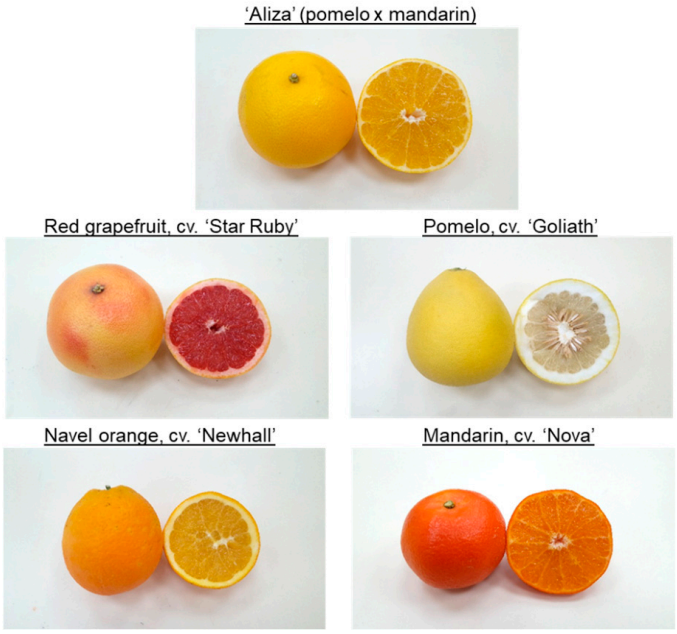


**Figure 1.** Photographs of 'Aliza', grapefruit, pomelo, orange and mandarin fruits used in this study.

**Table 1.** Fruit quality traits of different citrus fruits.

| | **'Aliza'** | **Grapefruit** | **Pomelo** | **Orange** | **Mandarin** |
|---|---|---|---|---|---|
| **Physical Traits** | | | | | |
| Weight (g) | 541 b | 484 b | 1035 a | 281 c | 151d |
| Height (mm) | 87.89 b | 85.22 b | 144.5 a | 84.60 b | 54.84 c |
| Diameter (mm) | 100.5 b | 104.1 b | 129.3 a | 80.10 c | 69.37 d |
| Shape (height/diameter) | 0.88 b | 0.82 bc | 1.12 a | 1.06 a | 0.79 c |
| Albedo thickness (mm) | 3.72 c | 5.44 b | 16.57 a | 5.30 b | 2.55 c |
| Flavedo thickness (mm) | 0.89 bc | 1.78 ab | 2.43 a | 1.10 bc | 0.85 c |
| Peel thickness (mm) | 4.61 c | 7.22 b | 19 a | 6.40 b | 3.40 d |
| Juice content (%) | 52.75 a | 42.55 b | 17.62 d | 37.64 c | 44.39 b |
| Seed number | 0 b | 1.11 b | 82.86 a | 0 b | 2.5 b |
| **Peel Color** | | | | | |
| Hue angle (°h) | 99.40 a | 64.30 b | 95.92 a | 62.98 b | 64.80 b |
| Lightness (1–100) | 78.90 a | 66.30 c | 74.51 b | 65.59 c | 62.50 d |
| Chroma (1–100) | 52.10 c | 45.80 d | 42.25 d | 60.97 b | 68.60 a |
| **Biochemical Parameters** | | | | | |
| TSS (%) | 12.10 ab | 11.93 b | 11.80 b | 12.56 ab | 13.27 a |
| Acidity (%) | 1.21 b | 1.59 a | 1.55 a | 0.83 c | 1.17 b |
| Ripening ratio (TSS/acidity) | 10.5 b | 7.5 c | 7.6 c | 15.2 a | 11.34 b |
| Vitamin C (mg 100 $mL^{-1}$) | 54.0 b | 56.7 ab | 38.2 c | 59.1 a | 56.6 ab |

Data concerning physical traits and peel color are means of 10 replications; data from biochemical analyses are means of five replications. Different letters within rows indicate significant differences at $p \leq 0.05$. Bold fonts indicate citrus fruit not significantly different from 'Aliza'.

### *2.2. Evaluations of Fruit Quality*

Fruit height, diameter and peel thickness were measured with a digital caliber. Peel thickness was measured in the equatorial zone of the fruit. Juice was extracted using a manual metal home juice squeezer. The seeds per fruit were counted after the juice was extracted.

Peel color was measured using a Minolta Chromo Meter, Model CR-400 (Minolta, Tokyo, Japan). All color data are means of 15 measurements.

The TSS contents of the extracted juices were determined with a Model PAL-1 digital refractometer (Atago, Tokyo, Japan). Acidity levels were measured using a Model CH-9101 automatic titrator (Metrohm, Herisau, Switzerland). TSS and acidity data are means of five replications.

The vitamin C contents of the fruit juices were measured by titration with 2,6-dichlorophenolindophenol. Concentrations of vitamin C were determined by comparing the titration volumes of the fruit juices with those of a standard solution containing 100 mg $L^{-1}$ ascorbic acid. Presented data are means of five replications.

### *2.3. Descriptive Sensory Tests*

Descriptive flavor tests were performed with the aid of a trained sensory panel comprised of 10 members, including four males and six females aged 25 to 65, who routinely perform flavor tests of citrus fruits [16,17]. Each panelist assessed the various attributes according to an unstructured 100-mm linear intensity scale for each attribute. The scale ranged from 'very weak' to 'very strong' and sensory data were recorded as distances (mm) from the origin. All samples contained cut segments prepared from at least five different fruits and were assigned three-digit codes for identification. The sensory attributes were defined following preliminary tasting sessions. The sensory panel was trained by tasting standards of 0.5–1.5% sucrose to evaluate sweetness, 0–0.5% citric acid to evaluate sourness and 500–1000 mg $L^{-1}$ naringin to evaluate bitterness. Citrusy aroma was related to the smell of citrus peel and tropical aroma was related to the smell of bananas and tropical fruit.

### *2.4. Consumer Acceptance Tests*

Consumer flavor acceptance tests were conducted with the help of 90 untrained participants who were employees and students working at the ARO, The Volcani Institute. The samples contained cut segments prepared from five different fruits and were assigned three-digit codes for identification. Flavor scores were assigned according to a 9-point hedonic scale that ranged from 'extreme dislike' to 'extreme like'.

### *2.5. Consumer Preference Test*

For the preference test, 90 untrained study participants tasted cut segments of the various citrus fruits and were asked to rank samples by preference as the first, second, third, four, and fifth choice The results were expressed as the percentage of testers who chose each species as their first choice.

### *2.6. Electronic Tongue*

The electrical taste profiles were measured using the Taste-Sensing System SA-402B (e-tongue; Intelligent Sensor Technology Co., Kanagawa, Japan) [18]. The system included three positively charged lipid membranes for sweetness (GL1), bitterness (C00) and astringency (AE1) and three negatively charged lipid membranes for saltiness (CT0), sourness (CA0) and umami (AAE). The taste intensity signals were measured as the differences between the sample and reference solutions. Data are means of three replications. Taste intensities of the various attributes were calculated using a conversion method, as described previously [19].

### *2.7. Aroma Volatiles*

Aroma volatiles of citrus juices were analyzed by gas chromatography coupled with mass spectrometry (GC–MS), as described previously [17,20]. Samples (1 mL) were placed in glass vials with an equal volume of 30% (*w*/*v*) NaCl and 0.6 g NaCl. We prepared five samples from each variety, each containing the juice of three fruits. Volatiles were extracted by solid-phase micro-extraction (SPME) using a divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) stable flex fiber (Supelco, Bellefonte, PA, USA). The aroma volatiles were separated on an HP-5 column, as described recently [17,20]. Chromatograph peaks were identified by comparing the mass spectrum of each compound with the US National Institute of Standards and Technology (NIST) 2006 Mass Spectral Library. The identification of aroma volatiles was confirmed by calculating their retention indices. The identification of 26 volatiles was also confirmed using chemical standards (Sigma-Aldrich, St Louis, MO, USA). Volatile levels were calculated according to calibration curves and represented as limonene equivalents.

### *2.8. Statistical Analysis*

One-way analysis of variance (ANOVA) and Tukey's HSD pair-wise comparison tests were conducted by JMP, version 14 (SAS Institute Inc., Cary, NC, USA). Principal component analysis (PCA) was conducted with the ClustVis tool [21].

## 3. Results

### *3.1. Fruit Quality*

The fruit quality attributes of 'Aliza', 'Newhall' orange, 'Star Ruby' grapefruit, 'Goliath' pomelo and 'Nova' mandarins are presented in Table 1. The 'Aliza' fruits were not significantly different from grapefruit in terms of fruit weight, height, diameter and shape, but did have significantly different peel thickness and juice contents. In fact, the 'Aliza' fruit had the highest juice content of all of the tested citrus fruits. Furthermore, the 'Aliza' fruits were significantly different from pomelo, orange and mandarin in terms of most of the examined physical traits. The 'Aliza' fruit differed significantly from all of the other fruits in terms of all three of the examined color parameters: lightness, chrome and hue angle values. The 'Aliza' fruits were not significantly different from the other species in

terms of their TSS values, but their acidity levels were significantly lower than those of the grapefruit and pomelo and significantly higher than those of the orange. Accordingly, the ripening ratio of the 'Aliza' fruit was higher than that of the pomelo and grapefruit, but lower than the orange's ripening ratio. The vitamin C levels of the 'Aliza' fruit were not significantly different from those of the grapefruit, orange and mandarin (Table 1). Biplot PCA based on the fruit quality data revealed that all of the tested citrus fruits had distinct quality profiles (Figure 2). More specifically, the 'Aliza' fruit were distinct from the mandarin, orange, and pomelo on the PC1 axis and different from all of the other citrus fruit on the PC2 axis (Figure 2).

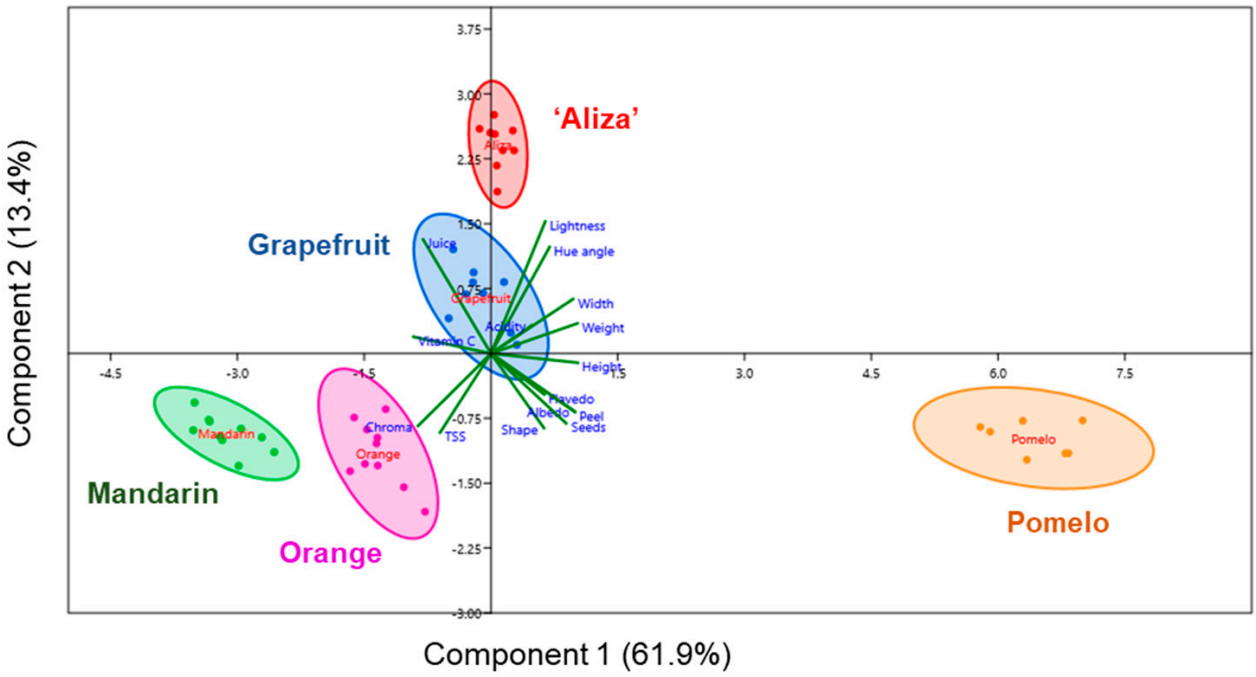


**Figure 2.** Biplot PCA chart of fruit quality data of 'Aliza', grapefruit, pomelo, orange and mandarin. The marked ellipses indicate the 95% probability that a new observation from the same group will fall inside the ellipse.

### *3.2. Descriptive Sensory Tests*

Descriptive sensory tests conducted with the aid of a trained panel revealed that the flavor profile of the 'Aliza' fruit was different from those of the grapefruit, pomelo, orange and mandarin (Figure 3). Overall, the flavor of the 'Aliza' fruit was characterized by high sweetness, low sourness, moderate bitterness, high juiciness and high freshness, as well as citrusy and tropical odors. The flavor of the 'Aliza' fruit was different from that of the grapefruit, in that it was sweeter, had stronger tropical odors and was less sour and less bitter. Compared to the pomelo fruit, the 'Aliza' fruit was sweeter, had a stronger tropical odor, greater juiciness and freshness, and was less sour and easier to chew. Compared to orange and mandarin, the 'Aliza' fruits were more bitter, juicier and had a stronger tropical odor. Biplot PCA based on the descriptive sensory data revealed that the flavor of 'Aliza' fruit had some overlap with grapefruit and a very slight overlap with orange, but was entirely distinct from pomelo and mandarin (Figure 4).

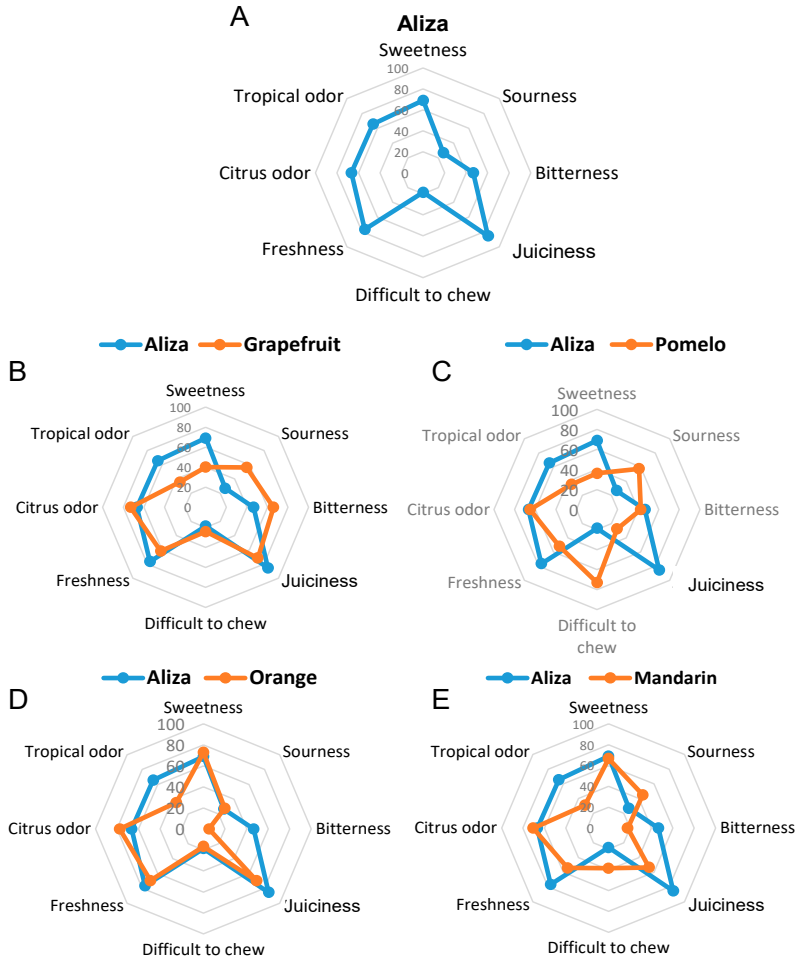


**Figure 3.** Flavor profiles of 'Aliza', grapefruit, pomelo, orange and mandarin fruits. (**A**) 'Aliza'; (**B**) 'Aliza' and grapefruit; (**C**) 'Aliza' and pomelo; (**D**) 'Aliza' and orange; (**E**) 'Aliza' and mandarin. Flavor profiles were evaluated by a trained sensory panel and data are means of the scores assigned by 10 testers.

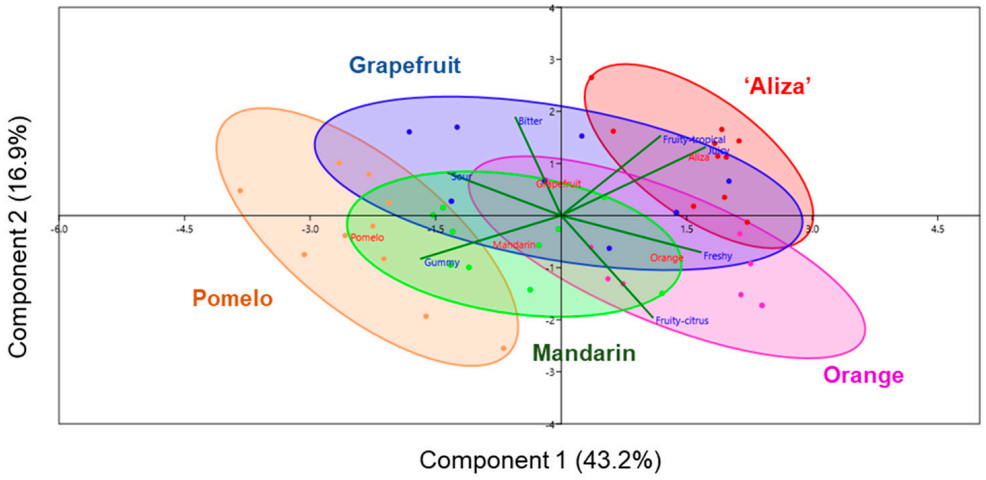


**Figure 4.** Biplot PCA chart of descriptive sensory data for 'Aliza', grapefruit, pomelo, orange and mandarin. The marked ellipses indicate the 95% probability that a new observation from the same group will fall inside the ellipse.

### *3.3. Flavor Acceptance and Flavor Preference Tests*

Consumer acceptance tests were conducted among 90 untrained panelists who assigned hedonic scores on a scale from 1 ('extreme dislike') to 9 ('extreme like'). The 'Aliza' fruit achieved the highest acceptance score of 7.3, as compared with somewhat lower scores of 6.6, 6.5, 6.1 and 5.0 for the mandarin, orange, pomelo and grapefruit, respectively (Figure 5A). The acceptance score of the 'Aliza' fruit was significantly higher than that of the grapefruit, but was not significantly different from the scores for the mandarin, orange and pomelo.

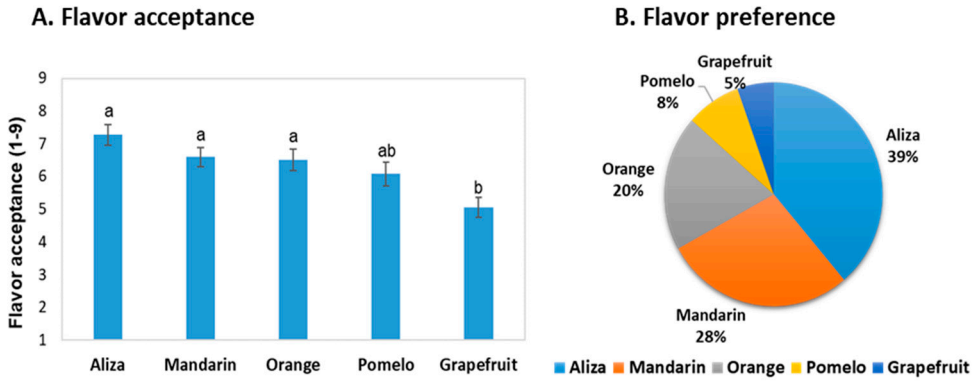


**Figure 5.** Consumer (**A**) flavor acceptance and (**B**) flavor preference scores for 'Aliza', grapefruit, pomelo, orange and mandarin. Data are means ± S.E. of the scores assigned by 90 testers. Different letters in A indicate significant differences at $p \leq 0.05$.

We further conducted a flavor preference test among 90 untrained participants. In that test, 39% of the participants chose 'Aliza' fruit as their first choice, as compared to just 28%, 20%, 8% and 5% who chose mandarin, orange, pomelo or grapefruit, respectively (Figure 5B).

### *3.4. Sensory Evaluations Conducted Using the Electronic Tongue*

Sensory evaluations of the different citrus fruits were also conducted using an electronic tongue (e-tongue) instrument. The data collected using the e-tongue with sensors for sweetness (GL1), sourness (CA0) and bitterness (C00) are presented in Figure 6. The results indicate that the 'Aliza' juice was significantly less sweet than that of the orange juice and mandarin juice, but significantly sweeter than the pomelo juice and grapefruit juice (Figure 6A). The 'Aliza' juice was significantly less sour than the grapefruit juice and pomelo juice, but significantly more sour than the orange juice (Figure 6B). Finally, the 'Aliza' juice was significantly less bitter than the pomelo juice and grapefruit juice, but significantly more bitter than the orange juice (Figure 6C). Biplot PCA of the e-tongue data indicated that all of the examined citrus fruits had distinct flavor profiles and, according to the PC1 axis, the flavor of 'Aliza' juice was nearer to that of mandarin, but very distinct from the profiles of orange and grapefruit (Figure 7).

### *3.5. Composition of Aroma Volatiles*

The aroma volatile contents of 'Aliza', pomelo, mandarin, orange and grapefruit are presented in Table 2. As can be seen from that table, mandarin had the highest total volatile content, followed by orange, grapefruit, 'Aliza' and pomelo. The total level of aroma volatiles was mainly determined by the presence of high levels of the monoterpene limonene. The detected aroma volatiles belong to various chemical classes, including alcohols, aldehydes, esters, monoterpenes, terpene alcohols, terpene aldehydes, terpene ketones and sesquiterpenes. A biplot PCA based on the aroma volatile contents revealed that the aroma profile of 'Aliza' fruit was similar to those of pomelo and grapefruit, but very distinct from the profiles of orange and mandarin (Figure 8).

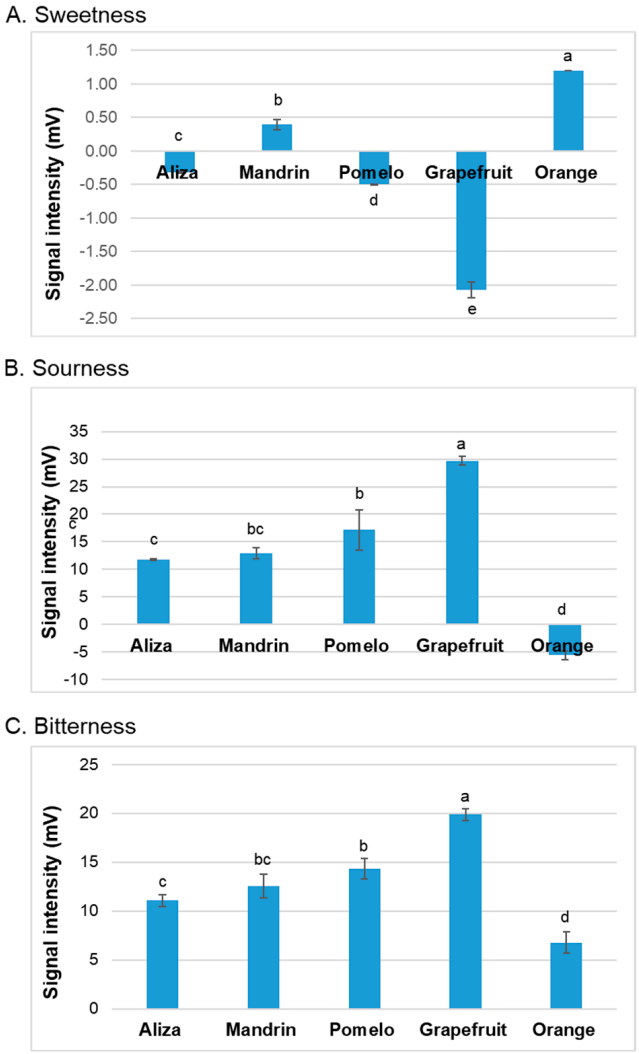


**Figure 6.** Taste scores of 'Aliza', grapefruit, pomelo, orange and mandarin fruits as determined by the e-tongue. (**A**) sweetness; (**B**) sourness; (**C**) bitterness. Data are means ± S.E. of 3 replications. Different letters indicate significant differences at $\alpha \leq 0.05$.

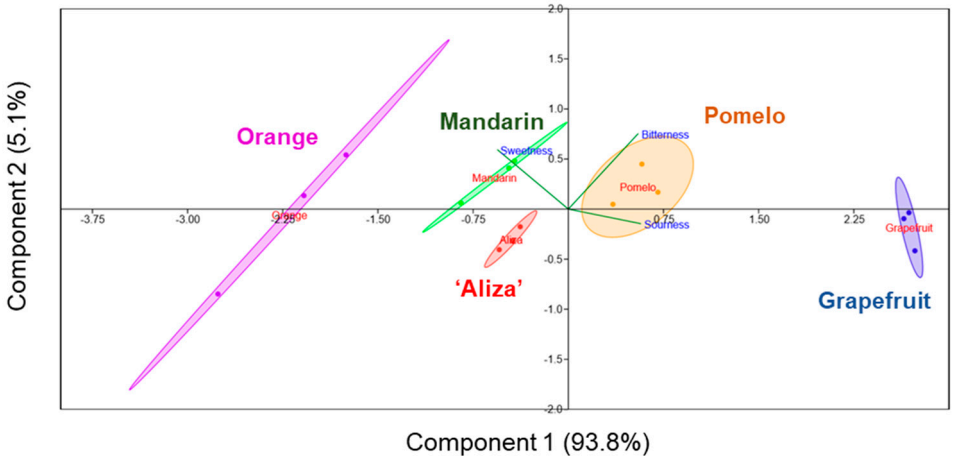


**Figure 7.** Biplot PCA chart of electronic-tongue data for 'Aliza', grapefruit, pomelo, orange and mandarin. The marked ellipses indicate the 95% probability that a new observation from the same group will fall inside the ellipse.

**Table 2.** Aroma volatile concentrations in the juices of 'Aliza', pomelo, mandarin, orange and grapefruit.

| | | | Concentration (μg $L^{-1}$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Pomelo | | Grapefruit | | Mandarin | | Orange | | |
| | RI [b] | RI [c] | 'Aliza' | | 'Goliath' | | 'Star Ruby' | | 'Nova' | | 'Newhall' | | Odor Description [f] |
| **Alcohols** | | | | | | | | | | | | | |
| Octanol [a] | 1069 | 1068 | tr | c | ND | c | 70 | bc | 115 | b | 240 | a | soapy |
| Nonanol | 1171 | 1171 | ND | b | ND | b | ND | b | 90 | a | 54 | ab | oily, floral, powerful |
| **Aldehydes** | | | | | | | | | | | | | |
| 2-Hexenal [a] | 851 | 850 | 67 | a | tr | b | 4 | b | 3 | b | 57 | a | green, banana |
| Octanal [a] | 1001 | 1002 | tr | b | ND | b | 351 | ab | 40 | ab | 621 | a | tallowy, citrus |
| Nonanal [a] | 1103 | 1103 | 11 | b | 7 | b | 34 | b | 205 | a | 207 | a | pine, floral, citrus |
| Decanal [a] | 1203 | 1203 | 10 | b | 6 | b | 116 | b | 3143 | a | 928 | b | musty, cucumber |
| 2-Decenal | 1263 | 1262 | ND | b | ND | b | ND | b | 116 | a | ND | b | Geranium |
| Undecanal | 1308 | 1306 | ND | b | ND | b | 7 | b | 176 | a | 75 | b | soapy |
| Dodecanal | 1410 | 1407 | ND | b | tr | b | 10 | b | 850 | a | 227 | b | sweet, waxy, herbaceous |
| 2-Dodecenal | 1466 | 1466 | ND | b | ND | b | ND | b | 121 | a | ND | b | - |
| **Esters** | | | | | | | | | | | | | |
| Octyl acetate | 1209 | 1208 | ND | b | ND | b | 36 | b | 119 | a | tr | b | fruity, slightly fatty |
| Neryl acetate | 1366 | 1362 [d] | 11 | ab | 7 | b | 12 | ab | 47 | a | 27 | ab | fruity, floral, sweet |
| **Terpene Alcohols** | | | | | | | | | | | | | |
| Linalool [a] | 1098 | 1100 | 51 | b | 87 | b | 194 | b | 3526 | a | 1106 | b | citrus-like, bergamot |
| 4-Terpineol [a] | 1178 | 1177 [d] | 8 | c | 13 | c | 97 | c | 782 | a | 436 | b | wood, earthy |
| α-Terpineol [a] | 1191 | 1193 | 22 | a | 84 | a | 282 | a | 614 | a | 478 | a | floral, lilac |
| β-Citronellol [a] | 1227 | 1226 | ND | c | 12 | bc | ND | c | 76 | ab | 127 | a | rose-like, fresh |
| cis-Carveol | 1231 | 1229 | ND | c | 15 | bc | 13 | bc | 84 | ab | 125 | a | spearmint, caraway |
| Geraniol [a] | 1254 | 1253 | ND | c | 14 | bc | ND | c | 63 | a | 31 | b | floral, rose-like |
| **Terpene Aldehydes** | | | | | | | | | | | | | |
| Neral [a] | 1242 | 1241 | 5 | b | 7 | b | 6 | b | 35 | b | 279 | a | lemony, citrusy |
| Geranial [a] | 1273 | 1270 | 9 | b | 11 | b | 11 | b | 133 | b | 549 | a | citrus-like, flowery, fruity |
| **Terpene Ketones** | | | | | | | | | | | | | |
| Carvone | 1246 | 1249 | 3 | b | 5 | b | 18 | b | 1235 | a | 30 | b | spearmint, caraway |
| Nootkatone [a] | 1837 | 1807 [d] | ND | b | 2 | a | tr | ab | ND | ab | 2 | a | green, grapefruit |
| **Monoterpenes** | | | | | | | | | | | | | |
| α-Pinene [a] | 934 | 936 | 33 | b | 26 | b | 63 | b | 2686 | a | 694 | b | pine, resinous |
| β-Pinene [a] | 974 | 980 | tr | c | 2 | c | 2 | c | 861 | a | 498 | b | peppery, green |
| Myrcene [a] | 989 | 991 | 572 | b | 232 | b | 934 | b | 12,405 | a | 4656 | b | resinous, woody |
| α-Phellandrene [a] | 1005 | 1008 | tr | a | 70 | b | 11 | ab | 32 | ab | 46 | ab | herbaceous, dill |
| D-Limonene [a] | 1033 | 1031 | 13,636 | b | 7528 | b | 18,264 | b | 190,507 | a | 71,703 | b | citrus, fresh |
| β-Ocimene [a] | 1047 | 1037 | 24 | b | 29 | b | 123 | b | 1939 | a | 158 | b | herb, tropical |
| γ-Terpinene | 1058 | 1071 | tr | b | 8 | b | 47 | ab | 286 | a | 182 | ab | lemony, lime |
| Terpinolene [a] | 1089 | 1091 | 29 | b | 53 | b | ND | b | 711 | a | 404 | ab | citrus, pine |
| Perillaldehyde [a] | 1278 | 1279 | ND | b | ND | b | 18 | b | 268 | a | 101 | b | green, oily, fatty, cherry |

**Table 2.** *Cont.*

| | Concentration (μg $L^{-1}$) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Pomelo | | Grapefruit | | Mandarin | | Orange | | |
| | **RI** [b] | **RI** [c] | **'Aliza'** | | **'Goliath'** | | **'Star Ruby'** | | **'Nova'** | | **'Newhall'** | | **Odor Description** [f] |
| **Sesquiterpenes** | | | | | | | | | | | | | |
| δ-Elemene | 1343 | 1338 [d] | 26 | b | ND | b | 8 | b | 904 | a | 17 | b | sweet, wood |
| α-Cubebene | 1355 | 1351 | 35 | cd | ND | d | 58 | bc | 389 | a | 103 | b | herbal, waxy |
| Ylangene | 1378 | 1372 | 6 | b | ND | b | ND | b | 29 | a | ND | b | - |
| Copaene | 1383 | 1376 | 40 | b | 2 | b | 205 | b | 1412 | a | 285 | b | spicy, honey |
| β-Elemene | 1397 | 1391 | 19 | a | ND | a | 35 | a | 835 | a | 187 | a | herb, wax, fresh |
| Caryophyllene [a] | 1430 | 1432 | 76 | b | 30 | b | 3154 | a | 614 | b | 174 | b | sweet, clove |
| Sesquiterpene I | 1437 | | 28 | b | 2 | b | 29 | b | 894 | a | 193 | ab | - |
| γ-Elemene | 1440 | 1433 [e] | 3 | b | 2 | b | ND | b | 263 | a | 15 | b | green, woody, oily [g] |
| β-Farnesene [a] | 1461 | 1457 [d] | 10 | c | ND | c | 4 | c | 296 | a | 108 | b | woody, herbal, sweet [g] |
| Humulene [a] | 1463 | 1454 | 12 | b | 30 | b | 307 | b | 864 | a | 57 | b | woody, ocean, clove [g] |
| γ-Muurolene | 1484 | 1480 [d] | 39 | b | 15 | b | 117 | ab | 316 | a | 81 | ab | herbal, woody, spicy [g] |
| α-Muurolene | 1490 | 1490 | 112 | b | tr | b | 16 | b | 728 | a | 29 | b | woody [g] |
| Valencene [a] | 1502 | 1506 | 70 | b | ND | b | 29 | b | 17 | b | 1152 | a | woody, citrusy |
| α-Farnesene [a] | 1509 | 1508 [d] | 27 | a | ND | a | 21 | a | 572 | a | 58 | a | sweet, mild |
| γ-Cadinene | 1528 | 1513 [e] | 35 | b | 4 | b | 7 | b | 156 | a | 19 | b | herbal, woody [g] |
| δ-Cadinene | 1537 | 1524 | 119 | b | 14 | b | 193 | b | 1613 | a | 196 | b | woody, dry, mild |
| Sesquiterpene II | 1548 | | 7 | a | 10 | a | 7 | a | 717 | a | 16 | a | - |
| α-Calacorene | 1559 | 1546 [d] | 5 | b | 5 | b | 3 | b | 51 | a | 7 | b | woody [g] |
| Total Volatiles | | | 15,161 | | 8330 | | 231,608 | | 86,686 | | 24,915 | | |

Aroma volatiles were detected by HS-SPME GC-MS analysis. Data are means of four replications, each of juice from three different fruits. Different letters within rows indicate significant differences at $p \leq 0.05$. tr = traces, ND = not determined. [a] The identification of the volatiles was confirmed with chemical standards. [b] Calculated retention indices based on a series of n-alkanes. [c] Published retention indices on DB-5 column according to the University of Florida citrus flavor database unless mentioned otherwise. [d] Published retention indices on DB-5 column according to Adams (2001). [e] Published retention indices on DB-5 column according to PubChem. [f] Odor descriptions according to the University of Florida Citrus Flavor Database unless mentioned otherwise. [g] Odor descriptions according to The Good Scents Company.

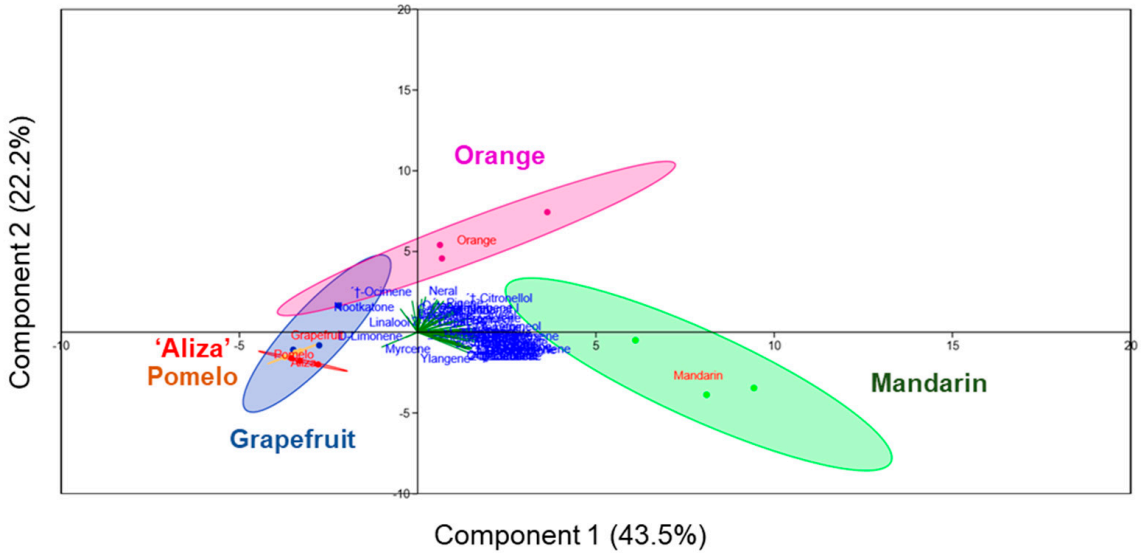


**Figure 8.** Biplot PCA chart of the aroma volatile contents of 'Aliza', grapefruit, pomelo, orange and mandarin. The marked ellipses indicate the 95% probability that a new observation from the same group will fall inside the ellipse.

## 4. Discussion

The main goal of the current research was to characterize the fruit quality and flavor traits of 'Aliza', which is a new pomelo × mandarin hybrid (*Citrus maxima* cv. Red Chandler × *Citrus reticulata* cv. Ora) developed by the Israeli citrus breeding program, as compared to other commercially grown citrus fruits, specifically grapefruit, pomelo, orange and mandarin. The evaluations included general quality parameters and sensory evaluations by human panels and an e-tongue, as well as a biochemical analysis of the composition of aroma volatiles.

Fruit quality evaluations revealed that 'Aliza' fruits are somewhat similar to grapefruits in their physical traits (i.e., fruit weight, height, diameter and shape), but have a thinner peel, as well as the highest juice content of all of the examined citrus fruits (Table 1). 'Aliza' fruits also have a unique yellowish/golden color that is distinct from the colors of all of the other citrus fruits (Table 1, Figure 1). It is worth noting that 'Aliza' fruits are also completely seedless. Thus, altogether, in terms of quality traits, 'Aliza' fruits are different from other citrus fruits (Figure 2).

To examine the sensory quality of 'Aliza' fruits, we conducted various human and instrumental sensory tests, including descriptive tests conducted with the aid of a trained panel, consumer acceptance and preference tests, and a sensory test using an e-tongue. The descriptive tests revealed that 'Aliza' fruits have a unique flavor profile that is different from those of all of the other examined citrus fruits. The 'Aliza' flavor is characterized by high sweetness, low sourness, moderate bitterness, high juiciness and high freshness, as well as citrusy and tropical odors (Figure 3). More detailed descriptions regarding the flavor characteristics of citrus fruit are discussed elsewhere [15].

In a previous study, we reported that the flavor profile of 'Aliza' juice was different from those of orange and grapefruit juices [9]. However, in the current study, we evaluated the flavor of the fruit (i.e., the flavor of cut segments), as opposed to the flavor of extracted juices, and compared 'Aliza' fruit to pomelo and mandarin, in addition to orange and grapefruit. Overall, the current results confirm the previous finding that 'Aliza' fruits have a unique flavor profile that differs from the flavor profiles of other citrus fruits.

We also conducted consumer acceptance and preference tests among 90 untrained participants. In those tests, 'Aliza' fruit achieved the highest acceptance score and was most preferred among all of the tested citrus fruits (Figure 5). Again, these results are in agreement with those of our previous study, in which 'Aliza' juice received the highest

acceptance score and was most preferred among 'Aliza', orange and grapefruit juices [9]. The flavor profile of 'Aliza' fruit was further evaluated using an e-tongue and that objective instrumental measurement also confirmed that the flavor profile of 'Aliza' fruits is different from those of all of the other examined citrus fruits (Figures 6 and 7). E-tongue has also recently been used as a freshness indicator for citrus fruit [22].

GC-MS analysis of aroma volatiles revealed that 'Aliza' juice has lower volatile levels than orange juice and mandarin juice, mainly due to its lower levels of monoterpenes and sesquiterpenes. Overall, the aroma volatiles' profile of the 'Aliza' juice was more similar to those of grapefruit juice and pomelo juice and less similar to those of orange and mandarin juice (Table 2, Figure 8). Despite its unique flavor, we have not detected any specific aroma volatiles that are unique to 'Aliza' fruit. Similarly, a recent study characterized the quality and flavor of a new early-ripening pomelo variety but also failed to detect any specific aroma volatiles for that variety [23]. Nonetheless, other studies have succeeded in identifying variations in aroma volatiles among new varieties [24]. In a previous study, we analyzed the aroma volatile compositions of 13 mandarin varieties belonging to different natural subgroups and observed major differences in total volatile contents, as well as in the proportion of the aroma volatiles belonging to different chemical classes such as monoterpenes, sesquiterpenes, esters and aldehydes [20]. Accordingly, we suggest that the unique flavor of 'Aliza' fruit may be due to a unique combination of different chemical classes of aroma volatiles rather than from any unique aroma compounds.

In summary, the current research demonstrates that 'Aliza' is a unique pomelo × mandarin hybrid with unique fruit quality and flavor characteristics. This hybrid's special yellowish/golden color, extremely high juice content, seedlessness and unique and highly preferred flavor are particularly noteworthy.

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