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Impact of ethylene degreening treatment on sensory properties and consumer response to citrus fruits

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Abstract

Degreening treatment is normally applied to early-season citrus varieties grown in the Mediterranean area in order to enhance the external colour when fruits have already reached internal maturity. Despite profound knowledge about the effect of ethylene on the physico-chemical quality of citrus fruit, less is known about its effect on consumers' expectations in the supermarket or consumer quality perceptions when they eat such fruit. In this study, three mandarin cultivars ('Owari', 'Clemenules' and 'Oronules') with two initial colours at harvest, and one orange cultivar, 'Navelina', were submitted to the degreening treatment under commercial conditions. The effect of treatment on both external and internal qualities perceived by consumers was evaluated. The main physico-chemical parameters were also determined. The degreening treatment slightly affected firmness, total soluble solids or acidity level in 'Owari' and 'Navelina'. However, sensory triangle tests, in which 100 to 122 consumers compared the internal quality of degreened fruit and control fruit, did not show significant differences between treatments for any of the studied cultivars. A survey based on images of citrus fruit was responded by 340 consumers; it showed that the degreening treatment strongly affected consumers' maturity expectations, which resulted in improved fruit liking expectations and increased the number of consumers willing to buy. The extent of this effect depended on the initial colour of the fruit submitted to degreening. In order to improve liking expectations, fruit should arrive on the market with an external colour index (CI=1000a/Lb) between +10 and +20. We conclude that the ethylene degreening treatment, which did not have any effect on the internal quality that consumers perceive, is a potent postharvest tool to increase citrus fruit sales at the beginning of the season.

Keywords: mandarin, orange, triangle test, rind colour, quality, purchase intention, expected liking

1. INTRODUCTION

In citrus fruit, skin colour development is promoted by cool overnight temperatures late in autumn. This is due to the low temperatures during fruit ripening being associated with the chlorophyll degradation process, and the synthesis and/or manifestation of carotenoids in peel (Rodrigo & Zacarías, 2007). However, in subtropical and tropical growing regions where temperatures drop later, earlier varieties may reach internal maturity while skin is still green. As skin colour is one of the main quality parameters for citrus appearance, green tones on the skin may negatively affect consumer acceptance (Campbell et al., 2004). In fact, in European Union markets, the proportion of the fruit surface with a minimum colouration is one of the maturity indexes used to define fruit quality (Lado et al., 2018). Thus a common practice to enhance the skin colour development of early citrus cultivars is to apply the ethylene degreening treatment (Machado et al., 2015; Da Costa et al., 2017; Hu et al., 2018). Citrus fruit are classified as non-climateric according to their respiration and ethylene production patterns (Kader, 2002). However, they respond to exogenous ethylene application and an important response is to hasten both chlorophyll degradation (Yin et al., 2016; Li et al., 2019) and carotenoid biosynthesis (Yuan et al., 2017; Sumiasih et al., 2018);

The effectiveness of the degreening treatment depends on factors that are intrinsic to the process, such as ethylene concentration, temperature or relative humidity, and the cultivar and external fruit colour when being treated (Porat, 2008). Recently, Sumiashi et al. (2018) reported that the efficacy of the degreening treatment may be improved by adding a precooling treatment. Exposure of fruit to 1-5 $\mu\text{L L}^{-1}$ of ethylene enhances colour changes during citrus degreening, but does not negatively affect external quality (Cuquerella et al., 2005; Miller et al., 2018). Nevertheless, higher ethylene levels can result in quality loss, mainly associated with skin and calyx disorders (Porat, 2008). The time of ethylene exposure required to reach the desired colour of fruit principally depends on the initial fruit colour (Martínez-Jávega et al., 2008) and the minimum colour for optimal degreening is cultivar-dependent. Thus, for example, early Navel oranges must be a minimum one-third natural colour before being harvested; if less, the final colour is pale and unattractive (Poole & Grey, 2002). It was recently reported that

the degreening process of mandarins happens faster in the stem-end peel than in the equatorial peel (Deng et al., 2019). Moreover, the characteristic colour of a given variety conditions the final colour achieved after degreening. Hence the colour tones naturally reached by mandarins belonging to the satsumas group are paler and more yellowish than those reached by the group of clementines.

Despite profound knowledge about the effect of ethylene on external citrus fruit quality, less is known about its effect on internal quality. As pointed out by Mayouni et al (2011), the common dogma is that ethylene has a minor effect on flesh quality. However, an effect of ethylene on internal processes has been reported by different authors. Thus ethylene and respiration rates (Mayouni et al., 2011), and those of other volatile compounds, have been shown to be modified during degreening of citrus fruit (Sdiri et al., 2017). Similarly, Chaudhary et al. (2017) reported a significant effect of degreening treatment on phytochemicals and flavonoid pathway genes in ‘Rio Red’ grapefruit. Moreover, the acidity level of ‘Mosambi’ oranges decreased after being treated with ethylene (Ladaniya & Singh, 2001). As these studies were only based on instrumental determinations, and no sensory measurements were collected, we are unable to know the effect on the sensory quality of the fruit. Similarly, both acidity and total soluble solids were modified after the degreening of ‘Clemenules’ mandarins (Sdiri et al., 2012). In this case, the hedonic liking response of a semi-trained panel showed similar values for the degreened and control fruit, but similar liking did not necessarily imply lack of differences between treatments on sensory properties. In order to bridge this gap, Mayouni et al. (2011) evaluated the effect of degreening treatment on the main sensory attributes of various citrus species, including ‘Navel’ oranges, ‘Star Ruby’ grapefruit, and ‘Satsuma’ mandarins. These authors concluded that according to a trained panel, ethylene treatment ($4\mu\text{L L}^{-1}$ of ethylene applied for 24 h, 48 h and 72 h) did not affect the flavour of oranges and grapefruit, but marginally impaired the liking of mandarins. They suggested that the effect observed on mandarins could be due, at least partially, to temperature conditions, rather than only to ethylene exposure. Therefore, doubts still arise about the effect of ethylene itself on the sensory quality of mandarins. In some specialized sectors, as organic farming products, degreening treatment is not authorized. Moreover, the non-use of degreening often has the objective of differentiation via superior organoleptic quality, as described for Belmin et al., (2018) for the Protected Geographical Indication “Clémentine de Corse”. Thus, from a commercial point of view, it would be of special interest to know if consumers can

discern differences between ethylene degreened and untreated fruit when they eat citrus fruit (Poole & Grey, 2002).

Thus the objective of this study was to clarify if external ethylene exposure itself has an effect on the sensory quality of citrus fruit detected by consumers. To do so, we selected one orange and three early mandarin cultivars of much commercial importance in Spain. Fruit degreened under commercial conditions and control fruit (both kept in air under the same temperature and RH conditions) were compared by a panel of consumers using the triangle test. We also investigated to what extent skin colour enhancement due to degreening treatment affected consumers' expectations and, therefore, their purchase intent for the fruit.

2. MATERIAL AND METHODS

2.1. Plant material and ethylene degreening

'Navelina' orange (*Citrus sinensis* L. Osbeck), satsuma mandarin cv. Owari (*Citrus unshiu*) and two clementines (*Citrus clementina* Hort. ex Tanaka) cv. Clemenules and cv. Oronules were obtained from a packing house. Fruits were harvested from orchards in Valencia (Spain) when they reached a commercial maturity index (MI=total soluble solids/acidity) (UNECE, 2017). Harvesting took place during four consecutive weeks, starting with the 'Owari' mandarin (23rd October, 2018) and finishing with the 'Navelina' orange (21st November, 2018). After harvest, fruits were sorted by colour in the packing house using a colour electronic calibrator. For the three mandarin cultivars, two different fruit lots were selected according to the initial rind colour sorted by the packing house on each harvest date. The fruit showing the greener colour were denominated Stage 1, while those displaying the darker orange colour were denominated Stage 2. For the 'Navelina' orange, only one initial colour was available at harvest (Figure 1). After being sorted by colour, the fruit from each stage were divided into two homogeneous lots of 100 fruits each. The fruits from one lot were subjected to a standard degreening treatment in the packing house under commercial conditions (2 μ L L⁻¹ of ethylene in a chamber with a continuous flow regulated at 21 °C and 95 % relative humidity (RH) for 2-8 d depending on the initial colour) (Table 1). The fruits from the second lot were transferred to the Postharvest Department of the Valencian Institute for Agricultural Research (IVIA) to act as the control. They were kept under the same temperature and RH conditions with no ethylene exposure. After the

degreening treatment, the fruit underwent air ventilation at ambient temperature for 6 hours, and then was transferred to a cooling chamber at 5 °C for 2 d.

2.2. Physico-chemical analysis

At harvest and after the degreening treatment, the following parameters were evaluated in both the control and degreened fruit: external colour, firmness, total soluble solids (TSS), titratable acidity (TA) and ethanol concentration. The ripening level was expressed according to the maturity index calculated as TSS/TA.

Peel colour was measured by a Minolta colorimeter (model CR- 300; Minolta Co. Ltd., Osaka, Japan) using 30 fruits per treatment and three measurements were taken in the equatorial zone of each fruit. The mean lightness (L), red-green (a), and yellow-blue (b) Hunter parameter values were calculated for each fruit and expressed as a colour index (CI= 1000 a/Lb) (Jiménez-Cuesta et al., 1981). This index is useful especially for citrus fruit and other fruits like persimmons or loquats, in which external colour evolves from green to yellow, and then to orange and orange-red tones. In these cases, the colour index gives negative values when fruit is still green, and positive values when fruit changes to orange tones. Therefore, colour index values that come close to zero correspond to colour breaking. After colour breaking, colour index values increase as fruit evolves from yellow to orange and red tones. Thus the higher the colour index values are, the darker orange fruit colour is.

Firmness measurements were taken by an Instron Universal Testing Machine (model 3343, Instron Ltd., Buckinghamshire, UK) using 20 fruits per treatment. The results were expressed as the percentage of millimetres of fruit deformation that resulted from 10 N pressure, applied by a 3.5 cm plunger on the longitudinal axis at constant speed.

For the total soluble solids contents (TSS) and titratable acidity (TA), four samples of five fruits each per treatment were squeezed in an electric juice extractor with a rotating head (Lomi®, Model 4, Lorenzo Miguel, S.L., Madrid, Spain).

TA was determined by titration with 0.1 N NaOH solution, using phenolphthalein as the indicator, expressed as g of citric acid per 1 L of juice. The TSS in juice was determined by a digital refractometer (Atago PR-1, Atago Co., Ltd., Tokyo, Japan). Data were expressed as %. The ripening level was expressed according to the maturity index calculated as TSS/TA.

Five millilitres of juice were transferred to 10-mL phials with crimp-top caps and TFE/silicone septa seals to be frozen (−20 °C) until the analysis. Ethanol levels were

determined by carrying out a headspace analysis in a gas chromatograph (model 1020, Perkin Elmer Corp., Norwalk, CT, USA), equipped with a flame ionisation detector and a 1/8 in.x 1.2 m Porapak QS 80/100 column. The injector was set at 175°C, the column at 150°C, the detector (FID) at 200 °C and the carrier gas at 12.3 psi. A 1 mL aliquot of the headspace was withdrawn from the phials previously equilibrated for 1 h at 20 °C and 10 min at 30 °C to be injected into the gas chromatograph. Ethanol was identified by comparing the retention times with that of a standard solution and was expressed as mg.L⁻¹.

2.3. Sensory evaluations

2.3.1. Evaluating internal quality

The sensory evaluation of the fruit from the different cultivars was executed on four different days (one session per cultivar). The number of consumers participating in each session ranged from 100 to 122 people (Table 2). The consumers were workers at the the Instituto de Agroquímica y Tecnología de Alimentos (IATA), IVIA and the Universidad Politécnica de Valencia (UPV), who voluntarily agreed to participate in the evaluation sessions, and ranged in age from 20 to 63 years. The male/female ratio (%) was between 45/55 and 36/64 depending on the session.

The triangle discrimination test (Lawless & Heymann, 2010) was used to determine whether there were any detectable differences in the internal quality of the mandarins/oranges submitted to the degreening treatment compared to the control fruit.

Consumers were seated in partitioned booths and were simultaneously presented with three samples, two from the degreened fruit and one control fruit, or *vice versa*. . The fruits were hand peeled, and separated segments were placed in glass cups. In order to compensate for sample variability, each sample was composed of three segments, each from three different fruits. In this way, a minimum of 60 fruits of each lot was evaluated. Samples were randomly presented to avoid any positional bias. The possible combinations of samples from one triad were: AAB, ABA, BAA, BBA, BAB, and ABB. All the samples were coded with a 3-digit random number, and each consumer evaluated two triads from each mandarin cultivar (one from the fruit in Stage 1 and another one from the fruit in Stage 2), with only one triad for the ‘Navelina’ orange. Samples were served at room temperature and consumers were provided with a glass of water for palate cleansing, which they used between samples and between triads. Consumers received the three samples and were informed that two of the samples were

identical and one was different. Then they were asked to taste samples from left to right (by tasting at least two segments of each sample) and to indicate the odd sample.

At the end of the experiment, demographic data, including gender, age and frequency of mandarin/orange consumption during the season, were also collected. The response options for fruit consumption were as follows: “twice a week or more”, “once a week” or “2 or 3 times a month”.

2.3.2. Evaluating external appearance

The pictures of mandarins ‘Clemenules’ and ‘Oronules’ were selected in order to evaluate the change in the consumers’ expected liking and purchase intentions with the change in the colour index, as result of the degreening process. Consumers who consume citrus fruit at least 2 to 3 times per month per season, evaluated the images of the control fruit and their corresponding degreened mandarins. It was necessary to bear in mind that the extent of the effect of the degreening treatment on consumer expectations probably depended on the initial fruit colour. This was why mandarins ‘Clemenules’ and ‘Oronules’ were selected because if the control fruits of these two cultivars were combined, it would cover a wide range of initial colours, ranging from dark green (Stage 1 of Clemenules, CI= - 11.7) to an intense orange with slight remains of green tones (Stage 2 of Oronules, CI=+ 17) (Figure 2). Thus eight images in total were evaluated, the control fruit of ‘Clemenules’ and ‘Oronules’ in Stages 1 and 2, and the corresponding degreened fruit. In each picture the fruits were placed in plastic baskets, as they would habitually be sold on the market. The evaluation of the images was made by online surveys. The image of one sample was presented (without any information about the variety) and the consumer was asked to observe it and to first indicate if he/she would buy it on a 5-point scale of purchase intentions: ‘definitely would not buy’, ‘probably would not buy’, ‘might buy or might not buy’, ‘probably would buy’ and ‘definitely would buy’. Secondly, they were asked to indicate how much they expected they would like the sample on a 9-point hedonic scale, ranging from ‘I would extremely dislike these mandarins’ to ‘I would extremely like these mandarins’. Finally, they were asked to indicate their view of the degree of maturity of fruit on a 5-point JAR (just about right) scale (‘too overripe’, ‘slightly overripe’, ‘optimum maturity’, ‘slightly too immature’, ‘too immature’). Different forms were generated to present images randomly and to avoid any positional bias.

At the end of the questionnaire, participants were asked about their gender, age and the frequency of mandarin consumption during the season. None of the consumers who participated in this part of the study had previously participated in the triangle test. To investigate if consumers' expectations based on fruit external colour depended on the relation or familiarity with the citrus crop, the questionnaire was completed by consumers of mandarins (at least 2 or 3 times a month) from two regions of Spain: 179 consumers were from the Valencian Community (one of the main citrus fruit-producing areas in Spain) and 161 consumers were from Galicia (a region in north Spain where citrus fruit are not produced at all). The (%) male/female ratio ranged from 40/60 to 42/58.

2.4. Statistical Analysis

ANOVA was applied to the physico-chemical data to compare the control and degreened fruit. A multiple comparison between means was run by the LSD test ($P=0.05$) and the Statgraphics Plus 5.1 software application (Manugistics, Inc., Rockville, MD, USA).

To determine if significant differences were perceived between the control and degreened samples, the number of correct answers in each triangle test was calculated and the significance of differences according to binomial distribution was established with the XL-stat programme (the 2019 version).

To determine if there were differences in the responses of the consumers from the two geographical regions, the proportions of consumers that would buy and would not buy each sample were compared between the regions using the z-test of proportions. Similarly the percentages of consumers who considered the sample was too immature and too ripe were also compared between both regions. The expected liking values were analysed by a 3-factor ANOVA (region, sample and treatment). A penalty analysis was applied to estimate the decrease in consumers' expected likings when they considered that the degree of maturity of fruit was not ideal (the JAR level) (Lawless & Heymann, 2010; Symmank et al., 2018).

3. RESULTS AND DISCUSSION

3.1. Effect of ethylene degreening on physico-chemical parameters is cultivar-dependent

Regarding to the fruit external colour, the degreening treatment is normally applied to two types of fruit: 1) fruits that have just reached internal maturity, but externally show mainly green tones; these fruits obtain negative CI values; 2) fruits in which rind colour has already changed to orange tones, but these tones are too pale or some skin areas are still green; these fruits generally obtain positive CI values. This study covered all these possibilities. The skin of the fruit in Stage 1 of mandarins ‘Owari’ and ‘Clemenules’ was completely green (CI= -11.9 and -16, respectively). The skin of the fruit in Stage 2 displayed green-yellowish tones (CI= -3.5 and -5.3). ‘Oronules’ were harvested when fruit showed intense orange tones, but some wide (Stage 1, CI= -0.8) or really small areas (Stage 2, CI= +16) were still green. Finally, ‘Navelina’ oranges were harvested with quite a homogenous pale orange tone (CI=+10) (Figure 1, Table 1). Thus according to the commercial procedure in the packing house, treatment duration ranged from 2 to 8 d depending on the initial colour at harvest (Table 1). Ethylene treatment enhanced the colour of all the studied cultivars, and the colour finally reached depended not only on the initial colour, but also on the characteristic colour that naturally develops in each variety (Figure 2 and 3). So the characteristic colour of satsuma mandarins is more yellow (Figure 2) than that of clementine mandarins, which naturally display more intense orange tones (Figure 2). In the clementines group, ‘Oronules’ stand out for their redder tones compared to other varieties (Figure 2). With the ‘Navelina’ oranges, degreening treatment enhanced the colour from pale orange tones at harvest to intense orange tones (Figure 2 and 3). Orange colour development of the citrus peel as result of the degreening treatment has been associated with the accumulation of carotenoid pigments, such as zeaxanthin and mainly β -cryptoxanthin and β -citraurin (Hu et al., 2018; Sumiashi et al., 2018). It is noteworthy that temperature itself had an effect on the rind colour of the studied three mandarins as the control fruit showed enhanced colour compared to the fruit at harvest (Figure 3). Indeed this effect was not detected in the ‘Navelina’ oranges. According to this, Sdiri et al. (2012) have described that when ‘Navelina’ oranges are harvested still green, temperature itself strongly affects external colour. However, when fruits are harvested with pale orange tones, the temperature effect on skin colour is almost undetectable.

In addition to external colour, a group of physico-chemical parameters associated with internal maturity was determined at harvest and also after degreening treatment: firmness, acidity, TSS and the maturity index (Table 1). Ethanol concentration was also evaluated as this volatile has been shown to increase when fruits are exposed to ethylene

or moderate temperatures (Sdiri et al., 2012; Alhassan et al., 2019), and it has frequently been associated with off-flavours developed when accumulated in excess (Hagenmaier, 2000).

As previously explained, this study was carried out with commercial fruits. Therefore, they all followed the minimum criteria required for export and marketing. Agricultural Quality Standards of the United Nations Economic Commission for Europe (UNECE) established a minimum sugar/acid ratio (where titratable acidity is expressed as percentage of citric acid) of 6.5 in satsuma mandarins and oranges, 7.0 in clementines and 7.5 in other mandarins or hybrids (UNECE, 2017). Satsuma mandarins are the earliest variety to appear at the beginning of the citrus harvesting season and are, thus, normally harvested as soon as possible. In this study, although the ‘Owari’ fruit showed a lower maturity index at harvest than the other two mandarin cultivars, it met the minimum requirements (Table 1).

The study of the effect of degreening treatment on the main physico-chemical parameters revealed that of the three mandarin varieties, ‘Owari’ was the only one in which ethylene treatment had an effect on parameters like firmness and TSS. The effect of ethylene on fruit firmness was similar irrespectively of the initial colour at harvest with a 1% increase in the deformation percentage. However, an effect of degreening treatment on increasing TSS was detected only in the fruit harvested with a CI of -3.5. This rise in TSS was associated with the ethylene application and was also reflected in the MI, which was slightly higher in the fruit submitted to degreening (MI=0.96) than in the control fruit (MI=0.85) (Table 1). Similar results have been described by Tietel et al. (2010) and Mayouni et al., (2011) in ‘Miho’, another satsuma mandarin. So these mandarins seem susceptible to manifest a TSS increase when exposed to ethylene.

In the other two mandarin cultivars, namely ‘Oronules’ and ‘Clemenules’, no significant differences were detected when comparing the degreened and control fruit. This finding indicates that external ethylene itself does not affect quality parameters like firmness, acidity, TSS or ethanol concentration. However, it is worth highlighting an effect of temperature on firmness and acidity: after the degreening period, the control fruit obtained lower firmness and acidity values than at harvest. This effect was marked in ‘Oronules’, but was also detected in ‘Clemenules’.

With the ‘Navelina’ oranges, ethylene application resulted in a lower acidity level, which was also reflected by an increase in the maturity index. Temperature itself had no effect on colour evolution, TSS or acidity levels. However, the firmness values were

slightly affected by temperature, with no differences between the control and degreened fruit. The control fruit showed higher ethanol values than the fruit at harvest, and the increase in this volatile was enhanced in the fruit submitted to degreening. Thus the control fruit showed 491 mg L⁻¹ of EtOH, while the degreened fruit gave values of 771 mg L⁻¹. Ethanol concentration has been associated with flavour degradation of oranges (Hagenmaier, 2000) and mandarins (Obenland & Arpai, 2019). According to Hagenmaier (2000), an ethanol concentration between 800 and 5,000 mg L⁻¹ implies a risk of fruit flavour deterioration in oranges, while values over 5,000 mg L⁻¹ are likely to result in off-flavours.

3.2. The internal sensory properties of fruits were not affected by degreening treatment

The triangle test has proven very useful for evaluating if the sensory quality of fruits and vegetables affected by certain preharvest (Radovich et al., 2004; Bowen et al., 2016) or postharvest treatments (Feliziani et al., 2014; Servili et al., 2017).

In the present study, the triangle test results revealed that, according to consumers' responses, the samples submitted to degreening were indistinguishable from the control samples (Table 2). This result was corroborated for the three mandarin varieties and also for the 'Navelina' orange. Therefore, the effect of degreening treatment on the physico-chemical parameters of the 'Owari' mandarins (lower firmness and increased TSS values of the fruit harvested with a CI of +3.1) and the 'Navelina' orange (lower acidity level and increased ethanol concentration values) had no detectable effect on the sensory quality of fruit. So although the degreening treatment applied to 'Navelina' increased the ethanol concentration to 771 mg L⁻¹, no off-flavours were detected by consumers. This result agrees with Hagenmaier (2000) as the ethanol level was lower than the 800 mg L⁻¹, which he set as a threshold. Thus our results also suggest that the changes in the aroma-active compounds associated with the degreening of 'Oronules' and 'Navelina', as recently described by Sdiri et al. (2017), were not obvious enough to be detected by consumers.

3.3. The consumers' expectations for liking and purchase intention changed with the change in external colour, as affected by the degreening treatment

According to the statistical analysis, no significant differences appeared in the responses of consumers from the Valencian Community and Galicia based on expected maturity,

expected liking and purchase intention. This result indicates that consumers' responses were not affected by their familiarity with different citrus cultivars. Therefore, the data from the two questionnaires were global and the combined results of 340 consumers are shown in Figure 4.

When focusing on the control fruit only, we find that when the rind colour was green or yellow, most consumers expected 'too immature' fruit (Figure 4A), which they would dislike (Figure 4B). As rind naturally changed to orange tones, the number of consumers who expected optimum maturity progressively increased. Oddly enough for the control fruit with the highest colour index, CI of +17, almost the same percentage of consumers (around 20%) considered that fruits were slightly immature than slightly overripe. In parallel to the changes in the expected maturity described for the control fruit, both expected liking scores (Figure 4B) and the number of consumers who manifested buying intentions (Figure 4C) gradually increased. Thus the control fruit with the darker orange tone (IC=+17) showed expected liking values of 6.5 and 55% of consumers willing to buy.

In all cases, the application of degreening treatment modified consumers' expectations (expected liking and maturity) and purchase intentions. The extent of this effect was smaller with a higher colour index in the control fruit. When treatment was applied to green and yellow fruit (CI=-11.7 and +1.5), the increment in colour to values of +10.3 and +13 increased the liking scores by more than 3 points (Figure 4B), and purchase intent by 50% and 70%, respectively (Figure 4C). However, when the fruit with an initial CI of +17 was submitted to degreening and colour was enhanced by +20.2, expected liking increased by 0.7 points and only 15% more consumers were willing to buy (Figure 4C). In this sense, it has been previously demonstrated that consumers' expectations of fruit and vegetables quality are affected not only by the external colour (Schifferstein et al., 2019) but also by other characteristics of fruit appearance (De Hooge et al., 2017; Lombart et al., 2019)

Relevant information was also obtained by globally analysing all the data. On the one hand, when we set a minimum expected liking value of 6, i.e. "I would slightly like these mandarins", the optimum CI range to satisfy consumer expectations lay between CI=+10 and CI=+20. For these fruits, the highest values of expected liking (7.4) and purchase intentions (82 %) were observed in the fruit with a CI=+13.2. On the other hand, the mean expected liking value obtained when consumers considered that fruit was in the optimum maturity stage was 7.5, which came close to "I would very much

like these mandarins” and almost 90% of the consumers stated that they would buy this fruit. The penalty analysis (Figure 5) revealed that green/yellow rinds were highly penalised by consumers as the mean expected liking values lowered 5 and 2 points in those fruits considered too and slightly immature, respectively, and no-one or fewer than 20 % of the consumers were willing to buy them (Figure 6). The penalty analysis also revealed that consumers gave higher expected liking scores to overripe fruit than to immature fruit (Figure 5). Thus expected liking only lowered 1 and 2 points for the slightly and too overripe fruit, and 25-50 % of the consumers still indicated purchase intentions (Figure 5 and 6).

All these results provide the citrus industry with clues as to the colour fruit demanded by consumers, and can be useful for deciding whether or not to apply the degreening treatment based on the expected benefits and costs.

4. CONCLUSIONS

Our results demonstrate that ethylene degreening treatment is a potent postharvest tool to increase citrus fruit sales at the beginning of the season. The change of skin colour associated with this treatment positively affects consumers’ expectations and, therefore, their purchase intentions. The extent of this benefit depends on the initial fruit colour at harvest. When the degreening treatment was applied to the fruit with green or green-yellowish rinds, it markedly increased consumers’ purchase intentions (50-70 % more consumers were willing to buy). The benefits were not as remarkable, but still significant, when the degreening treatment was applied to fruits whose rind colour had already changed to orange tones (10-40 % increase). It is demonstrated for the first time that, although external ethylene exposure slightly affects some physico-chemical parameters in the ‘Owari’ mandarin and the ‘Navelina’ orange, it causes no significant differences to the internal sensory characteristics of fruit for any studied cultivar.

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FIGURES CAPTIONS

Figure 1. External fruit aspect at harvest

Figure 2. External aspect of the Control and Degreened fruit.

Figure 3. External fruit colour (CI= 1000a/Lb) at harvest, after the degreening treatment and after being kept under the control conditions. Vertical bars represent the LSD intervals ($p = 0.05$).

Figure 4. Expected maturity (A), expected liking (B) and purchase intentions (C) depending on fruit external colour (colour index is indicated on the X-axis). Percentages are based on the responses of 340 consumers. *Ctl-* control fruit, *Dg-* degreened fruit. Expected liking was evaluated on a 9-point scale from 1- I would extremely dislike to 9- I would extremely like. The initial 5-point scale for purchase intentions was collapsed to only 3 points, with 'Would not buy' (1-2) and 'Would buy' (4-5). Vertical bars represent the LSD intervals ($p = 0.05$).

Figure 5. Penalty analysis. The mean drops in expected liking in relation to the mean value in the optimum maturity stage (expected liking =7.5) are shown.

Figure 6. Purchase intentions depending on the expected maturity. The initial 5-point scale for purchase intentions was collapsed to only three points, with 'Would not buy' (1-2) and 'Would buy' (4-5).

TABLES

Table 1. Effect of the degreening treatment (1-2 $\mu\text{L L}^{-1}$ ethylene, 20 °C, 95% HR) on firmness, titratable acidity, total soluble solids (TSS) and maturity index of mandarins (cv. Owari, Oronules and Clemenules) and oranges (cv. Navelina). Treatment duration is indicated in days in the column 'Days Dg'. In each cultivar and the initial colour at harvest, different letters denote the statistically significant differences at $p < 0.05$ among treatments. Bold denotes significant differences. *Hv-harvest*, *Ctl-control fruit*, *Dg- degreened fruit*.

Cultivar and colour index (CI) at harvest	Days Dg		Firmness (% def)	Acidity (g citric ac. L^{-1} juice)	TSS (%)	MI (TSS/Ac)	EtOH (mg.L^{-1})
Owari (CI= -12)	4	<i>Hv</i>	5.5a	11.8a	9.18a	0.77a	100b
		<i>Ctl</i>	5.7a	12.4a	9.11a	0.73a	44.5a
		<i>Dg</i>	6.7b	11.9a	9.16a	0.77a	65.9a
Owari (CI = -3.5)	3	<i>Hv</i>	6.1a	13.1b	8.3a	0.63a	123.3a
		<i>Ctl</i>	5.7a	10.6a	8.5a	0.85b	99.6a
		<i>Dg</i>	6.8b	9.4a	9.0b	0.96c	105.9a
Clemenules (CI= -16)	8	<i>Hv</i>	2.6a	8.5b	9.6a	1.12a	35.1a
		<i>Ctl</i>	3.9b	8.2a	10.2b	1.25ab	27.5a
		<i>Dg</i>	4.1b	8.2a	10.6b	1.30b	34.0a
Clemenules (CI= -5)	7	<i>Hv</i>	4.1a	8.0a	10.9a	1.34a	65.8a
		<i>Ctl</i>	4.8b	7.7a	10.9a	1.42ab	70.2a
		<i>Dg</i>	4.7b	7.5a	11.2a	1.49b	57.3a
Oronules (CI= - 0.8)	6	<i>Hv</i>	4.2a	11.0b	11.1a	1.01a	102.7a
		<i>Ctl</i>	5.45b	8.3a	11.1a	1.33b	85.5a
		<i>Dg</i>	5.57b	8.6a	10.8a	1.25b	131.0a
Oronules (CI= +16)	2	<i>Hv</i>	5.6a	10.6b	12.1a	1.14a	82.5a
		<i>Ctl</i>	6.6b	7.8a	11.3a	1.45b	96.9a
		<i>Dg</i>	6.9b	8.5a	11.6a	1.36b	109.0a
Navelina (CI= +7)	4	<i>Hv</i>	1.9a	10.6b	11.5b	1.08ab	304.4a
		<i>Ctl</i>	2.5b	11.0b	11.1ab	1.01a	491.2b
		<i>Dg</i>	2.5b	8.8a	10.5a	1.20b	771.3c

Table 2. The results of the triangular test applied to compare the Control and Degreened fruit. *CI-colour index. p -value > 0.05 indicates no significant differences.*

Variety	CI at harvest	Trials	Correct Answers	p -value
Owari	-12	105	38	0.300
	-3.5	105	42	0.090
Clemenules	-16	122	44	0.082
	-5	122	33	0.215
Oronules	-0.8	107	43	0.291
	16	107	40	0.944
Navelina	10	100	39	0.137