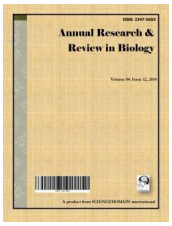

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Fruit Quality Analysis in Four New Mandarin Hybrids during Maturation Period

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Producing fruits with a desirable degree of maturity and specific organoleptic characteristics has become a necessity in the citrus industry to meet consumer needs. Breeding approaches, with a particular focus on organoleptic quality, may provide the sector with performant varieties and therefore meet its expectations. In this study, four citrus cultivars obtained by hybridization and grafted onto different rootstocks were evaluated for fruit pomological and organoleptic traits, including juice content, organic acids, soluble solids content (SSC). The results obtained for these attributes at different stages of maturity highlighted increasing trends of soluble solids content and maturity index and a decreasing trend of acidity during fruit maturation. In addition, all studied hybrids reached the minimum maturity index (SSC/Acidity = 7.0) by early December. The H8 cultivar was particularly characterized as a late-maturing cultivar since its fruits matured much later than Afourer control. The variation of maturity parameters, which was maintained throughout the harvest period, was influenced by variety and harvest time, while the rootstock factor had little effect.

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Keywords: Citrus fruits; hybridization; pomology; organic acid; soluble solids content; maturity index.

1. INTRODUCTION

Citrus plays an important socioeconomic role in Morocco and is one of the most important branches of national economy [1]. Nowadays, citrus producers must take into account consumer and world market requirements which are more and more demanding in terms of quality [2]. These specifications are based on external and internal fruit quality from harvest until the fruit reaches the consumer. The meaning and perception of quality are relative [3]. Indeed, the quality of a fruit is a complex combination of size, color, firmness, taste, texture, pleasant aromas resulting from a balanced chemical composition (content of soluble extract, sugars, organic acids, aromas.), and nutritional qualities [4].

Maturation corresponds to a series of physiological and biochemical events [5] and is considered as a very important stage of fruit development since it is characterized by reserve accumulation in the fruit, a loss of firmness, a decrease in acidity, an increase in sugar content, the development of aromas, ethylene and the appearance of color [4]. Naturally, soluble solids content (sugar) and acidity are inseparable indicators for the evaluation of fruit maturity [6]. In citrus, the determination of juice content in soluble solids is also a common fruit characterization method [7,8]. In addition, commercial standards usually include the notion of soluble solids content / Acidity ratio (E/A) [9] which remains one of the main parameters in the determination of fruit flavor and texture.

In this context, the National Institute for Agricultural Research in Kenitra (INRA) has developed a breeding program for the improvement of organoleptic quality of mandarin fruits. The objective of this study, which makes part of this program, is to evaluate the variability of organoleptic traits in fruits of some new Afourer mandarin hybrids during maturation. It aims particularly to highlight the qualitative and quantitative importance of sugar and acid contents and the relationship between these two criteria.

2. MATERIALS AND METHODS

The study was conducted at the experimental field of the National Institute for Agricultural Research (INRA) in Kenitra, Morocco. The climate of the region is Mediterranean and the soil is sandy on the surface and sandy clay at depth.

2.1 Plant Material

Fruits (Fig. 1) were randomly harvested from four mandarin hybrids grafted on three rootstocks, *i.e*. sour orange (*citrus aurantium*), Troyer citrange (*Citrus sinensis* 'Washington' x *Poncirus trifoliata*) and Volkamer lemon (*Citrus volkameriana*). Other fruits were collected from Afourer mandarin trees grafted on the same rootstocks to be used as control. The harvest was carried out periodically by hand from December to February. In each time, samples of 5 fruits were collected (sampled) and carried immediately to the laboratory to evaluate changes in fruit quality during maturation.

2.2 Methods

2.2.1 Juice content

Fruits were weighed, cut in half and pressed in an electric rotary juicer to extract all their juice. After filtration with a plastic filter, the juice was weighed and juice content was estimated relative to weight using the following formula [10]:

Juice content = (Juice weight / Total fruit weight) x 100

Fig. 1. Fruits of the four mandarin hybrids studied

2.2.2 Soluble solids content

Juice SSC was determined using a laboratory refractometer which reports the amount of sugar in °Brix.

2.2.3 Acidity

After juice extraction, 10 ml of each sample were placed in a beaker. Acidity was determined by titration with 0.1 N NaOH [11].

2.2.4 Sugar/acid ratio

The E/A ratio is a maturity index, which is calculated based on Extract soluble (E) and acidity (A) [10].

E / A = Extract soluble / Acidity

3. RESULTS

3.1 Variance analysis

ANOVA results showed significant effects of harvest date, variety and the interaction between these two factors on all studied parameters, whereas the rootstock factor affected only acidity and E/A ratio (Table 1).

3.2 Evolution of Fruit Quality Parameters during Maturation Period: Differences among Scion Cultivars

3.2.1 Juice content

On the first harvest date, juice content was higher than 40% as well in Afourer as in the four hybrids studied (Fig. 2). The fruits of H13 had the highest juice content (48.27%) and Afourer fruits had the lowest juice content (40.5%), but these were not significantly different from those of the other hybrid cultivars. We should note that all hybrids showed acceptable and almost constant values throughout the experimental period (until February).

3.2.2 Acidity

Juice acidity varied between 0.5 and 1.2% depending on cultivar and harvest date. Among hybrids, the H8 cultivar had significantly higher concentrations of citric acid in December (1.2%) which was maintained until January. By contrast, the lowest average (0.5%) was recorded in Afourer mandarin in February (Fig. 3). The decrease in acidity over time is due to fruit maturation. ANOVA results showed highly significant effects ($P < 0.01$) of harvest date, variety and the interaction between these two factors on juice acidity (Table 1).

Table 1. Effects of harvest date, variety, rootstock and their interactions on fruit quality of the citrus cultivars studied resulting from ANOVA analysis.

Dependent variable	Factor*	DDL	CM	F	Signification
Soluble Solids Content	D	6	11,9897619	62,23	< 0,0001
	V	4	2,06800000	10,73	< 0,0001
	R	2	0,60295238	1,81	0,1693
	D x V	24	0,58743056	3,05	0,0002
	D x R	12	0,25528571	0,77	0,6807
	R x V	8	0,48200000	1,76	0,0960
	D	6	0,29828449	42,17	< 0,0001
Acidity	V	4	0,35874682	50,72	< 0,0001
	R	2	0,06893489	5,02	0,0087
	D x V	24	0,01464745	2,07	0,0100
	D x R	12	0,00872317	0,64	0,8059
	Rx V	8	0,0180560	2,01	0,0540
	D	6	159,253026	106,94	< 0,0001
	V	4	38,0227538	25,53	< 0,0001
	R	2	11,5778552	5,08	0,0083
E/A	D x V	24	3,5162619	2,36	0,0029
	D x R	12	1,5679313	0,69	0,7580
	R x V	8	2,5066267	1,02	0,4280

***** *D= Harvest date; V=Variety; R= Rootstocks.*

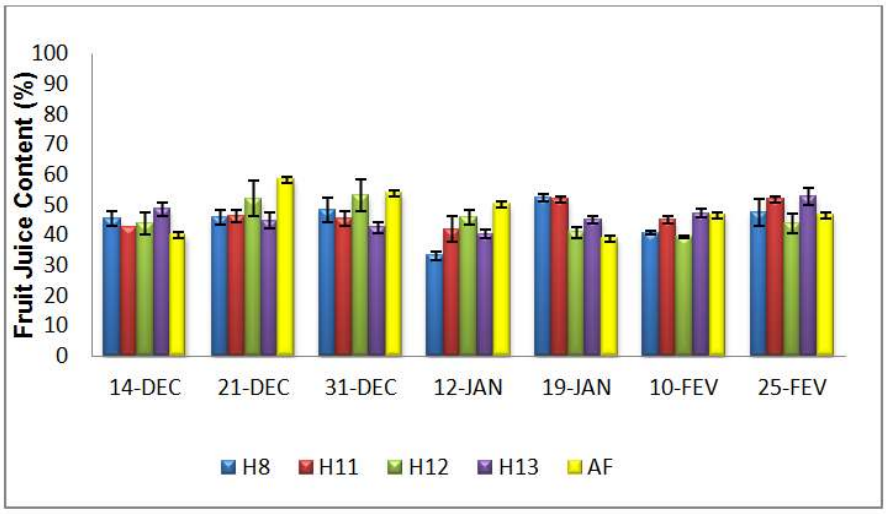

Fig. 2. Variations in juice content of fruits of Afourer mandarin and four hybrid cultivars during maturation period.

** Displayed values are means of 3 replications (rootstocks).*
*** Vertical bars indicate standard error of the mean.*

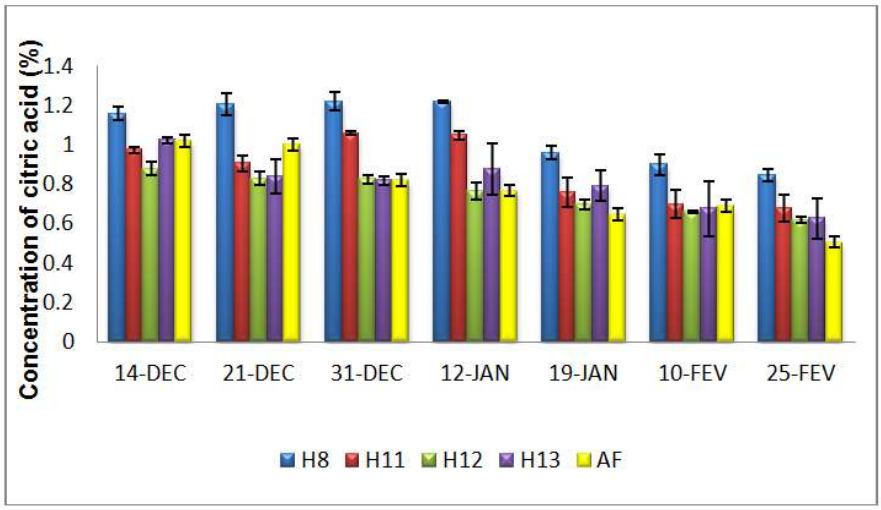

Fig. 3. Variations in titratable acidity (TA) of fruits of Afourer mandarin and four hybrid cultivars during maturation period.

** Displayed values are means of 3 replications (rootstocks).*
*** Vertical bars indicate standard error of the mean.*

3.2.3 Soluble solids content

SSC increased progressively over time depending on fruit maturity level. The effects of variety, harvest date and their interaction were highly significant ($P < 0.001$). The analysis of sugar content showed an increasing trend from the beginning of maturation to the last harvest date in all hybrids. The lowest value (7.7 °Brix) was observed in the H8 cultivar on December 14th, whereas the highest (12.5 °Brix) was observed on February 25th in the same cultivar (Fig. 4).

3.2.4 Maturity index E/A

Similarly to the other quality parameters, maturity index was significantly affected by harvest date, variety and their interaction ($P < 0.01$). On the first harvest date, the E/A maturity index was 7.5

in H8, 9.1 in H11, 8.9 in H12, 8.4 in H13 and 7.8 in Afourer. There was an increase in E/A values over time in all hybrids that was more pronounced in the H8 cultivar (Fig. 5).

3.2 Evolution of Fruit Quality Parameters during Maturation Period: Effect of Rootstock

When plotting the average values of fruit quality parameters (juice sugar content, acidity and maturity index) with respect to the rootstock varieties used, there were no significant differences, except in the H13 cultivar, whose behavior seems to be rootstock-dependant at a certain level. Fig. 6, for example, shows little variation of soluble solids content in response to rootstock. However, a slight increase was noticed when grafting H13 trees on sour orange. The average value for this association was 10 °Brix.

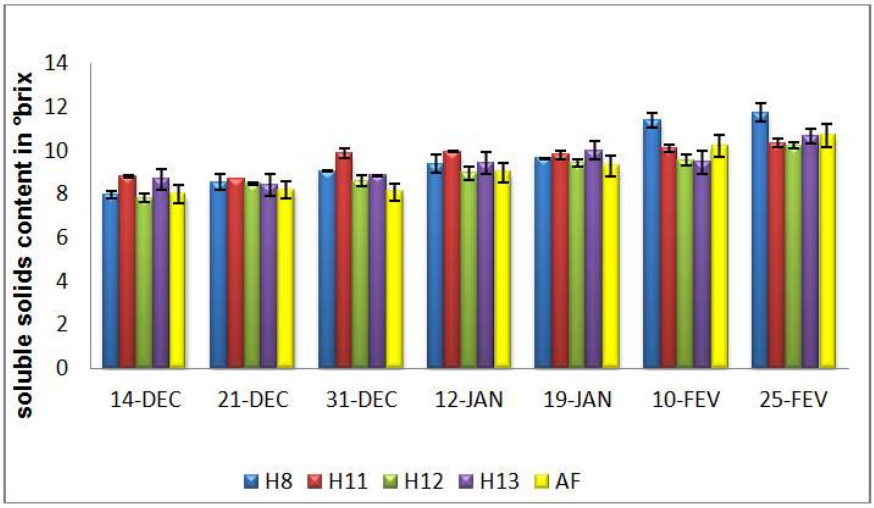

Fig. 4. Variations in soluble solids content (SSC) of fruits of Afourer mandarin and four hybrid cultivars during maturation period

** Displayed values are means of 3 replications (rootstocks).*
*** Vertical bars indicate standard error of the mean.*

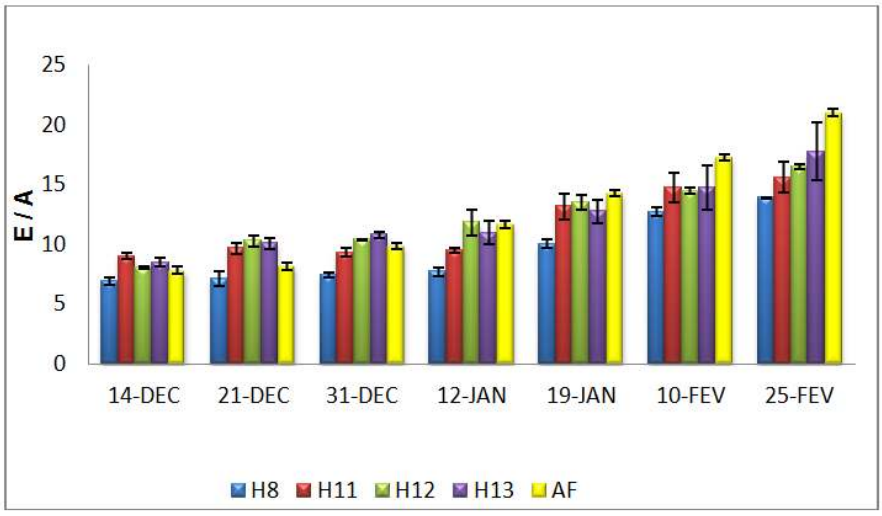

Fig. 5. Variations in fruit maturity index (SSC/TA) of fruits of Afourer mandarin and four hybrid cultivars over time

** Displayed values are means of 3 replications (rootstocks), ** Vertical bars indicate standard error of the mean.*

In terms of juice acidity, the results shown in Fig. 7 support those reported in Table 1, which revealed no effect of the rootstock factor. Despite the non-significant differences observed among rootstocks in this regard, H13 trees tended to have more acidic fruits when associated with sour orange (0.94% citric acid) than when grafted on Troyer citrange or Valkamer lemon rootstocks (0.72 and 0.75% citric acid).

Fig. 8 indicates a slight variation in maturity index E/A of H13 fruits in response to rootstock, but no significant variation in maturity index of H8, H11, H12 and Afourer mandarin. The values recorded when associating H13 trees with sour orange rootstock (average of 10.6) were lower than those obtained with Troyer citrange (12.9) and Volkamer lemon (13.1).

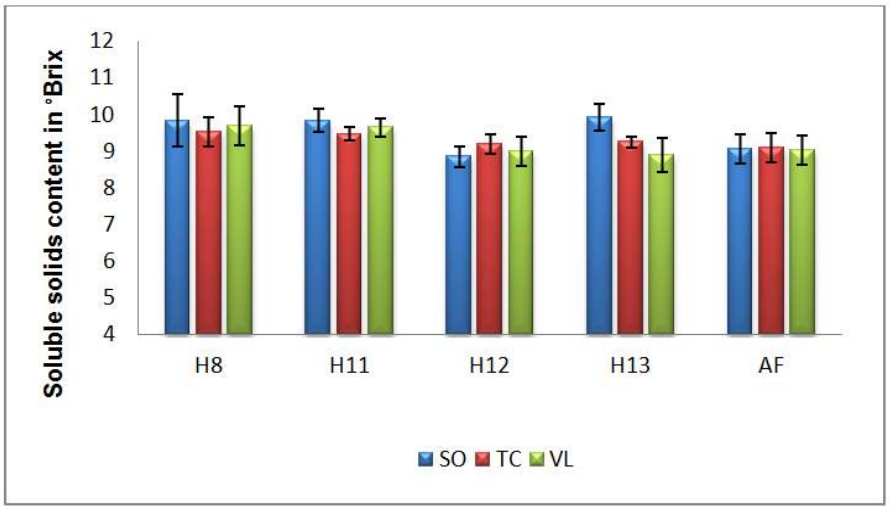

Fig. 6. Influence of rootstock on soluble solids content (SSC) of fruits of Afourer mandarin and four hybrid cultivars

** Displayed values are means of 7 replications (harvest dates).*
*** Vertical bars indicate standard error of the mean.*

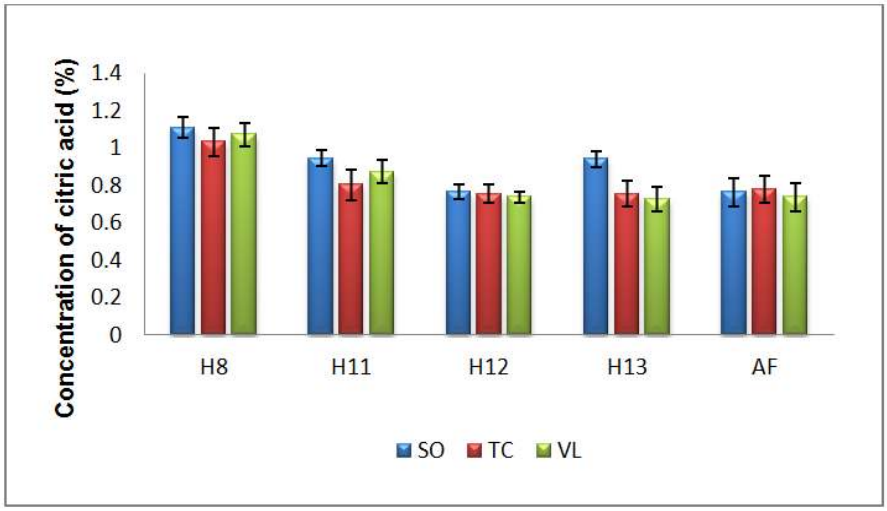

Fig. 7. Influence of rootstock on titratable acidity (TA) of fruits of Afourer mandarin and four hybrid cultivars

** Displayed values are means of 7 replications (harvest dates).*
*** Vertical bars indicate standard error of the mean.*

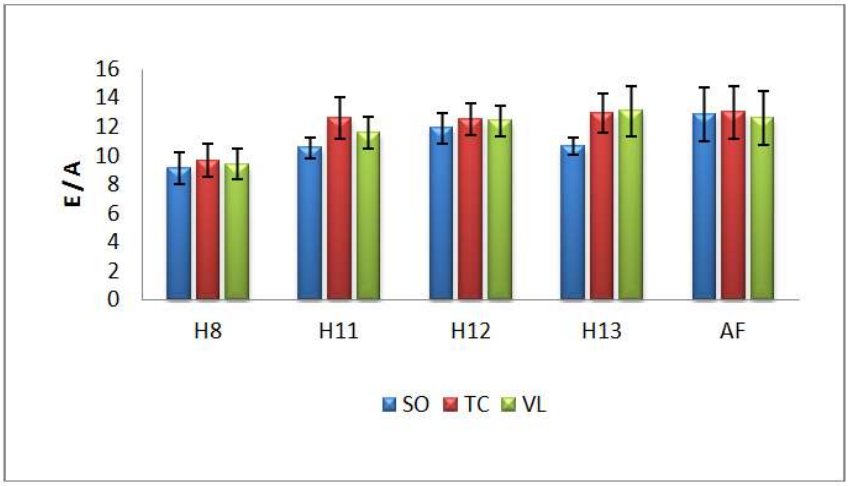

Fig. 8. Influence of rootstock on fruit maturity index E/A of fruits of Afourer mandarin and four hybrid cultivars

** Displayed values are means of 7 replications (harvest dates), ** Vertical bars indicate standard error of the mean.*

4. DISCUSSION

Citrus is one of the most important fruit tree species in the world since its fruits are a valuable source of nutrients, vitamins and other antioxidant compounds [12]. The internal quality is much more important than the external appearance of the fruit. The organoleptic quality is mainly related to sugar and acid contents and to the presence of volatile substances in juice [13]. It is therefore very important to know and characterize the various quality-related changes that occur in fruits of citrus species during maturation process. In particular, we should know when maturity indices are reached along with color changes, sugar accumulation, acid dissipation, firmness loss [11].

Juice content is an essential parameter in determining fruit quality, particularly in citrus [14, 8]. Indeed, the juiciest fruits are the most in demand and the most appreciated by consumers. According to Iqbal et al. [15], Juice content may vary depending on variety, maturity level and climatic conditions. In Morocco, citrus fruits intended for export must have a minimum of 35% to 40% juice content depending on varieties [16]. Remarkably, the results obtained in our study have shown high juice contents (> 40%) in all hybrid cultivars with a slight increase during maturation period. These results are consistent with the findings of El-Otmani and Ait-Oubahou [16], who reported that juice content of fruits increases as they mature to reach maximum values at full maturity and decreases thereafter if fruits remain for a long time on the tree at high temperatures and low air humidity. In the same line, Chahidi et al. [11] and Agustí et al. [17] demonstrated that fruits lose progressively their juice after fruit color-break.

Juice soluble solids content and titratable acidity of citrus are inherently variable. This variability can be large, and is a result of various factors that affect juice quality [18]. Titratable acidity is an important indicator in defining juice quality or determining optimum harvest dates [19,20]. In general, the concentration of organic acids is reported to decrease during fruit maturation [19,21]. This decrease was attributed to the conversion of organic acids into sugars [21]. According to our results, the concentration of titratable acids decreased during maturation period and differed from one hybrid to another. Similarly, Naim [22] reported that late harvested fruits are less acidic than early harvested fruits. Acidity decreased earlier in Afourer control than in the mandarin hybrids. As compared to the other hybrid cultivars, H8 maintained the most acidic fruits throughout the study period. According to Coggins [23], Clementine mandarin fruits that have less than 0.8% acidity are considered of low quality as their sweet taste prevails over the sour taste. Thus, these fruits are somewhat insipid and more prone to postharvest decay organisms as well. Based on the results that we obtained in February, the fruits of the H8 cultivar can be considered of

good quality as these resulted in 0.9% citrate percentage, which was higher than the average recorded in Afourer control (0.5%).

Fruit maturity is related to the timing of rapid physiological changes, mainly the increase in soluble solids content and the decrease in acidity [24]. It is particularly well established that fruit sugar content increases considerably during maturation [4]. In this sense, our findings are in agreement with the works of Deshmukh et al. [21] and Yi et al. [25]. The minimum level (9 °Brix) required for exportable Clementine [26] was rapidly reached in all hybrid cultivars except for H8 (7.7 °Brix) which accumulated sugars at a much slower rate and did not reach that minimum level until December.

The E/A ratio is very sensitive to the aforementioned changes and is often used as a maturity index for citrus fruits intended for fresh consumption. The delay or advance in fruit maturation is of great interest in mandarin industry since it enables to extend the commercialization period [17]. The results of our study were consistent with previous works which have shown a continuous increasing tendency in sugar/acid ratio during fruit ripening [25]. Furthermore, the analysis of E/A values enabled us to project the maturation of each cultivar on a time scale and to establish a cultivar ranking based on the duration of maturation process. For example, it is evident that the H8 hybrid – in which E/A reached 12 in February - has the longest harvest period and a later maturity as compared to Afourer which resulted in a maturity index of 17. H8 was therefore ranked as the latest cultivar, followed by hybrids H11, H12, H13.

Concerning rootstock influence on fruit quality, our results showed no significant effects on sugar content and little effects on acidity and E/A index. Many previous works reported no relationship between rootstock and fruit acidity in citrus [27]. By contrast, other authors showed that citrus rootstocks have many interactive effects not only on tree performance (growth, yield), but also on fruit internal and external characteristics such as juice content, color, soluble and acidic solids concentrations and their ratios [28].

5. CONCLUSION

In conclusion, the analysis of fruit quality parameters and their evolution over time highlighted the variability in maturation period among cultivars and enabled us to distinguish mandarin hybrids of great agronomic interest. The H8 cultivar was particularly characterized as late-maturing cultivar with long harvest period. This was followed respectively by H11, H12 and H13. To improve reliability of fruit quality tests in citrus (particularly improved varieties), cultural practices and environmental factors, such as temperature and solar radiation, should be taken into consideration in future research since they are known to affect the expression of fruit quality characteristics, and may therefore provide better explanations of seasonal organoleptic variations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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