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Effects of Harvest Time on the Fruit Quality of Kinnow and Feutrell's Early Mandarins (*Citrus reticulata* Blanco)

Meryam Manzoor [1], Syed Bilal Hussain [2], Muhammad Akbar Anjum [1,*], Mudassar Naseer [3], Riaz Ahmad [4] and Vasileios Ziogas [5,*]

1. Department of Horticulture, Bahauddin Zakariya University, Multan 60800, Pakistan
2. Citrus Research and Education Center, University of Florida, 700 Experiment Station Rd., Lake Alfred, FL 33850, USA; syedbilalhussain@ufl.edu
3. Horticultural Research Station, Sahiwal 57000, Pakistan
4. Department of Horticulture, The University of Agriculture, Dera Ismail Khan 29111, Pakistan
5. Institute of Olive Tree, Subtropical Plants and Viticulture, ELGO—DIMITRA, 73134 Chania, Greece

* Correspondence: akbaranjum@bzu.edu.pk (M.A.A.); ziogas@elgo.iosv.gr (V.Z.)

Abstract: The intrinsic and extrinsic traits of citrus fruits change throughout their developmental process, and, therefore, to ensure the highest quality, fruit must be harvested at an appropriate stage of maturity. In a 2-year study, mandarin (*Citrus reticulata* Blanco) cultivars (Kinnow and Feutrell's Early) grafted on rough lemon (*C. jambheri* Lush) rootstock were selected to analyze the effect of harvest time on their physicochemical characteristics and antioxidant potential in two consecutive growing seasons in the Multan region of South Pakistan, which has a subtropical climate. Fruits were harvested from commercial citrus groves at intervals of one month (from September to February). The results showed that different maturity stages/harvesting dates have a significant effect on the fruit quality and yield characteristics of mandarin cultivars. An increase in fruit weight, juice content, total soluble solids, ripening index, juice pH, and total sugar content was observed with the advancement of fruit maturity, while juice acidity, antioxidant capacity, total phenolic content, and vitamin C content had a decreasing trend towards fruit maturity. Overall, both cultivars showed similar profiles to the change in fruit quality traits during growth and development, but their amounts showed great variation. Based on the comprehensive consideration, Kinnow attained the maximum fruit quality and yield values from mid-January to February, whilst Feutrell's Early attained the maximum values of these parameters from mid-December to mid-January, attributing to higher consumer acceptability. This study demonstrated that harvest time plays a key role in controlling the fruit quality and yield of mandarin cultivars. In practice, harvest time should be highly considered for the fresh and processed citrus market and industry.

Keywords: mandarin; fruit quality; fruit development; harvest time; physicochemical composition

Citation: Manzoor, M.; Hussain, S.B.; Anjum, M.A.; Naseer, M.; Ahmad, R.; Ziogas, V. Effects of Harvest Time on the Fruit Quality of Kinnow and Feutrell's Early Mandarins (*Citrus reticulata* Blanco). *Agronomy* **2023**, *13*, 802. https://doi.org/10.3390/agronomy13030802

Academic Editor: Susanna Bartolini

Received: 30 December 2022
Revised: 22 February 2023
Accepted: 6 March 2023
Published: 9 March 2023

1. Introduction

Citrus is a major fruit crop that is largely grown and consumed all over the world. Citrus fruits are famous due to their excellent flavor, taste, aroma, and many health benefits [1,2]. Consumption of citrus fruits or juices boosts the immune system and is found to be inversely associated with several chronic diseases [3]. According to the world crop production statistics of the FAO [4], 15.73 million tons of citrus fruit were produced from an area of 1.07 million ha in 2020. In Pakistan, citrus fruits occupy a prominent position with a total production of 2.30 million tons from an area of 145.18 thousand ha [5]. Although many citrus species are grown on a commercial scale, Kinnow and Feutrell's Early are two promising mandarin varieties that are largely produced for domestic and international markets where consumers demand high fruit quality and appreciate their healthy properties [6,7].

Fruit quality is necessary in order to support the marketing potential of the commodity. From a consumer perspective, good-looking citrus fruit will most likely exhibit a superior taste experience. However, consumer choice of subsequent procurements is based on the fruit's internal quality characteristics such as total soluble solids (TSS) and titratable acidity (TA), as well as the ratio of TSS to TA [8,9]. The external and internal fruit quality characters primarily depend on the species, cultivar, and their individuals due to different genetic make-up [10,11], scion–rootstock combination [12], fruit position in the canopy [13–15], fruit maturity stages [16–18], growing conditions [19,20], and cultural operations [21,22].

Fruit harvesting at the proper stage and time is important for attaining desired physical and nutritional compounds [23]. Proper harvest time is essential to the effective concentration of biochemical, bioactive, and volatile compounds in fruits [17,18,24]. Hence, fruit harvesting at an appropriate time with proper maturity is necessary for increased production and good quality, and both early and late harvest can lead to several negative aspects, decreasing the fruit quality. The fruit quality affected by the developmental stage has attracted much research attention in recent years. Some studies have reported changes in chemical composition and antioxidant activity during the development of citrus fruits [18,25–27], and others have studied the changes in nutritional compounds, sensory characteristics, and volatile compounds [17,28]. Along with the influence of harvest date, the varietal difference is of great importance and exhibits changes in pomological and biochemical characteristics. Previous research indicated that the nutritional values and antioxidant potential of citrus species differed from one to the next [11,29]. In a study carried out on 46 mandarin varieties within the Israeli Citrus breeding collection, it was found that mandarin cultivars exhibit a high level of genetic diversity in terms of quality attributes [30]. According to Costanzo et al. [31], the concentration of functional compounds in terms of photosynthetic pigments, total polyphenols, antioxidant activity, and vitamin C contents highly varied among mandarin cultivars.

Fruit color, juice content, sugar, acid content, and ripening index are major indicators of fruit maturity and ripening stage [32]. The information regarding the maturity and harvest time of citrus is imperative. To the best of our knowledge, a lot of work is available on the increase in production and postharvest management, however, limited work is reported on maturity time and harvesting time. It was hypothesized that the fruit maturity stage at harvest will influence the quality of citrus fruit. Therefore, the objective of the present study was to evaluate the influence of harvest time on fruit quality, yield, and antioxidant potential of the two commercially important mandarin cultivars [Feutrell's Early (early-season cultivar) and Kinnow (late-season cultivar)] on the basis of their physicochemical characteristics. We aim to determine the optimum harvest time of these cultivars for fresh consumption. Our findings will facilitate citrus growers to harvest their produce at the proper time, for better market demand, and will also benefit the citrus juice processing industries to decide at what time the fruit should be harvested. Moreover, the volume of poor-quality fruits can be reduced by creating the importance of harvesting time.

2. Materials and Methods

2.1. Plant Materials and Experimental Site

In the present study, healthy and vigorously growing twelve-year-old plants of two commercial mandarin (*Citrus reticulata* Blanco) cultivars (Kinnow and Feutrell's Early) grafted on rough lemon (*C. jambheri* Lush) rootstock were selected from local commercial citrus groves located in Multan, Pakistan (30°150′ N 71°360′ E; 122 m above sea level). Kinnow and Feutrell's Early mandarin cultivars have been actively grown and produced in this area as major citrus cultivars. Thus, these citrus cultivars were used in this study. Recommended agronomic practices were performed on selected experimental trees during the period of study. From the selected orchard, soil samples were collected at a depth of 30 cm. The soil status of an experimental citrus orchard is given in Table 1.

Table 1. Soil status of a citrus orchard at the study location in Punjab, Pakistan.

Soil Depth (cm)	Texture	Saturation (%)	pH	SAR	EC (ds m^{-1})	Total N (%)	Available P (ppm)	Available K (ppm)
30	Loam	42	7.9	0.6	1.82	0.048	8	153

Healthy, uniform-sized and disease-free fruit samples were randomly collected at different stages of maturity/ripening from September to February with a one-month interval, during two consecutive fruiting seasons (2018–2019 and 2019–2020). Immediately after harvesting, the fruits were directly transported to the Postgraduate Laboratory of the Department of Horticulture, Bahauddin Zakariya University, Multan (Pakistan), for physicochemical analysis. A total of 20 fruits without diseases, insect pests, and mechanical damage in the middle and outer parts of the fruit trees were collected for each cultivar. Four replicates were performed, with each replication consisting of five fruits. Meteorological data from the experimental location during the studied period is presented in Figure 1 (Source: Pakistan Meteorological Department). Based on the given meteorological result, the studied area has a sub-tropical climate.

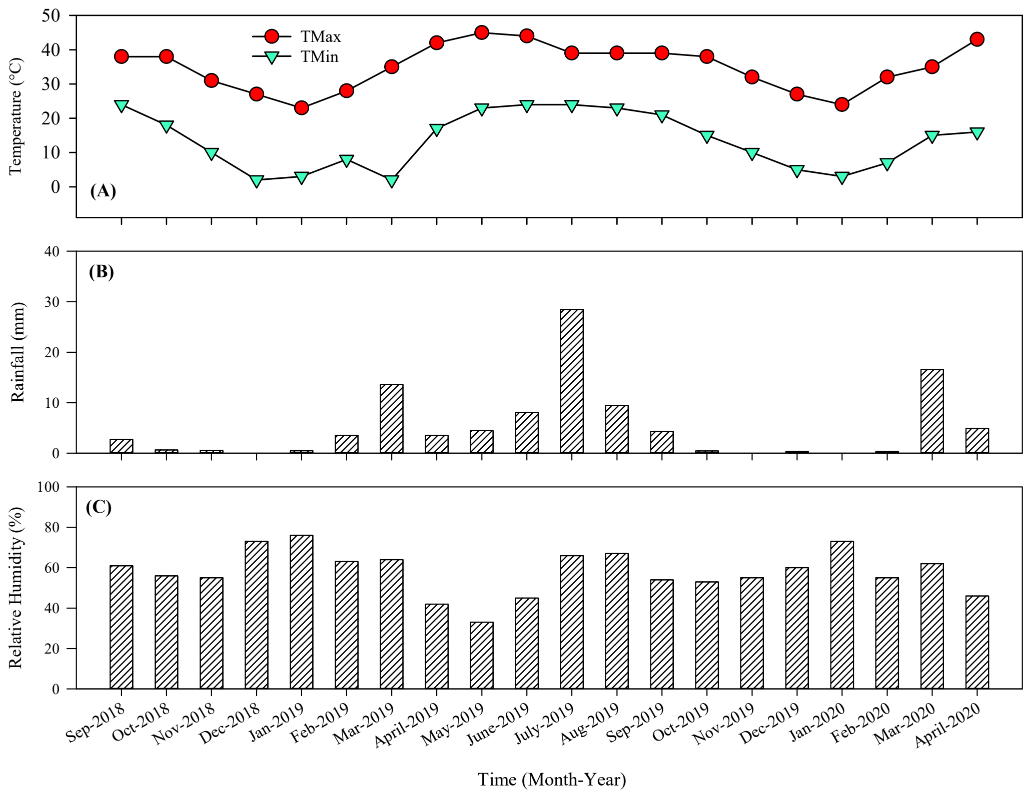

Figure 1. Tmax, maximum temperature, and Tmin, minimum temperature (**A**), average rainfall (**B**), and average relative humidity (**C**) occurring at the experimental location (Source: Pakistan Meteorological Department).

2.2. Measurements

2.2.1. Physical Parameters

Physical parameters, i.e., total fruit weight, peel, seed, juice, and rag weight from each sampled fruit per cultivar were measured by using an electronic weighing balance (model WT6002D; WANT Balance Instrument Co. Ltd., Changzhou, Jiangsu, China). The fruit diameter and peel thickness of each fruit for both cultivars were measured separately with a vernier-type calliper (General Tools & Instruments Co., LLC, New York, NY, USA).

2.2.1.1. Total Soluble Solids, Titratable Acidity, Ripening Index, and Juice pH

Once the physical attributes were assessed, fruits were cut in half and carefully hand-squeezed in a commercial juicer. The fresh juice was centrifuged at 13,000× *g* for 20 min (model 3-18K; Sigma, Darmstadt, Germany).

The content of total soluble solids (TSS) was determined through a handheld refractometer (model MASTER-53S; Atago Co. Ltd., Tokyo, Japan) and expressed as °Brix. Titratable acidity (TA) was determined by titrating 10 mL juice to the end point of pH 8.1 with 0.1 N NaOH and expressed as a percentage of citric acid. Once the TSS and TA contents had been assessed, the ripening index was calculated as the TSS/TA ratio. The pH of juice samples was measured by using a digital pH meter (model InoLab 720; WTW GmbH, Weilheim, Germany). All analyses were carried out at constant room temperature (22 ± 2 °C).

2.2.2. Total Sugars

To quantify sugar content, a fresh juice sample (10 mL) was taken in a 250 mL volumetric flask, followed by the addition of distilled water (100 mL), 25% lead acetate solution (25 mL), and 20% potassium oxalate solution (10 mL). Then, the final volume was achieved by adding distilled water. The mixture was homogenized and filtered by using Whatman No. 2 filter paper. Afterwards, by using the titration-based Fehling's solution method, total sugar contents were determined as described in previous research [33]. The contents of total sugars were expressed as a percentage.

2.2.2.1. Vitamin C Content

The content of vitamin C (ascorbic acid) in the juice was determined following the method described earlier by Ruck [34]. Briefly, 10 mL of each sample juice and 90 mL of oxalic acid solution (0.4%) were homogenized and filtered with Whatman No. 2 filter paper. A 5 mL aliquot was titrated to the newly prepared 2,6-dichlorophenolindophenol dye to a light pink endpoint. By using the given below formula, vitamin C contents were calculated and expressed as mg 100 mL^{-1} juice.

$$\text{Vitamin C content} = (1 \times R1 \times V \times 100)/(R \times W \times V1) \quad (1)$$

where R1 = mL of dye used to titrate against aliquot V1 (sample reading); V = volume of the aliquot made by 0.4% oxalic acid; R = mL of dye used to titrate against 1.0 mL of reference solution (standard reading); W = mL of juice used; and V1 = mL of aliquot used for titration.

2.2.3. Determination of Antioxidant Profile

The total antioxidant activity and capacity were determined following the modified method outlined by Özgen et al. [35]. For that, a 20 mL juice sample and 50 mL methanol were homogenized and subjected to gentle shaking for 2 h. Afterwards, on a rotary evaporator, the methanol extracts were concentrated and adjusted to a volume of 10 mL with methanol.

Antioxidant activity was measured in terms of 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity. Briefly, 1 mL of the above-prepared methanolic extract was homogenized in 1 mL of DPPH solution (0.2 mM) and vortexed. After 4 min of initial mixing, samples were subjected to dark incubation at room temperature for 30 min. Absorbance was measured at 571 nm using a UV-VIS spectrophotometer (UV-3000, ORI, Brandenburg, Germany). Trolox equivalent antioxidant capacity was determined by plotting a Trolox standard graph against various concentrations (5–30 μM). The Trolox standard series was used to compare sample absorbance readings of juice samples taken for DPPH radical scavenging activity. The results for antioxidant activity and capacity are expressed as a percentage and mM Trolox equivalent 100 mL^{-1} juice, respectively.

2.2.4. Total Phenolic Contents

Total phenolic content (TPC) was quantified using Folin-Ciocalteu (FC) reagent. Briefly, for each sample, 0.2 mL of centrifuged juice samples (10,000 rpm for 15 min at 4 °C) was homogenized in 0.8 mL of 7.5% Na_2CO_3 and 1 mL of 5-fold diluted FC reagent. The sample was incubated at 50 °C for 10 min with intermittent agitation. Afterwards, the sample was cooled, and absorption was measured at 760 nm using a UV-VIS spectrophotometer (UV-3000, ORI, Brandenburg, Germany) against a blank without juice sample. The results are expressed as micrograms of gallic acid 100 mL^{-1} juice equivalents.

2.3. Statistical Analysis

The collected data were analyzed through Statistix 8.1 (Tallahassee, FL, USA) under a two-way (harvest time and cultivar) analysis of variance (ANOVA). However, two years of data were pooled before analysis and hence not discussed in the following sections. Mean values were evaluated through the least significant difference (LSD) test and differences were considered significant when $p < 0.05$. The figures were generated using Sigma Plot 10.0 (SPSS, Chicago, IL, USA). Furthermore, principal component analysis (PCA) was performed using the JMP version 16.0 (SAS Institute Inc., Cary, NC, USA).

3. Results

3.1. Variation in Physical Attributes of Mandarin Fruits at Different Harvesting Dates

In the current study, changes in physical attributes (fruit weight, fruit diameter, fruit circumference, peel thickness, and contents of peel, rag, seed, and juice) were investigated at different harvest times (Figures 2 and 3). Kinnow showed more fruit weight, diameter, and circumference than Feutrell's Early, regardless of harvest time (Figure 2A–C). Moreover, Kinnow fruits gained significantly higher fruit weight, fruit diameter, and circumference during February, while lower in September. On the other hand, Feutrell's Early gained significantly greater fruit weight, fruit diameter, and circumference in December, while significantly lower in September (Figure 2A–C). There was no significant difference in the peel thickness of both cultivars (Figure 2D). From September to November, peel thickness was slightly increased, and then a decreasing trend was recorded until February (Figure 2D).

Similar to peel thickness, there was no significant difference in peel content of both cultivars (Figure 3A). From September to November, peel content was slightly increased, and then a decreasing trend was recorded until February (Figure 3A). Greater rag content was measured in Kinnow fruits than in Feutrell's Early, except in February. Irrespective of cultivars, rag content was higher during September, followed by a gradual decrease (Figure 3B). A significant increase was observed in juice and seed content as maturity increased. These quality parameters were found to be greater in Kinnow. Thus, Kinnow showed higher juice and seed contents when harvested in February, while these traits were also the maximum in Feutrell's Early when harvested during December (Figure 3C,D).

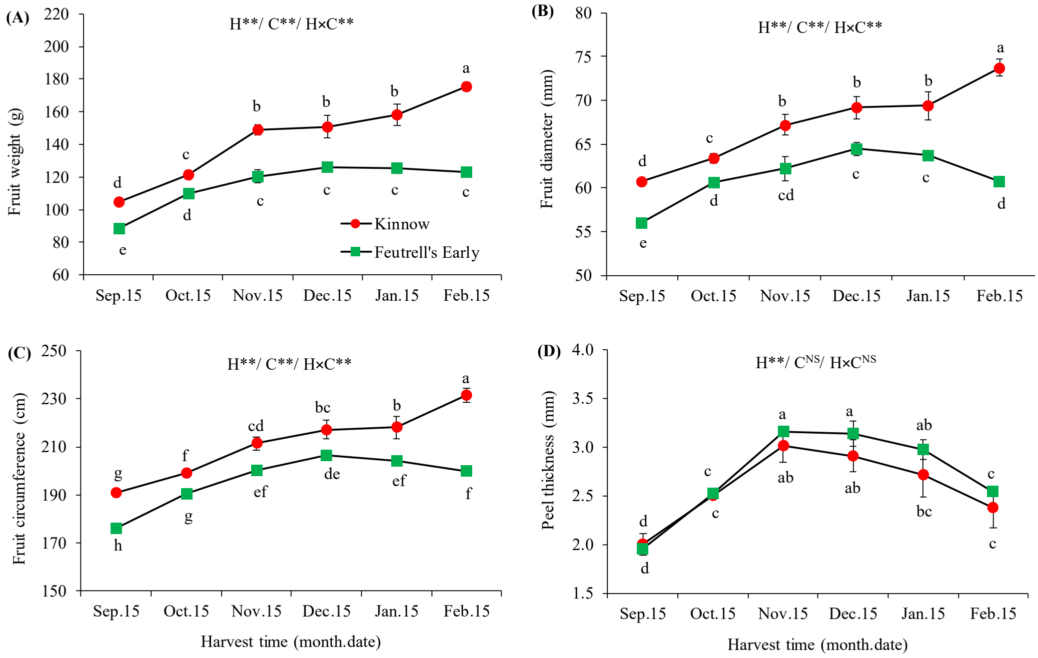

Figure 2. Changes in fruit weight (**A**), fruit diameter (**B**), circumference (**C**), and peel thickness (**D**) of mandarin fruits (Kinnow and Feutrell's Early) at different harvest times. Error bars show standard errors of the means (n = 4). Different lowercase letters in each graph indicate significant differences at $p < 0.05$ between tested samples at different stages by the least significant difference test. H and C stand for harvest time and cultivar, respectively. H × C presents the effect of the interaction of harvest time and cultivar. NS, non-significant; significant at ** $p < 0.01$.

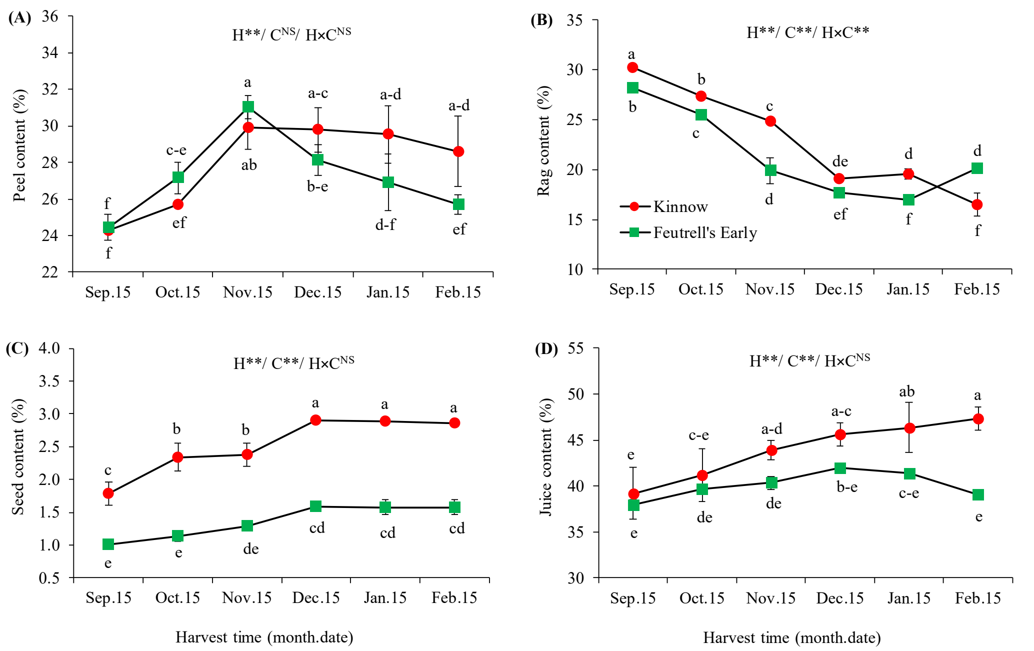

Figure 3. Changes in peel (**A**), rag (**B**), seed (**C**), and juice (**D**) content of mandarin fruits (Kinnow and Feutrell's Early) at different harvest times. Error bars show standard errors of the means (n = 4). Different lowercase letters in each graph indicate significant differences at $p < 0.05$ between tested samples at different stages by the least significant difference test. H and C stand for harvest time and cultivar, respectively. H × C presents the effect of the interaction of harvest time and cultivar. NS, non-significant; significant at ** $p < 0.01$.

3.2. Variations in Biochemical Attributes at Different Harvesting Dates

In the current study, changes in different biochemical attributes (TSS content, TA, and total sugar content), pH, and ripening index were investigated during the different harvest times (Figure 4). Overall, TSS, ripening index, juice pH, and total sugar content had an increasing trend towards maturity, while TA had a decreasing trend towards ripening (Figure 4). Kinnow showed a higher TSS value, which was harvested in February. Feutrell's Early attained the maximum level during December. Both cultivars had a minimum amount of TSS in the month of September (Figure 4A).

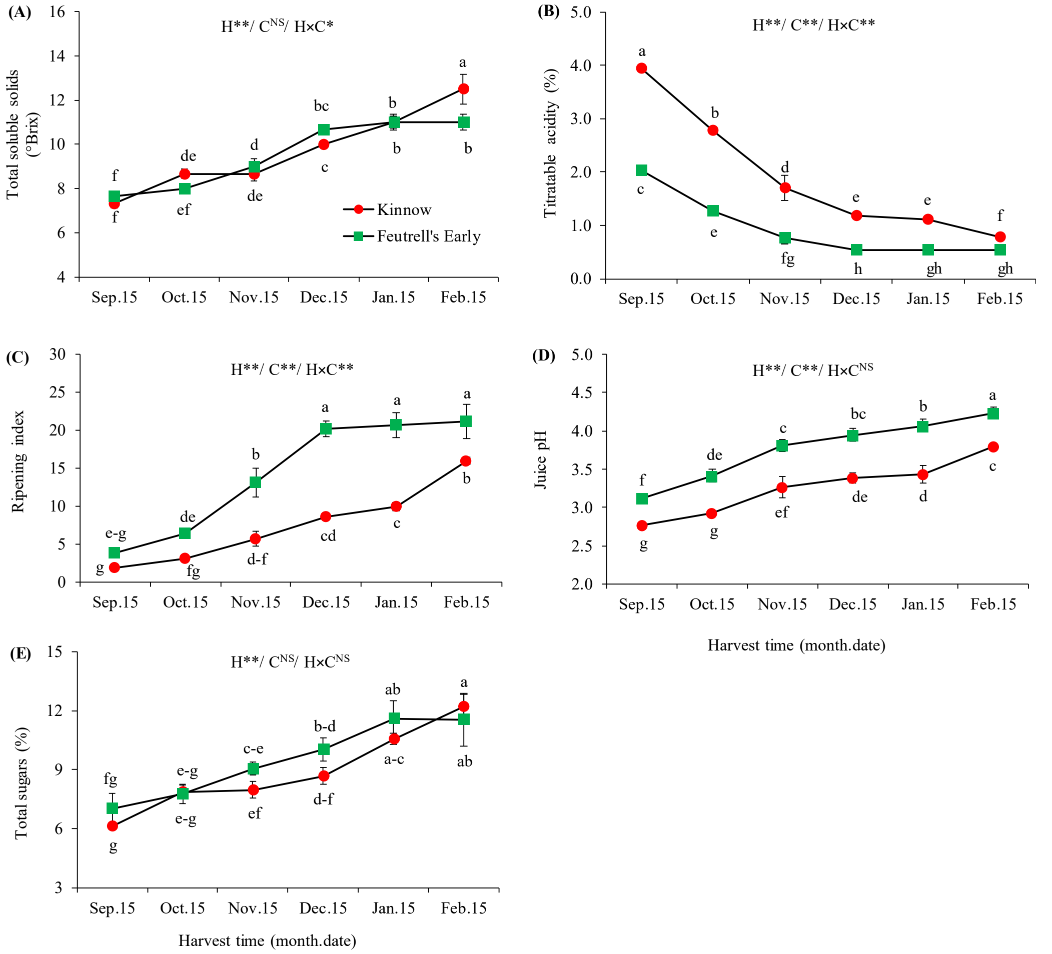

Figure 4. Changes in total soluble solids (**A**), titratable acidity (**B**), ripening index (**C**), juice pH (**D**), and total sugars (**E**) of mandarin fruits (Kinnow and Feutrell's Early) at different harvest times. Error bars show standard errors of the means (n = 4). Different lowercase letters in each graph indicate significant differences at $p < 0.05$ between tested samples at different times by the least significant difference test. H and C stand for harvest times and cultivar, respectively. H × C presents the effect of the interaction of harvest times and cultivar. NS, non-significant; significant at * $p < 0.05$ or ** $p < 0.01$.

The minimum fruit acidity was recorded in Feutrell's Early compared to in Kinnow fruits at different harvest times (Figure 4B). Kinnow showed a minimum TA value in February, whereas Feutrell's Early attained the minimum value during December. Feutrell's Early exhibited a higher ripening index as well as juice pH as compared to Kinnow. Higher ripening index and pH were exhibited during December and January in Feutrell's Early and during February in Kinnow (Figure 4C,D; Table S1). In mandarin cultivars, Feutrell's Early had more amounts of total sugar content as compared to Kinnow fruits. Taking into account the harvest times, Feutrell's Early attained the maximum total sugar content during December, January, and February, while Kinnow attained the maximum total sugar content during February (Figure 4E).

3.3. Variations in Bioactive Compounds at Different Harvesting Dates

In this study, changes in different bioactive compounds (vitamin C and total phenolic content) and antioxidant capacity and antioxidant activity were observed (Figure 5). A prominent difference was observed in vitamin C content at different harvest times for both cultivars (Figure 5A). An overall decreasing trend was observed in our research for both cultivars. Vitamin C content was maximum in September harvested fruits of both cultivars, while the minimum was observed in January. Similar trends were observed in total antioxidant activity, antioxidant capacity, and total phenolic content (Figure 5B–D). Comparatively, Feutrell's Early had greater vitamin C, antioxidant activity, and capacity than Kinnow fruits, while more total phenolic content was observed in Kinnow fruits (Figure 5).

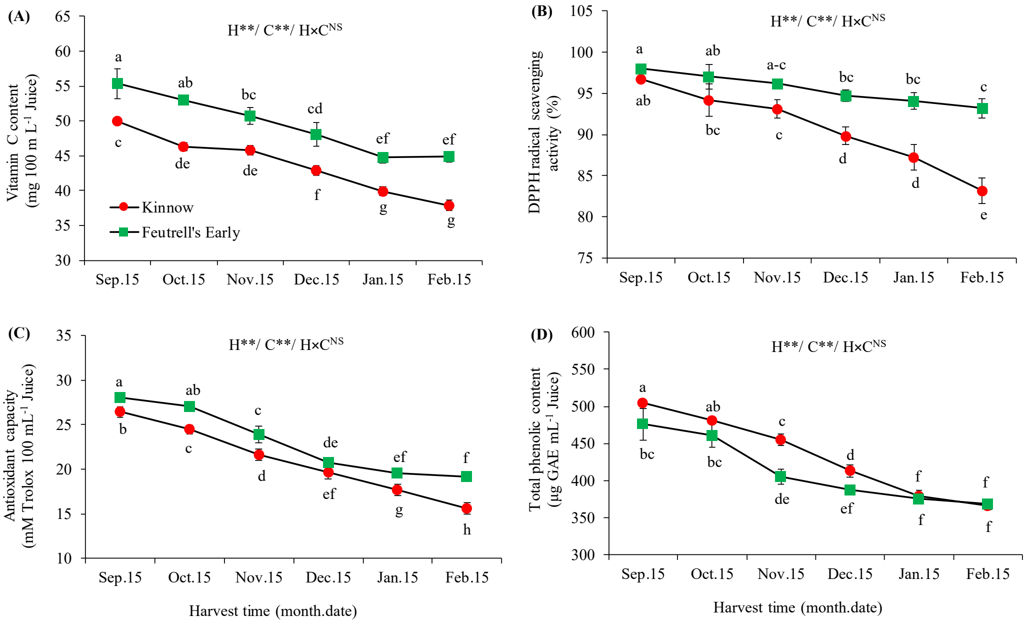

Figure 5. Changes in vitamin C content (**A**), DPPH radical scavenging activity (**B**), antioxidant capacity (**C**), and total phenolic content (**D**) of mandarin fruits (Kinnow and Feutrell's Early) at different harvest times. Error bars show standard errors of the means (n = 4). Different lowercase letters in each graph indicate significant differences at $p < 0.05$ between tested samples at different times by the least significant difference test. H and C stand for harvest time and cultivar, respectively. H × C presents the effect of the interaction of harvest time and cultivar. NS, non-significant; significant at ** $p < 0.01$.

3.4. Principal Component Analysis

PCA is a statistical method that reduces a large number of variables into a smaller number of uncorrelated variables and provides an overview of the complete dataset. The PCA carried out in our work showed more than 70% of the variability in the first two components for both mandarin cultivars (Table 2). For Kinnow, PC1 and PC2 accounted for 68.83% and 10.13% of the variability, respectively, whereas in Feutrell's Early, PC1 and PC2 accounted for 65.42% and 10.33% of the variability, respectively (Table 2).

The results of the PCA are presented as the scores and loading plots (Figure 6), where the contribution of a variable to PC1 and PC2 (Table 3) is indicated by the direction and length of the vector. As shown in Figure 6A, the Kinnow fruits harvested on 15 September and 15 October were grouped very well, while those harvested on 15 December and 15 January were grouped together. The proximity of the early harvesting fruits (September and October) to the loading vectors involving TPC, TA, rag content, vitamin C, and antioxidant activity revealed that the Kinnow fruits harvested at the early ripening stage were characterized by high contents of rag content, TA, and antioxidant compounds. The loading vectors for TSS and juice pH were close to the fruits harvested at the late maturity stage (February), indicating these three were the main chemical components in the late-harvest fruits. From the PCA plot (Figure 6B), Feutrell's Early fruits harvested on 15 September and 15 October were grouped separately, whereas fruits harvested on 15 December, 15 January, and 15 February overlapped each other partially. The proximity of the early-harvested fruits (September) to the loading vectors involving rag content and TA revealed that Feutrell's Early fruits harvested at the early ripening stage were characterized by high contents of rag content and TA, followed by more antioxidant contents in October. The loading vectors for ripening index, TS, TSS, RI, and juice pH were close to the fruits harvested at the late maturity stage (January), indicating these three were the main chemical components in the late-harvest fruits.

Table 2. Eigenvalues and proportion of total variability among fruit quality characters as explained by the first 10 principal components for Kinnow and Feutrell's Early.

	Kinnow			Feutrell's Early		
Number	**Eigenvalue**	**Percent Variability**	**Cumulative**	**Eigenvalue**	**Percent Variability**	**Cumulative**
1	11.702	68.835	68.835	11.1228	65.428	65.428
2	1.7232	10.137	78.972	1.7561	10.33	75.758
3	0.9374	5.514	84.486	1.1022	6.483	82.242
4	0.6415	3.773	88.259	0.7151	4.206	86.448
5	0.4985	2.933	91.192	0.5069	2.982	89.43
6	0.4311	2.536	93.727	0.3977	2.34	91.769
7	0.2981	1.754	95.481	0.3319	1.953	93.722
8	0.2347	1.381	96.862	0.2631	1.548	95.269
9	0.1862	1.095	97.957	0.2227	1.31	96.579
10	0.1077	0.634	98.591	0.1821	1.071	97.651

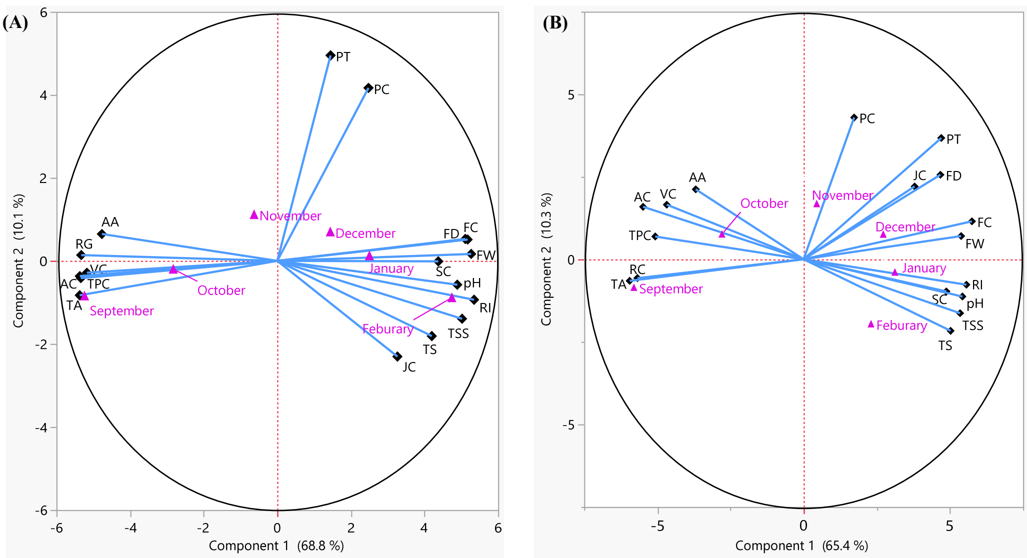

Figure 6. The biplots of the PCA describing the segregation of fruit quality characters of Kinnow (**A**) and Feutrell's Early (**B**) harvested from September to February. Parameter codes: FW—fresh weight, FE—fruit diameter, FC—fruit circumference, PT—peel thickness, SC—seed content, RG—rag content, PC—peel content, JC—juice content, pH—juice pH, TSS—total soluble solids, RA—titratable acidity, RI—ripening index, TS—total sugar content, VC—vitamin C content, AA—antioxidant activity, AC—antioxidant capacity, and TPC—total phenolic content.

Table 3. The correlation between the quality variables and the first 2 principal components: PC1 represents mainly fresh weight, fruit circumference, fruit diameter, ripening index, and total soluble solids in both cultivars; PC2 explains peel thickness in Kinnow and peel content in Feutrell's Early.

Quality Variables	Kinnow		Feutrell's Early	
	PC1	PC1	PC2	PC2
FW	0.92719	0.92719	0.87547	0.11457
FD	0.89935	0.89935	0.76053	0.4167
FC	0.91049	0.91049	0.93586	0.18699
PT	0.25507	0.25507	0.76519	0.59784
SC	0.77023	0.77023	0.79339	−0.15869
RG	−0.93687	−0.93687	−0.92394	−0.09251
PC	0.43634	0.43634	0.28065	0.69848
JC	0.57468	0.57468	0.6174	0.35912
pH	0.86065	0.86065	0.88308	−0.18336
TSS	0.8837	0.8837	0.87001	−0.26575
TA	−0.94433	−0.94433	−0.96712	−0.10611
RI	0.94103	0.94103	0.90487	−0.12532
TS	0.73905	0.73905	0.81721	−0.35272
VC	−0.90967	−0.90967	−0.76098	0.26897
AA	−0.83843	−0.83843	−0.59941	0.3449
AC	−0.93873	−0.93873	−0.89263	0.25852
TPC	−0.94396	−0.94396	−0.82438	0.11242

Parameter codes: FW—fresh weight, FE—fruit diameter, FC—fruit circumference, PT—peel thickness, SC—seed content, RG—rag content, PC—peel content, JC—juice content, pH—juice pH, TSS—total soluble solids, RA—titratable acidity, RI—ripening index, TS—total sugar content, VC—vitamin C content, AA—antioxidant activity, AC—antioxidant capacity, and TPC—total phenolic content.

4. Discussion

Maturity at harvest is the most important factor that determines final fruit quality as well as storage life. Fruit size, quality, and appearance are the most valuable attributes in fruit crops. The present findings revealed that fruits of Kinnow and Feutrell's Early gained the maximum fruit weight, diameter, and circumference during February and December months, respectively. The findings of Iqbal et al. [36] are similar to our data regarding fruit weight and circumference. In addition, similar results were noted by Rokaya et al. [37], since fruit weight, diameter, and circumference were increased from September to February towards the advancement of proper fruit harvesting time, fruit weight increased significantly, and consequently fruit diameter and circumference also increased. According to Nawaz et al. [38] in the Kinnow fruits, the diameter, circumference, weight, and peel thickness had an increasing trend towards maturity. An increase in fruit weight is mainly attributed to the production of juice within the juice sacs, and the circumference of fruits may possibly be increased due to cell division as well as the accumulation of dry matter [37].

In our study, it was found that peel thickness and peel content were gradually improved from the month of September to November, and after that a decreased level was measured until February. The present findings are in line with earlier works [37,39] because peel content and thickness were lower at the initial stages of maturity and then increased with the enhancement of maturity and dropped proximately after a peak point of growth. In our results, maximum rag contents were measured during the month of September with a slight decline with fruit maturity until January as well as February. Similarly, Rokaya et al. [37] also examined a slight reduction in rag content with the improvement of maturity stages because of replacement with juice content. The reduction in juice content indicates the poor quality of fruits. Our study showed an increasing trend of average juice content towards maturity, especially for Kinnow mandarin, but a dramatic decrease during February for Feutrell's Early fruits. This finding indicates that Feutrell's Early fruits should not remain beyond mid-January upon the tree, since the juice content is decreasing. These findings of our research are in some agreement with Grewal et al. [40], Khan et al. [41], and Rokaya et al. [37].

The improved level of different sugars, TSS, and reduction in organic acids in fruit juices are critical components in the ripening and development of flavor [42]. Overall, according to the current study, TSS, ripening index, pH, and total sugar content had an increasing trend towards maturity, while TA had a decreasing trend towards ripeness. Normally, TSS levels increase as citrus matures. However, it can be reduced due to the over-maturity of fruits. Rokaya et al. [37] also observed a greater increase in the TSS of Feutrell's Early and Kinnow fruits. The findings of the present research also agree with the observations for TSS, TA, and sugar content of Gannan navel orange, indicating that TSS and sugar content gradually increases, while acidity decreases with the advancement of fruit maturity [18]. The ripening index is an important parameter for determining the maturity of fruit crops and to prevent quality loss [31,36,43]. It is generally observed that the value of the ripening index increases as the fruit matures and ripens, which can be attributed to the decrease in TA levels and increase in TSS levels. Riaz et al. [44] also reported a similar trend, suggesting that as the maturity stages advance, the ripening index increases. In the present study, an increase in the ripening index was observed in both cultivars. However, it is noteworthy that Feutrell's Early showed the highest ripening index values from November onwards, which could be attributed to the rapid decline in TA levels.

Citrus fruits possess numerous changes in biochemical properties during fruit growth as well as maturation [45]. In our findings, mandarin fruits indicated a greater juice pH with the improvement of maturity stages in the September to February months, while reducing the level of organic acids during fruit ripening. These results are closely related to the findings of Ahmed et al. [24] for different grapefruit cultivars. These changes were possibly linked to the degradation of acidic compounds in the respiration mechanism and biosynthesis of reducing sugars. Sugar content is an important component of mandarin fruits that correlates with sweetness and is a basic fruit ingredient [18,44–46]. In our findings, the maximum amount of total sugar content was measured in December and February, in Feutrell's Early and Kinnow, respectively. In our study, the overall increasing trend was followed by the advancement of maturity stages, which is in close confirmation with the results of Ahmed et al. [24].

The presence of antioxidant activity, as well as capacity in fruits, is mainly linked with vitamin C and phenolic content, as reported by Tsai et al. [47] and Sun et al. [16]. Generally, unripe fruits indicated a higher level of antioxidants than ripe fruits [23,48], therefore, the current findings are in line with previous work because vitamin C, phenolics, and antioxidant activity and capacity are reduced with the development of fruit maturity [16,18,44].

Based on the present study results, Feutrell's Early should not remain upon the tree beyond mid-January, since there is no increase in fruit weight, fruit size (circumference), juice content, TSS, and ripening index, whereas TA, vitamin C, and total phenolic and antioxidant capacity drops dramatically. In addition, delayed harvesting of Feutrell's Early, until mid-February, could prolong the movement of carbohydrates to the fruits (sink organs), a factor that favors the occurrence of alternate bearing. Previously, Albrigo [49] determined the negative impact of the late harvest of sweet orange (*C. sinensis*) cultivars Hamlin and Valencia on fruit drop, fruit quality, and return yield in the following year. However, the impact of late harvesting on the following year(s) fruit yield and quality of mandarins is not clear, which needs further study in the future.

5. Conclusions

The present research has demonstrated that harvest time significantly influences the physicochemical parameters and quality attributes of mandarin cultivars. Thus, it is important to harvest the fruits at their proper maturity stage, as under- and over-mature fruits may not contain the proper amount of nutrients in terms of quality and are often not acceptable to consumers. For better-quality mandarin fruits, particularly in sub-tropical climatic conditions, Feutrell's Early should be harvested from mid-December to mid-January, while Kinnow should be harvested from mid-January to February. This study also suggests that the fruits should be marketed with differentiation, and further consumer taste panels should be conducted to determine consumer preferences for potential commercial cultivars at different harvesting times.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy13030802/s1, Table S1: Changes in TSS/TA ratio of mandarin fruits (Kinnow and Feutrell's Early) at different harvesting dates during 2018–2019 and 2019–2020. Different lower-case letters indicate significant differences ($p < 0.05$) among or between tested samples at different stages, as determined by the least significant difference test. Different upper-case letters indicate significant differences ($p < 0.05$) among or between the mean values.

Author Contributions: Conceptualization, M.A.A.; methodology, M.M.; software, M.M and S.B.H.; formal analysis, M.M., M.N. and R.A.; investigation, M.M. and R.A.; resources, M.A.A. and M.N.; writing—original draft preparation, M.M.; writing—review and editing, S.B.H., V.Z. and M.A.A.; supervision, M.A.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors are highly grateful to the Department of Horticulture, Bahauddin Zakariya University, Multan, for support in conducting the present research work.

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

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