Effect of pre-harvest conditions and postharvest storage time on the quality of whole and fresh-cut *calçots* (*Allium cepa* L.)

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Abbreviations

ΔE^*: color difference

DPPH$^{\cdot}$: 2,2-diphenyl-1-picrylhydrazyl

FRAP: Ferric Reducing Antioxidant Power

SSC: Soluble Solids Content

TA: Titratable acidity

TMB: Total Aerobic Mesophilic Bacteria

TPC: Total Phenolic Content

Y&M: Yeast and Moulds

Abstract

Pre-harvest conditions such as cultivar, cultivation site and planting time could affect the storability, quality and shelf-life of fruit and vegetables. The influence of onion cultivar, cultivation site and planting time on the storability and quality of whole fresh and roasted *calçots* (*Allium cepa* L.) was investigated. Moreover, the suitability for fresh-cut processing of four different *calçots* was studied. Samples from 'Montferri' onion cultivar presented the best storability. Overall, postharvest storage time had no remarkable effect on the quality of whole *calçots* but produced an increase on the antioxidant properties of all samples. In relation to the aptitude to minimal processing, 'Montferri' ~~early~~ onion cultivar cultivated at Viladecans in August showed the best results in terms of quality throughout their postharvest storage time. Therefore, cultivar and postharvest storage time could have more effect than cultivation site and planting time on the quality of whole and fresh-cut *calçots*.

Keywords: *Allium;* storage; cultivation; planting; fresh-cut; quality.

1. Introduction

Calçots (*Allium cepa* L.) are the immature floral stems of second-year onion resprouts of the 'Ceba Blanca Tardana de Lleida' onion landrace. The singularity of the production of this product has helped to confer protected status from the European Union and 'Calçot de Valls' being awarded with the Protected Geographical Indication (EC No 905/2002; Simó et al., 2013; Zudaire et al., 2017).

In the last years, the consumption of fresh-cut vegetables has increased in Europe since consumers demand fresh, healthy and convenient product (Rico et al., 2007). The quality and safety of fresh-cut vegetables rely on many factors including those affecting the quality of whole fruit and vegetables (cultivar and pre-harvest practices and conditions) as well as specific factors such as handling procedures, conditioning, minimal processing, and following storage conditions (Gil and Allende, 2012; Kader, 2002).

However, *calçots* are subjected to the limit of seasonality and there is a need to find an adequate combination of pre-harvest and postharvest factors to prolong their storability. The first step to increase storage potential of *calçots* is the selection of the proper onion cultivar (Petropoulos et al., 2016b). Cultivar choice is the main factor in the quality as the genetic nature of the plant determines the structural and chemical attributes of the product (Cliffe-Byrnes and O'Beirne, 2005), final product quality and acceptability by consumers (Echeverría et al., 2013). Moreover, the interaction of cultivar with environmental, agronomic and processing conditions could also have influence on the level and bioavailability of antioxidant compounds in the final product (Tiwari and Cummins, 2013). Not all varieties of vegetables are suitable for minimal processing. The correct choice of variety is particularly relevant for vegetables such as potato or onion (Laurila and Ahvenainen, 2002). For example, Silveira et al. (2017) demonstrated that cultivar had effect on the final total phenolic content of fresh-cut potato. 'Montferri' is a new late (usually harvested in January or March) *calçot* (*Allium cepa* L.) cultivar, which considerably increase the mean number of commercial *calçots* obtained for each plant while maintaining the sensory characteristics (Simó et al., 2012).

Similar cultivars grown in two different locations under comparable growing conditions could also have differences in phytochemical content as a result of variations in prevailing environmental conditions (Tiwari and Cummins, 2013). Giannino et al. (2018) reported that growth site variation caused the major differences in the content of flavonols, flavonoids and chlorophylls of fresh-cut endives and escaroles. Moreover, planting time might have a significant impact on the characteristics of plants and could affect the mean weight and marketable yield (Sekara et al., 2017). In the case of onions, the productivity is significantly affected by both the selection of the cultivar and the planting time (Caruso et al., 2014).

Postharvest storage time of raw material is also important because many biochemical characteristics change during storage (Chope et al., 2006; Tiwari and Cummins, 2013). Overall, bunched green onions which are similar to *calçot*, could be stored 3 to 4 weeks at 0 °C with 95-98 % of RH and in most European countries, onions are stored in regular storage, using cool and ambient air (Adamicki, 2016). In recent years, the number of studies focused on the effect of long-term storage on the overall quality of onions has increased (Petropoulos et al., 2016b). Petropoulos et al. (2016a) reported that overall quality of 'Vatikiotiko' onion bulbs was maintained after 210 d of storage at 5 ± 1 °C. Nevertheless, minimally processed fruit and vegetables have a short shelf-life principally due to mechanical stresses (Watada et al., 1996). The minimal processing could also rise microbial spoilage of minimally processed vegetables due to transmission of microflora from surface or decontamination water to the flesh (Qadri et al., 2015). Indeed, the following refrigerated storage is essential to ensure acceptable shelf-life (Garcia and Barrett, 2002).

The objective of this study was to evaluate the effect of cultivar, cultivation site, planting time and postharvest storage time of raw material on the morphological, physicochemical and sensorial quality and antioxidant potential of whole *calçots*. Moreover, their aptitude to be minimally processed as 'ready to eat' or 'ready to cook' products was evaluated through physicochemical, microbiological and sensorial analysis.

2. Materials and Methods

2.1 Effect of pre-harvest conditions and postharvest storage time on whole *calçots*

Calçots (*Allium cepa* L.) grown in the northeast of Spain were provided by 'Fundació Miquel Agustí' (Sabadell, Spain) at commercial size. They were cultivated during the crop growing season of 2015 and 2016. To avoid the effect of the first growing cycle conditions (from November to August, from seed planting to bulb obtaining) on *calçots* cultivation, bulb onions used in the experiments were produced in the same field. Bulbs onions were planted at a density of 32,000 plants per hectare, using a planting pattern of 0.3 x 0.75 m, at two different times, in mid-August (early planting) and in late September (late planting). *Calçots* were harvested in December. The experimental design was three randomized blocks, with 50 plants per plot. Each experimental field was managed by farmers using their own customary traditional cultivation techniques. The fertilization, irrigation, weed control and pest management were also managed using farmer cultivation practices (Sans et al., 2018).

The experiment was carried out with two different cultivars~~:~~ that differed on its yield: a traditional landrace (125,403 *calçots*/ha), which has not undergone any formal scientific breeding processes, and the improved variety Montferri (164,668 *calçots*/ha), derived from the historical landrace by scientific breeding (Sans et al., 2018; Simó et al., 2012) ~~Traditional (125,403 *calçots*/ha) and Montferri (164,668 *calçots*/ha) (Simó et al., 2012).~~ Those cultivars were grown in two areas of northeast of Spain: Viladecans (41°17'19.3" N, 2°02'42.5", Barcelona province) and La Juncosa del Montmell (41°18'59.4" N, 1°27'07.5"E, Tarragona province). The climatic conditions and soil characteristics of two cultivation sites were detailed in Tables 1 and 2. Table 3 shows the combinations tested.

The *calçots* were harvested at commercial conditions, transported to the laboratory and immediately cooled to 1 °C at arrival. The time between harvesting and cooling was around 3 h. *Calçots* were then stored under air at 1 °C with 85 % of relative humidity (RH) for 30 d. The morphological, physicochemical and nutritional quality of samples was evaluated at day 0, 15 and 30. In addition, *calçots* were roasted as Zudaire et al. (2017) described. Briefly, *calçots* were roasted at 270 °C for 8 min and then, cooled into a blast chiller until they reached 3 °C. After conducting physicochemical assays, both fresh and roasted samples were crushed, powered and frozen with liquid nitrogen and stored at -80 °C for nutritional analysis.

2.1.1 Morphological and physicochemical quality

The measurements of morphological and quality parameters of raw *calçots* (whole samples) were made as Zudaire et al. (2017) described. The length and width of edible part (white shaft) and weight of the *calçots* were measured. Color, firmness, soluble solids content (SSC), titratable acidity (TA), pH and respiration rate were measured. SSC were expressed as percentage and TA as g of malic acid per liter. Respiration rate was expressed on a fresh weigh basis as mL of CO_2 per kg and h. Furthermore, color difference (ΔE^*) of external white shaft was calculated using the values a*, b* and L* and following the methodology described by Wibowo et al. (2015).

2.1.2 Consumer assessment

A portion of 3 cm of roasted *calçot* of each sample and at each storage time was presented to an untrained panel of 40 consumers immediately after they were heated for 10 s in the microwave at a 900 W. The assessment was carried out following the same methodology previously described by Altisent et al. (2014). Briefly, each consumer assessed all samples and was asked to indicate his/her degree of liking/disliking using a 9-point hedonic scale (1-dislike extremely to 9-like extremely). A score equal or superior to seven was used as the threshold to analyze the results. Moreover, the percentage of consumers who evaluated equal or greater than 7 was calculated.

2.1.3 Antioxidant potential

Antioxidant activity and total phenolic content of raw and roasted *calçots* were measured as Zudaire et al. (2017) described. Antioxidant activity was determined by two different methods: 2,2-diphenyl-1-picrylhydrazyl ($DPPH^{\cdot}$) radical scavenging assay and ferric reducing antioxidant power (FRAP) assay. Results were expressed on a fresh weight basis as a mol of ascorbic acid equivalents per kg. Total phenolic content was determined following the Folin-Ciocalteu method (Singleton et al., 1999) and results were expressed on a fresh weight basis as g of gallic acid equivalent per kg.

2.2 Effect of pre-harvest conditions and postharvest storage time on fresh-cut *calçots*

Minimal processing of *calçots* stored for 15 and 30 d was conducted according to the study of Aguiló-Aguayo et al. (2015) which consisted of cutting roots and external leaves from the edible part as well as removing the outer peel. Fresh-cut *calçots* were immersed in a 10 L bath which contained 80 mg L^{-1} peroxyacetic acid (39 %, Sigma-Aldrich, Steinheim, Germany) at room temperature under continuous agitation for 60 s. All samples were centrifuged at 210 rpm in a pilot plant centrifuge (Marrodán, Navarra, Spain) for 95 s. Fresh-cut *calçots* were packaged in polystyrene trays with retractable film and stored at 4 °C for 10 d. The microbiological and quality determinations (color, firmness, SSC, TA and pH) were carried out at day 0, 3, 7, and 10 d of shelf-life at 4 °C. Moreover, consumer assessment of fresh-cut and roasted *calçots* was carried out at day 0 and 6 of shelf-life at 4 °C.

2.2.1 Microbiological quality

The population of total aerobic mesophilic bacteria (TMB) and yeast and moulds (Y&M) was determined in triplicate (three different trays) at each sampling date. Two fresh-cut calçots from each tray were randomly selected, cut in small pieces and 25 g were weighed in a homogenizer sterile filter bag, diluted in 225 ml of buffered peptone water (BPW, Oxoid) and homogenized in a blender (IUL, Masticator, Spain) at 250 impact s^{-1} for 90 s. Serial dilutions of the suspension were conducted in sterile buffer saline peptone (8.5 g L^{-1} NaCl and 1 g L^{-1} peptone). Aliquots of duplicate serial dilutions were spread onto plates with PCA (Plate Count Agar, Biokar) and DRBC (Dichloran Rose Bengal Chlorotetracycline agar, Biokar) for mesophilic aerobic microorganisms and yeasts and moulds enumeration, respectively. PCA plates were incubated at 30 ± 1 °C for 3 d and DRBC plates were incubated at 25 ± 1 °C for 5 d. The results were reported as log colony forming units (cfu) per gram of fresh weight.

2.3 Statistical analysis

Results were expressed as mean ± standard deviation. All data was firstly evaluated for normality (Shapiro-Wilk W Test) and homogeneity of variance (Levene's Test) of residues. Significant differences between results were calculated by using one-way analysis of variance (ANOVA). In case of non-normality or unequal variances the non-parametric equivalents (Wilcoxon/Kruskal-Wallis Tests) were used. Differences were considered to be significant at $P<0.05$ (95 % confidence level). In case of significant differences, multiple comparison of means was established with the Post Hoc Tukey-Kramer HSD or Student's test. All statistical analyses were performed with JMP 8 software (SAS Institute Inc., Cary, NC, USA).

3. Results and discussion

3.1 Effect of pre-harvest conditions and postharvest storage time on whole *calçots*

3.1.1 Changes on morphological and quality parameters

Morphological parameters (width, length and weight) of whole *calçots* are shown in Table 4. Overall, morphological parameters of all samples were kept constant along postharvest storage time (30 d). V3 *calçots* presented the highest morphological values resulting in a more production yield due to their size. Both V3 and V4 *calçots* came from 'Montferri' onion cultivar produced in the same place but with different planting time, late and early, respectively, presented different initial and final values, demonstrating planting time could have influence on the morphological parameters of *calçots*. The difference regarding planting time perhaps could be associated with the minimum and maximum temperature values (differences around 4 °C between August and September) (Table 2). The planting time is very important inside the *calçot*'s cultivation cycle. However, Simó et al. (2015) reported that different planting times (August and September) had no effect on the length and diameter of *calçots*, and they reach the commercial size indicated by PGI. Furthermore, differences in length between V1 and V4 samples could be observed, which just differed in planting location, La Juncosa and Viladecans, respectively. Those differences could be associated with sodium, nitrogen and phosphorus concentration in soil, being higher in Viladecans than in La Juncosa. It is known that nitrogen is an essential elementary constituent of numerous organic compounds of general significance and its formation of protoplasm and new cells, including, its encouragement for elongation. Moreover, phosphorus is major essential element required for physiological mechanisms of plant growth (Aisha et al., 2007).

Browning index and firmness values are shown in Table 5. After harvest, browning index and firmness values of all *calçots* were similar without a clear influence of cultivar, planting site and time. In general, browning index of white shaft increased up to 15 d of postharvest storage and remained stable until day 30 except for sample V4. However, Zudaire et al. (2017) reported that

BI of *calçots* stored under air increased along storage time (60 d). Praeger et al. (2003) reported that during storage time (6 months) the onion cv. 'Sherpa' (type 'Rijnsburger') skin became slightly darker in all atmospheres (controlled atmosphere and air) being more notable in those stored under air. Moreover, in the study carried out by Fernández-León et al. (2013) a decrease in green color and an increase in yellow color of broccoli 'Parthenon' plants stored under air was observed after 21 d of storage and those color changes were more remarkable in those samples stored under air than under controlled atmosphere.

Overall, firmness values were kept constant along storage time (Table 5) except for *calçots* V3, since the firmness of those samples decreased as well as they showed a weight lost (Table 4). Those results were in agreement with those reported by Zudaire et al. (2017) who showed that firmness of *calçots* stored under air was maintained during the first 30 d of storage. In concordance, Melo et al. (2012) reported that the firmness of onion cv. 'Beta Cristal' stored under air remained constant up to 60 d of storage. However, Chope et al. (2007) showed that firmness of onion cv. SS1 stored under air decreased after 21 d of storage.

After harvest, soluble solid content (SSC) values of samples V1 and V3 were higher than V2 and V4 samples, without the possibility to establish a link between cultivar, cultivation site and time (Table 5). However, those values were similar in all samples at the end of the storage time (30 d). Regarding titratable acidity (TA) values, V1 samples presented the highest values after harvest and at the end of the storage time (30 d), but pre-harvest factors had no a clear influence as was shown in SSC values. pH values of soil in both La Juncosa and Viladecans were similar (around 8.40) and that could have influence in pH of samples because all samples presented similar values at all sampling points.

SSC, TA and pH values of all samples increased along storage time (Table 5). However, Zudaire et al. (2017) observed an increase in the TA and a decrease in both pH and SSC values of *calçots* stored under air up to 60 d of storage. Rodrigues et al. (2012) reported that SSC was maintained, and pH decreased in 'Branca da Póvoa' and 'Vermelha da Póvoa' onion cultivars after 6 months of storage time under refrigeration conditions. However, Chope et al. (2007)

reported that the total SSC of onions stored under air or controlled atmospheres depended on the cultivar. The observed increase in SSC could be associated by the metabolization of carbohydrates during the storage, due to high respiratory activity (Fernández-León et al., 2013) or caused by the low temperature hydrolysis of fructans which are the major oligosaccharides in onion bulbs (Benkeblia and Shiomi, 2004).

Respiration rate is usually a good index for the storage life of fresh vegetables; hence, the higher the rate, the shorter the life and vice versa (Özden and Bayindirli, 2002). After harvest, V1 samples presented the highest respiration rate values (Table 5). V1 samples were the only which were planted/cultivated in La Juncosa. Mean maximum and minimum monthly temperatures were lower (warmer) in La Juncosa than in Viladecans and perhaps temperature could have had effect on the respiration rate. It has been long recognized that respiration is temperature sensitive (Atkin and Tjoelker, 2003). For example, Mohammed and Tarpley (2009) reported an increase in respiration rates in rice plants as a result of an increase in night-time temperature. Respiration rate of V1-V3 *calçots* increased along storage time but without significant differences ($P>0.05$) respect to day 0, and a maximum respiration rate occurred during the first 15 d of storage. However, respiration rate of V4 sample increased along storage time with a maximum value at day 30. Moreover, respiration rate tendency observed in those V3 and V4 calçots could be related with the changes observed in SSC along storage time (30 d) because soluble sugars are used in respiration (Rodrigues et al., 2012). Those results were in agreement with those reported by Zudaire et al. (2017) where respiration rate of *calçots* stored under air conditions increased along storage time (60 d). The respiration rate results obtained in the present study could be analyzed either by cultivar (V4 vs V2) or by planting time (V4 vs V3). On the one hand, the increase in the respiration rate observed could be cultivar-dependent because V2 (Traditional) and V4 (‘Montferri’) planted at the same place and time presented different tendency. In concordance, Chope et al. (2007) reported that the respiration rates for onion cvs. ‘Carlos’ and ‘Renate’ were greater than for SS1 cultivated at the same place and time. On the other hand, respiration rate could be planting time-dependent because V3 (late) and

V4 (early) came from the same onion cultivar and they were planted at the same place. However, there is a lack of literature discussing the effect of planting or sowing date on the postharvest respiration rate of vegetables.

3.1.2 Consumer assessment

The percentage of consumers who evaluated above 7 points decreased along postharvest storage time for V1 and V2 samples, from 77.8 % to 57.0 % and from 63.0 % to 57.0 %, respectively (data not shown). However, opposite tendency was observed for V3 and V4 samples, where percentage increased from 55.6 % to 82.1 % and from 70.4 % to 92.0 %, respectively. *Calçots* which came from 'Montferri' onion cultivar and planted at the same place (Viladecans) presented the best scores, indicating that planting time had no effect on the sensorial quality of those *calçots*. Zudaire et al. (2017) reported that higher liking degree value was observed in *calçots* stored under air during 60 d than 30 d. Besides the differences observed in the tendency and consumer percentage of traditional and 'Montferri' cultivars, Simó et al. (2012) reported that there were no differences between *calçots* from the base population, 'Babosa' and 'Nerja' cultivars and those from the two new cultivars ('Montferri' and 'Roquerola') in the sensory analysis (sweetness, fiber and off-flavors).

3.1.3 Antioxidant activity

In the current study, two methods, DPPH$^{\cdot}$ and FRAP, were used to investigate the changes in total antioxidant activity (AA) of *calçots* after 30 d of postharvest storage (Figure 1A and 1B). Moreover, the effect of thermal processing (roasting) was assessed. After harvest, V3 samples presented the lowest antioxidant activity (DPPH$^{\cdot}$ and FRAP). A considerable difference was observed between V1 and V3 samples which came from the same cultivar and planting at the same time. The soil properties and temperature could have had influence on the antioxidant activity of harvested *calçots*. In addition, Tiwari and Cummins (2013) remarked that environmental factors including sunshine radiation, temperature variation and climatic conditions within a geographical location may influence the level of phytochemicals in fruit and vegetables. For example, Wang and Zheng (2001) observed that antioxidant capacity of strawberries (Earliglow and Kent cultivars) increased in those cultivated at day/night temperatures of 25/22 and 30/22 °C and plants grown in the cool day and night temperatures (18/22 °C) presented the lowest AA. Overall, AA values of whole raw *calçots* by DPPH$^{\cdot}$ method decreased along postharvest storage time with a maximum value at day 15 and increased by FRAP method. There was no observed a similar tendency in those samples that came from the same onion cultivar, planted at the same place or time. Petropoulos et al. (2016a) reported that AA as expressed by DPPH reduced during postharvest storage (139-210 d) under refrigeration conditions for all onion genotypes. However, Gunes et al. (2002) showed that the AA of cranberry fruit stored under air increased around 45 %.

Furthermore, AA values were maintained by DPPH method except at day 30 of postharvest storage and increased by FRAP method after thermal processing (270 °C, 8 min). It was not observed a clear tendency in those samples that came from the same onion cultivar, planted at the same place or time. However, Zudaire et al. (2017) reported that AA (DPPH and FRAP) of all *calçots* increased after roasting (270 °C, 8 min) regardless of postharvest storage regime and time. Moreover, Sharma et al. (2015) reported that the DPPH and FRAP values for all studied onion cultivars were increased after 30 min at 120 °C or 150 °C.

3.1.4 Total Phenolic Content

The total phenolic content (TPC) of raw and roasted *calçots* is shown in Figure 1C. After harvest, V2 and V4 samples which were planted at the same location and time, presented similar TPC values. Those results demonstrated that cultivar (Traditional or Montferri) had no effect on the TPC of those *calçots* cultivated at the same location and time. However, Nuutila et al. (2003) reported that TPC of onions not only vary according to cultivar but also within its layer. They showed that TPC of dry skin of red and yellow onions were 8000 and 2600 mg GAE 100 g^{-1} dry weight, respectively, whereas the intermediate levels of onion bulbs and stems ranged from 80 to 320 mg of GAE 100 g^{-1} dry weight. The TPC of raw samples V1 and V2 increased and samples V3 and V4 was maintained after 30 d of postharvest storage. Caruso et al. (2014) reported that polyphenol content of cured ‘Ramata di Montoro’ onion bulbs was not significantly affected by the transplanting time. In concordance with the results obtained in the present study, Zudaire et al. (2017) reported that the TPC of raw *calçots* increased after 60 d of postharvest storage at 1 °C without a relation between the AA and TPC. However, Petropoulos et al. (2016a) showed that the TPC of ‘Sivan F1’, ‘Vatikiotiko’ and ‘Creamgold’ onion cultivars decreased after 139-210 d at 5 °C. The effects of storage time under air depend on the vegetable matrix. For example, Singh and Singh (2013) reported that the concentration of total phenolic of Japanese plums stored under air (0-1 °C) declined after 8 weeks. Nevertheless, Li et al. (2015) showed that the TPC of kiwifruit increased along storage time (2 ± 2 °C) with a maximum value at day 15, and then decreased drastically by 30 d.

On the other hand, the impact of thermal processing on the TPC of *calçots* relied on the sample and postharvest storage date with an overall tendency to increase. The increase observed in TPC after roasting could be to the liberation by cleaving of the esterified and glycosylated bond or by the formation of Maillard reaction products (Sharma et al., 2015). In concordance, Zudaire et al. (2017) reported that the TPC of raw *calçots* stored under air increased after thermal processing. However, other authors reported that occurrence of Maillard reactions in roasting process could contribute to the reduction of polyphenol levels (Palermo et al., 2014). For example, Hwang et al. (2012) showed that roasting (190 °C; 5, 10 or 15 min) produced a decrease on the TPC of peppers. Moreover, Rawson et al. (2013) observed that roasting (160 °C; 15 min) produced a decrease on the TPC of fennel bulbs.

3.2 Effect of pre-harvest conditions and postharvest storage time on fresh-cut *calçots*

3.2.1 Changes on quality parameters

Overall, color differences (ΔE^*) and firmness retention (%) values of fresh-cut *calçots* were higher in those samples stored for 30 d than for 15 d, but without significant differences (P>0.05) between them (Supplementary Figures 1 and 2). Moreover, those values and weight values (data not shown) were kept constant in all samples along refrigerated storage time (10 d) at 4 °C. However, Zudaire et al. (unpublished data) reported that browning index values of fresh-cut *calçots* packaged under MAP system were higher in those previously stored under controlled atmosphere for 60 d than for 30 d, but firmness and weight values were not been affected. Odriozola-Serrano et al. (2008) reported that differences in CIELab parameters among six fresh-cut tomato cultivars appeared to be significant, but those parameters did not vary significantly during storage time (21 d) at 4 ± 1 °C. In concordance, Simon (2008) showed that cultivar had effect on the quality parameters of minimally processed cauliflower. For example, 'Lorien' cultivar presented very dark cuts or 'Caprio' and 'Cristallo' cultivars suffered an important toughness during storage (13 d) at 5 °C. Moreover, Blanco-Díaz et al. (2016) reported that b* values of fresh-cut zucchinis at day 0 were different among cultivars and those differences were maintained along storage time (10 d) at 6 °C. However, the cultivar had no effect on the firmness of those vegetables. Furthermore, Muratore et al. (2015) showed that browning values of minimally processed artichoke heads were significantly influenced by cultivar and storage time (16 d). There is a lack in the literature discussing the effect of planting or sowing date and cultivation site on the overall quality of minimally processed vegetables.

SSC, TA and pH values were similar or higher in those samples previously stored for 30 d than for 15 d (Table 6). After 15 d of postharvest storage, the SSC and TA values of V2 (Traditional) and V4 (Montferri) samples which were planted at the same place and time, presented the same tendency in the following refrigerated storage (4 °C). However, Blanco-Díaz et al. (2016) reported that SSC values of fresh-cut zucchinis were primarily affected by cultivar. In concordance, Nogales-Delgado et al. (2014) showed that SSC of fresh-cut nectarines depended on the cultivar. Moreover, Giné Bordonaba et al. (2014) reported that SSC values in fresh-cut nectarines were different among cultivars and values of all samples were remained stable during storage time (12 d) at 5 °C. They also showed that TA was different among the cultivars and decreased during cold storage. In the current study, after 30 d of postharvest storage and 10 d of refrigerated storage (4 °C), despite V1 fresh-cut *calçots* presented the highest SSC and TA values due to their high initial values, V3 samples were identified as the best fresh-cut *calçots* in preserving those chemical parameters.

3.2.2 Consumer assessment

Overall, the percentage of consumers who evaluated above 7 decreased from day 0 to day 6 in those samples stored previously for 15 d, except for V3 fresh-cut *calçots* (increased 1.5 %; final value of 65.5 %) (Data not shown). Despite of the high initial percentage observed in V3 and V4 samples (82.1 % and 92.9 %) after 30 d of postharvest storage time, the values were similar in all fresh-cut *calçots* at day 6 (around 50 %). Han et al. (2016) reported that fresh-cut Welsh onions (*Allium fistulosum* L. cv. Jin) stored at 4 °C presented a slight decrease of sensory quality in the first 3 d and a moderate reduction was observed from day 3 to 5, but all samples remained over the limit of usability (score 5) after 5 d of storage.

3.2.3 Microbial quality

The overall shelf life of a fresh-cut vegetable is decided by its physical and chemical quality as well as its microbial quality (Vandekinderen et al., 2008). Overall, the postharvest storage time of the raw material (15 or 30 d) had no effect on the total mesophilic bacteria (TMB), yeast and molds population of fresh-cut *calçots* (Figures 2-4). Moreover, the population of TMB was kept constant along refrigerated storage time (10 d) at 4 °C (Figure 2). The results have shown that disinfection treatment with peroxyacetic acid (80 mg L^{-1}) for 60 s was effective in reducing initial microbial load and maintaining those values along refrigerated storage time (10 d) at 4 °C. Only slight differences were observed in V3 and V4 fresh-cut *calçots* previously stored for 15 d, but without significant differences (P>0.05) among sampling days. In concordance, Licciardello et al. (2017) reported that TMB population of three different fresh-cut globe artichoke cultivars was remained constant along storage time (12 d) at 4 ± 0.5 °C. However, Muratore et al. (2015) reported that TMB of 'Tema 2000' fresh-cut globe artichoke heads increased rapidly while in 'Violet de Provence' the increase was more gradual during 13-16 d of storage time at 4 °C. Moreover, Cliffe-Byrnes and O'Beirne (2005) observed that using

OPP film, TMB counts of coleslaw mix were lower up to day 7 for Marathon than for Lennox cultivar and those values increased along storage time (9 d) at 4 or 8 °C. TMB counts of all studied fresh-cut *calçots* not exceeded the recommended limit of 8 log cfu g^{-1} proposed by CNERNA-CNRS (1996) and the maximum acceptable contamination value at the end of the microbiological shelf life fixed by the French regulation (7.7 log cfu g^{-1}**)** (Ministere de l'Economic des Finances et du Budget, 1988)**.**

In general, the population of yeast and molds remained constant along refrigerated storage time (10 d) at 4 °C (Figures 3 and 4). Only slight differences were observed in the population of yeasts in V3 fresh-cut *calçots* stored previously for 15 d and V2 and V4 samples stored previously for 30 d. In those cases a significant decrease was observed after disinfection, but the counts were kept constant along refrigerated storage time. Silveira et al. (2017) reported that postharvest storage length, cut type and variety did not affected the mold growth of fresh-cut potatoes and yeast growth was only affected by the variety and cut type in those stored previously for 4 months. Muratore et al. (2015) observed that yeast and mold population of two minimally processed globe artichoke head cultivars increased progressively along storage time (13-16 d) at 4 °C. It is noteworthy that any of the studied fresh-cut *calçots* presented yeast and mold counts more than 5 log cfu g^{-1} at the end of the refrigerated storage time, which is the limit proposed by CNERNA-CNRS (1996).

4. Conclusions

Cultivar, cultivation site and planting time could define the storability and shelf-life of whole and fresh-cut *calçots*. On the one hand, postharvest storage time (30 d) had no effect on the morphological characteristics, color and firmness, but produced an increase in respiration rate, physicochemical characteristics and antioxidant properties of whole *calçots*. The obtained results may explain that *calçots* came from 'Montferri' onion cultivar and planted in Viladecans in September had higher postharvest storage capacity than the other samples due to their morphological values (high production yield), low color difference, acceptable respiration rate and high consumer assessment scores. Hence, 'Montferri' improved onion cultivar for *calçots* production could have higher postharvest storage capacity than Traditional cultivar. It was not observed a clear influence by cultivation site or planting time regard to the postharvest storage capacity. Thermal processing (270 °C; 8 min) produced an increase in antioxidant properties of whole *calçots* irrespective of the cultivar, cultivation site and planting time. On the other hand, postharvest storage time (30 d) had effect on the colour and firmness of fresh-cut *calçots*, but it was not observed influence on the chemical, sensory and microbiological quality. *Calçots* came from 'Montferri' onion cultivar and planted in Viladecans in September maintained the best physicochemical and sensorial qualities after 30 d of postharvest storage time and 10 d of refrigerated storage (4 °C). It is noteworthy that total mesophilic bacteria and yeast and molds counts of all fresh-cut *calçots* were maintained below 7.7 log cfu g^{-1} and 5 log cfu g^{-1}, respectively, due to the effectiveness of peroxyacetic acid. Therefore, taking into account obtained results 'Montferri' improved onion cultivar could be a good alternative to Traditional cultivar in order to improve postharvest storability of whole *calçots* and shelf-life of fresh-cut *calçots* maintaining the best quality.

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References

Adamicki, F., 2016. Onion, in: Gross, K.C., Wang, C., Saltveit, M.E. (Eds.), The commercial storage of fruits, vegetables, and florist and nursery stocks. Agricultural Research Service. USDA., Beltsville, MD, pp. 436–440.

Aguiló-Aguayo, I., Simó, J., Ivars, N., Villaró, S., Zudaire, L., Echeverria, G., Plaza, L., Abadias, M., Viñas, I., 2015. Suitability of the 'calçots' (*Allium cepa* L.) for minimal processing, in: 2nd Euro-Mediterranean Symposium on Fruit and Vegetable Processing. Avignon, France.

Aisha, A.H., Rizk, F.A., Shaheen, A.M., Abdel-Mouty, M.M., 2007. Onion plant growth, bulbs yield and its physical and chemical properties as affected by organic and natural fertilization. Res. J. Agric. Biol. Sci. 3, 380–388.

Altisent, R., Plaza, L., Alegre, I., Viñas, I., Abadias, M., 2014. Comparative study of improved vs. traditional apple cultivars and their aptitude to be minimally processed as 'ready to eat' apple wedges. LWT - Food Sci. Technol. 58, 541–549. https://doi.org/10.1016/j.lwt.2014.03.019

Atkin, O.K., Tjoelker, M.G., 2003. Thermal acclimation and the dynamic response of plant respiration to temperature. Trends Plant Sci. 8, 343–351. https://doi.org/10.1016/S1360-1385(03)00136-5

Benkeblia, N., Shiomi, N., 2004. Chilling effect on soluble Sugars, respiration rate, total phenolics, peroxidase activity and dormancy of onion bulbs 281–285.

Blanco-Díaz, M.T., Pérez-Vicente, A., Font, R., 2016. Quality of fresh cut zucchini as affected by cultivar, maturity at processing and packaging. Packag. Technol. Sci. 29, 365–382. https://doi.org/10.1002/pts.2214

Caruso, G., Conti, S., Villari, G., Borrelli, C., Melchionna, G., Minutolo, M., Russo, G., Amalfitano, C., 2014. Effects of transplanting time and plant density on yield, quality and antioxidant content of onion (*Allium cepa* L.) in southern Italy. Sci. Hortic. (Amsterdam). 166, 111–120. https://doi.org/10.1016/j.scienta.2013.12.019

Chope, G.A., Terry, L.A., White, P.J., 2007. The effect of the transition between controlled atmosphere and regular atmosphere storage on bulbs of onion cultivars SS1, Carlos and Renate. Postharvest Biol. Technol. 44, 228–239. https://doi.org/10.1016/j.postharvbio.2006.12.018

Chope, G.A., Terry, L.A., White, P.J., 2006. Effect of controlled atmosphere storage on abscisic acid concentration and other biochemical attributes of onion bulbs. Postharvest Biol. Technol. 39, 233–242. https://doi.org/10.1016/j.postharvbio.2005.10.010

Cliffe-Byrnes, V., O'Beirne, D., 2005. The effects of cultivar and physiological age on quality and shelf-life of coleslaw mix packaged in modified atmospheres. Int. J. Food Sci. Technol. 40, 165–175. https://doi.org/10.1111/j.1365-2621.2004.00927.x

CNERNA-CNRS, 1996. Produits de la IV gamme, in: Jouve, J. (Ed.), La qualité microbiologique des aliments (Maîtrise et Critères). Polytechnica, Paris, pp. 73–98.

EC No 905/2002. Commission Regulation (EC) No 905/2002 of 30 May 2002 supplementing the Annex to Regulation (EC) No 2400/96 on the entry of certain names in the 'Register of protected designations of origin and protected geographical indications' [2002] OJ L 142/27.

Echeverría, G., López, M.L., Soria, Y., 2013. Calidad en fruta fresca: Manzana, pera y melocotón, in: Viñas, I., Recasens, I., Usall, J., Graell, J. (Eds.), Poscosecha de pera, manzana y melocotón. Mundi-prensa, Madrid, pp. 11–40.

Fernández-León, M.F., Fernández-León, A.M., Lozano, M., Ayuso, M.C., González-gómez, D., 2013. Altered commercial controlled atmosphere storage conditions for 'Parhenon' broccoli plants (*Brassica oleracea* L. var. *italica*). Influence on the outer quality parameters and on the health-promoting compounds. LWT - Food Sci. Technol. 50, 665–

672. https://doi.org/10.1016/j.lwt.2012.07.028

Garcia, E., Barrett, D.M., 2002. Preservtive treatments for fresh-cut fruits and vegetables, in: Lamikanra, O. (Ed.), Fresh-Cut Fruits and Vegetables: Science, Technology, and Market. CRC Press, Boca Raton, FL, USA, pp. 267–304.

Giannino, D., Gonnella, M., Russo, R., Pucci, L., Testone, G., Ciardi, M., Arnesi, G., Biancari, T., Longo, V., 2018. Antioxidant properties of minimally processed endives and escaroles vary as influenced by the cultivation site, cultivar and storage time. Postharvest Biol. Technol. 138, 82–90. https://doi.org/10.1016/j.postharvbio.2017.12.004

Gil, M.I., Allende, A., 2012. Minimal processing, in: Gómez-López, V.M. (Ed.), Decontamination of fresh and minimally processed produce. Wiley-Blackwell, Oxford, UK.

Giné Bordonaba, J., Cantin, C.M., Larrigaudière, C., López, L., López, R., Echeverria, G., 2014. Suitability of nectarine cultivars for minimal processing: The role of genotype, harvest season and maturity at harvest on quality and sensory attributes. Postharvest Biol. Technol. 93, 49–60. https://doi.org/10.1016/j.postharvbio.2014.02.007

Gunes, G., Liu, R.H., Watkins, C.B., 2002. Controlled-atmosphere effects on postharvest quality and antioxidant activity of cranberry fruits. J. Agric. Food Chem 50, 5932–5938. https://doi.org/10.1021/jf025572c

Han, C., Ji, Y., Li, M., Li, X., Jin, P., Zheng, Y., 2016. Influence of wounding intensity and storage temperature on quality and antioxidant activity of fresh-cut Welsh onions. Sci. Hortic. (Amsterdam). 212, 203–209. https://doi.org/10.1016/j.scienta.2016.10.004

Hwang, I.G., Shin, Y.J., Lee, S., Lee, J., Yoo, S.M., 2012. Effects of different cooking methods on the antioxidant properties of red pepper (*Capsicum annuum* L.). Prev. Nutr. Food Sci. 17, 286–292. https://doi.org/10.3746/pnf.2012.17.4.286

Kader, A., 2002. Quality parameters of fresh-cut fruit and vegetable products, in: Lamikanra, O.

(Ed.), Fresh-Cut Fruits and Vegetables: Science, Technology, and Market. CRC Press, Boca Raton, FL, USA.

Laurila, E., Ahvenainen, R., 2002. Minimal processing of fresh fruits and vegetables, in: Jongen, W. (Ed.), Fruit and Vegetable Processing. Improving Quality. CRC Press, Boca Raton, FL, USA, pp. 288–309.

Li, H., Zhu, Y., Luo, F., He, H., Yuan, H., Gao, J., Zeng, X., Huang, C., 2015. Use of controlled atmospheres to maintain postharvest quality and improve storage stability of a novel red-fleshed kiwifruit (*Actinidiachinensis Planch*. var. *rufopulpa* [C.F. Liang et R.H. Huang] C.F. Liang et A.R. Ferguson). J. Food Process. Preserv. 39, 907–914. https://doi.org/10.1111/jfpp.12303

Licciardello, F., Pandino, G., Barbagallo, R.N., Lombardo, S., Restuccia, C., Muratore, G., Mazzaglia, A., Strano, M.G., Mauromicale, G., 2017. Quality traits of ready-to-use globe artichoke slices as affected by genotype, harvest time and storage time. Part II: Physiological, microbiological and sensory aspects. LWT - Food Sci. Technol. 79, 554–560. https://doi.org/10.1016/j.lwt.2016.11.003

Melo, C.O., Moretti, C.L., Machado, C.M.M., Mattos, L.M., Muniz, L.B., 2012. Alterações físicas e químicas em cebolas armazenadas sob refrigeração. Ciência Rural 42, 2078–2084. https://doi.org/10.1590/S0103-84782012001100027

Ministere de l’Economic des Finances et du Budget, 1988. Marché consommation, produits vegetaus prêts à l’ emploi dits de la ‘IVemme gamme’: guide de bonnes pratique hygiéniques. J. Off. la République Française 1–29.

Mohammed, A.R., Tarpley, L., 2009. Impact of high nighttime temperature on respiration, membrane stability, antioxidant capacity, and yield of rice plants. Crop Sci. 49, 313–322. https://doi.org/10.2135/cropsci2008.03.0161

Muratore, G., Restuccia, C., Licciardello, F., Lombardo, S., Pandino, G., Mauromicale, G.,

2015. Effect of packaging film and antibrowning solution on quality maintenance of minimally processed globe artichoke heads. Innov. Food Sci. Emerg. Technol. 31, 97–104. https://doi.org/10.1016/j.ifset.2015.06.010

Nogales-Delgado, S., Fuentes-Pérez, M. del C., Ayuso-Yuste, C., Bohoyo-Gil, D., 2014. Study of different nectarine cultivars and their suitability for fresh-cut processing. Int. J. Food Sci. Technol. 49, 114–120. https://doi.org/10.1111/ijfs.12282

Nuutila, A.M., Puupponen-Pimia, R., Aarni, M., Oksman-Caldentey, K.-M., 2003. Comparison of antioxidant activities of onion and garlic extracts by inhibition of lipid peroxidation and radical scavenging activity. Food Chem. 81, 485–493. https://doi.org/10.1016/S0308-8146(02)00476-4

Odriozola-Serrano, I., Soliva-Fortuny, R., Martín-Belloso, O., 2008. Effect of minimal processing on bioactive compounds and color attributes of fresh-cut tomatoes. LWT - Food Sci. Technol. 41, 217–226. https://doi.org/10.1016/j.lwt.2007.03.002

Özden, Ç., Bayindirli, L., 2002. Effects of combinational use of controlled atmosphere, cold storage and edible coating applications on shelf life and quality attributes of green peppers. Eur. Food Res. Technol. 214, 320–326. https://doi.org/10.1007/s00217-001-0448-z

Palermo, M., Pellegrini, N., Fogliano, V., 2014. The effect of cooking on the phytochemical content of vegetables. J. Sci. Food Agric. 94, 1057–1070. https://doi.org/10.1002/jsfa.6478

Petropoulos, S.A., Ntatsi, G., Fernandes, Barros, L., Barreira, J.C.M., Ferreira, I.C.F.R., Antoniadis, V., 2016a. Long-term storage effect on chemical composition, nutritional value and quality of Greek onion landrace 'vatikiotiko'. Food Chem. 201, 168–176. https://doi.org/10.1016/j.foodchem.2016.01.095

Petropoulos, S.A., Ntatsi, G., Ferreira, I.C.F.R., 2016b. Long-term storage of onion and the factors that affect its quality: A critical review. Food Rev. Int. 33, 62–83. https://doi.org/10.1080/87559129.2015.1137312

Praeger, U., Ernst, M., Weichmann, J., 2003. Effects of ultra low oxygen storage on postharvest quality of onion bulbs (*Allium cepa* L. var. *cepa*). Eur. J. Hortic. Sci. 68, 14–19.

Qadri, O.S., Yousuf, B., Srivastava, A.K., 2015. Fresh-cut fruits and vegetables: Critical factors influencing microbiology and novel approaches to prevent microbial risks - A review. Cogent Food Agric. 1, 1–11. https://doi.org/10.1080/23311932.2015.1121606

Rawson, A., Hossain, M.B., Patras, A., Tuohy, M., Brunton, N., 2013. Effect of boiling and roasting on the polyacetylene and polyphenol content of fennel (*Foeniculum vulgare*) bulb. Food Res. Int. 50, 513–518. https://doi.org/10.1016/j.foodres.2011.01.009

Rico, D., Martín-Diana, A.B., Barat, J.M., Barry-Ryan, C., 2007. Extending and measuring the quality of fresh-cut fruit and vegetables: a review. Trends Food Sci. Technol. 18, 373–386. https://doi.org/10.1016/j.tifs.2007.03.011

Rodrigues, A.S., Almeida, D.P.F., García-Falcón, M.S., Simal-Gándara, J., Pérez-Gregorio, M.R., 2012. Postharvest storage systems affect phytochemical content and quality of traditional portuguese onion cultivars. Acta Hortic. 934, 1327–1334.

Sans, S., Casals, J., Simó, J., 2018. Improving the commercial value of the 'Calçot' (*Allium cepa* L .) Landrace : Influence of genetic and environmental factors in chemical composition and sensory attributes. Front. Plant Sci. 9, 1–12. https://doi.org/10.3389/fpls.2018.01465

Sekara, A., Pokluda, R., Del Vacchio, L., Somma, S., Caruso, G., 2017. Interactions among genotype, environment and agronomic practices on production and quality of storage onion (*Allium cepa* L.) - A review. Hortic. Sci. 44, 21–42. https://doi.org/10.17221/92/2015-HORTSCI

Sharma, K., Ko, E.Y., Assefa, A.D., Ha, S., Nile, S.H., Lee, E.T., Park, S.W., 2015. Temperature-dependent studies on the total phenolics, flavonoids, antioxidant activities, and sugar content in six onion varieties. J. Food Drug Anal. 23, 243–252.

https://doi.org/10.1016/j.jfda.2014.10.005

Silveira, A.C., Oyarzún, D., Sepúlveda, A., Escalona, V., 2017. Effect of genotype, raw-material storage time and cut type on native potato suitability for fresh-cut elaboration. Postharvest Biol. Technol. 128, 1–10. https://doi.org/10.1016/j.postharvbio.2017.01.011

Simó, J., Casañas, F., Muñoz, P., 2015. Els calçots i el seu cultiu [WWW Document]. Doss. Tècnic número 75, "Varietats Veg. Tradic. catalanes Els calçots". URL http://ruralcat.gencat.cat/documents/20181/160840/DLFE-33260.pdf/3168f13a-490d-44d7-8432-a3935998cf8b

Simó, J., del Castillo, R., Almirall, A., Casanas, F., 2012. `Roquerola' and `Montferri', first improved onion (*Allium cepa* L.) cultivars for 'Calcots' production. Hortscience 47, 801–802.

Simó, J., Valero, J., Plans, M., Romero del Castillo, R., Casañas, F., 2013. Breeding onions (*Allium cepa* L.) for consumption as 'calçots' (second-year resprouts). Sci. Hortic. (Amsterdam). 152, 74–79. https://doi.org/10.1016/j.scienta.2013.01.011

Simon, A., 2008. Quality characteristics of cauliflower cultivars for minimal processing. ITEA-INFORMACION Tec. Econ. Agrar. 104, 31–41.

Singh, S.P., Singh, Z., 2013. Controlled and modified atmospheres influence chilling injury, fruit quality and antioxidative system of Japanese plums (*Prunus salicina* Lindell). Int. J. Food Sci. Technol. 48, 363–374. https://doi.org/10.1111/j.1365-2621.2012.03196.x

Singleton, V., Orthofer, R., Lamuela-Raventós, R.M., 1999. Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. METHODS Enzimol. 299, 152–178.

Tiwari, U., Cummins, E., 2013. Factors influencing levels of phytochemicals in selected fruit and vegetables during pre- and post-harvest food processing operations. Food Res. Int. 50, 497–506. https://doi.org/10.1016/j.foodres.2011.09.007

Vandekinderen, I., Devlieghere, F., De Meulenaer, B., Veramme, K., Ragaert, P., Van Camp, J., 2008. Impact of decontamination agents and a packaging delay on the respiration rate of fresh-cut produce. Postharvest Biol. Technol. 49, 277–282. https://doi.org/10.1016/j.postharvbio.2008.01.011

Wang, S.Y., Zheng, W., 2001. Effect of plant growth temperature on antioxidant capacity in strawberry. J Agric Food Chem 49, 4977–4982. https://doi.org/jf0106244 [pii]

Watada, A.E., Ko, N.P., Minott, D.A., 1996. Factors affecting quality of fresh-cut horticultural products 9, 115–125.

Wibowo, S., Vervoort, L., Tomic, J., Santiago, J.S., Lemmens, L., Panozzo, A., Grauwet, T., Hendrickx, M., Van Loey, A., 2015. Colour and carotenoid changes of pasteurised orange juice during storage. Food Chem. 171, 330–340. https://doi.org/10.1016/j.foodchem.2014.09.007

Zudaire, L., Viñas, I., Abadias, M., Simó, J., Echeverria, G., Plaza, L., Aguiló-Aguayo, I., 2017. Quality and bioaccessibility of total phenols and antioxidant activity of *calçots* (*Allium cepa* L.) stored under controlled atmosphere conditions. Postharvest Biol. Technol. 129, 118–128. https://doi.org/10.1016/j.postharvbio.2017.03.013

FIGURE CAPTIONS

Fig. 1 Antioxidant activity (DPPH and FRAP methods) (A and B) and total phenolic content (C) of whole *calçots* after 30 d of postharvest storage time and after thermal processing (270 °C; 8 min). Different capital letters in the sample and state (raw or roasted) indicate significant differences between postharvest storage times ($P<0.05$). Different lower-case letters indicate significant differences between raw and roasted samples at the same postharvest storage time ($P<0.05$).

Fig. 2 Total mesophilic bacteria (TMB) counts of fresh-cut *calçots* along refrigerated storage time at 4 °C. A: V1 (●), B: V2 (■); C: V3 (♦) and D: V4 (▲). The continuous line is for samples stored for 15 d and the dotted line for those stored for 30 d. BT: Before disinfection treatment. AT: After disinfection treatment.

Fig. 3 Yeast counts of fresh-cut *calçots* along refrigerated storage time at 4 °C. A: V1 (●), B: V2 (■); C: V3 (♦) and D: V4 (▲). The continuous line is for samples stored for 15 d and the dotted line for those stored for 30 d. BT: Before disinfection treatment. AT: After disinfection treatment.

Fig. 4 Molds counts of fresh-cut *calçots* along refrigerated storage time at 4 °C. A: V1 (●), B: V2 (■); C: V3 (♦) and D: V4 (▲). The continuous line is for samples stored for 15 d and the dotted line for those stored for 30 d. BT: Before disinfection treatment. AT: After disinfection treatment.

SUPPLEMENTARY DATA

Fig. 1 (Sup) Color difference (ΔE^*) of fresh-cut calçots along refrigerated storage time at 4 °C. A: V1 (●), B: V2 (■); C: V3 (♦) and D: V4 (▲). The continuous line is for samples stored for 15 d and the dotted line for those stored for 30 d.

Fig. 2 (Sup) Firmness retention (%) of fresh-cut calçots along refrigerated storage time at 4 °C. A: V1 (●), B: V2 (■); C: V3 (♦) and D: V4 (▲). The continuous line is for samples stored for 15 d and the dotted line for those stored for 30 d.

TABLES

Table 1. Soil properties at the two locations.

Trait	La Juncosa	Viladecans
Soil pH	8.40	8.43
Electrical conductivity 25 °C (ds m^{-1})	0.174	0.275
Organic matter (%)	1.30	1.10
Calcium carbonate equivalent (%)	47	32
Nitrogen (mg N-NO3 kg^{-1})	14	47
Phosphorus (mg kg^{-1})	36	49
Potassium (mg kg^{-1})	626	293
Calcium (mg kg^{-1})	6,828	6,863
Magnesium (mg kg^{-1})	531	337
Sodium (mg kg^{-1})	17	104
Cation exchange capacity (cmol kg^{-1})	15.7	9.9

Data provided by Sans et al. (2018).

Table 2. Climatic data (ºC) of the two locations.

Location	August		September		October		November		December	
	Mean min.	**Mean max.**	**Mean min.**	**Mean max.**	**Mean min.**	**Mean max.**	**Mean min.**	**Mean max.**	**Mean min.**	**Mean max.**
La Juncosa	17.0	29.6	13.5	24.2	10.9	20.4	8.5	18.1	7.1	15.6
Viladecans	20.2	30.6	16.8	26.1	13.2	22.6	8.9	19.6	7.2	17.1

Data provided by Sans et al. (2018). Mean min.: mean of monthly minimum temperatures; Mean max.: mean of monthly maximum temperatures.

Table 3. The combinations tested.

Samples	Cultivar	Cultivation site	Planting time
V1	Montferri	La Juncosa	Early
V2	Traditional	Viladecans	Early
V3	Montferri	Viladecans	Late
V4	Montferri	Viladecans	Early

Table 4. Morphologic parameters of *calçots* at harvest and after 15 and 30 d of postharvest storage at 1 °C.

Samples	Time (days)	Width (mm)	Length (cm)	Weight (g)
V1	0	26.9 ± 6.3 A	8.2 ± 0.9 A	82.5 ± 22.9 A
	15	25.8 ± 5.8 A	8.6 ± 0.7 A	77.6 ± 21.8 A
	30	26.2 ± 5.2 A	8.9 ± 0.7 A	69.7 ± 19.1 A
V2	0	23.5 ± 6.1 A	10.1 ± 1.3 A	86.6 ± 33.6 A
	15	22.7 ± 5.8 A	10.9 ± 1.1 A	82.4 ± 32.8 A
	30	22.6 ± 5.7 A	10.4 ± 0.6 A	72.1 ± 29.0 A
V3	0	30.0 ± 3.9 A	12.7 ± 1.9 A	122.5 ± 16.7 A
	15	29.6 ± 2.7 A	12.8 ± 0.9 A	116.8 ± 15.5 AB
	30	29.2 ± 2.7 A	12.7 ± 0.7 A	104.0 ± 13.3 B
V4	0	22.3 ± 4.0 A	11.5 ± 1.0 A	85.2 ± 28.1 A
	15	22.1 ± 3.7 A	12.7 ± 0.9 A	82.1 ± 23.3 A
	30	22.5 ± 3.8 A	11.6 ± 0.8 A	74.4 ± 21.3 A

For each sample, different capital letters in the same column indicate significant differences between postharvest storage times ($P<0.05$) for each sample.

Table 5. Quality parameters of *calçots* at harvest and after 15 and 30 d of postharvest storage at 1 °C.

Samples	**Time (days)**	**BI**	**Firmness (N)**	**SSC (%)**	**TA (g malic acid L^{-1})**	**pH**	**Respiration rate (mL CO_2 kg^{-1} h^{-1})**
V1	0	6.3 ± 1.8 B	123.4 ± 24.6 A	12.5 ± 0.3 B	2.7 ± 0.0 B	5.7 ± 0.0 C	16.4 ± 2.4 A
	15	7.9 ± 3.5 A	109.9 ± 34.3 A	12.1 ± 0.0 C	2.5 ± 0.2 B	5.9 ± 0.0 B	29.0 ± 0.2 A
	30	8.4 ± 1.6 A	89.1 ± 28.2 A	16.0 ± 0.1 A	3.8 ± 0.2 A	6.1 ± 0.0 A	25.5 ± 5.2 A
V2	0	6.2 ± 1.6 B	98.3 ± 17.1 A	10.6 ± 0.2 B	1.5 ± 0.2 B	5.7 ± 0.0 C	11.9 ± 1.4 B
	15	7.6 ± 2.5 A	76.6 ± 29.3 A	10.6 ± 0.1 B	1.7 ± 0.1 B	5.8 ± 0.0 B	24.7 ± 4.2 A
	30	7.4 ± 2.0 A	86.3 ± 20.0 A	15.9 ± 0.1 A	2.2 ± 0.1 A	6.1 ± 0.0 A	17.4 ± 1.4 AB
V3	0	4.8 ± 0.9 B	127.3 ± 25.3 A	12.6 ± 0.4 B	1.5 ± 0.1 B	5.6 ± 0.0 C	10.1 ± 1.4 B
	15	6.1 ± 2.5 A	90.6 ± 21.3 B	11.4 ± 0.0 C	1.8 ± 0.2 AB	5.8 ± 0.0 B	27.4 ± 4.2 A
	30	6.9 ± 1.7 A	80.9 ± 15.6 B	16.0 ± 0.1 A	1.9 ± 0.1 A	6.0 ± 0.0 A	18.3 ± 2.4 B
V4	0	8.3 ± 3.6 A	107.8 ± 22.8 A	10.6 ± 0.0 C	1.9 ± 0.1 B	5.7 ± 0.0 C	11.9 ± 1.4 B
	15	5.8 ± 2.1 B	116.3 ± 40.5 A	11.1 ± 0.1 B	1.9 ± 0.1 B	5.8 ± 0.0 B	13.6 ± 1.4 AB
	30	6.4 ± 5.6 AB	86.4 ± 20.1 A	15.9 ± 0.1 A	2.2 ± 0.0 A	5.9 ± 0.0 A	25.6 ± 5.0 A

Values are expressed as mean ± standard deviation. For each sample, different capital letters in the same column indicate significant differences between postharvest storage times ($P<0.05$).

Table 6. Quality parameters of fresh-cut *calçots* after refrigerated storage (10 d) at 4 °C. Values are expressed as mean ± standard deviation.

Postharvest Storage	Samples	Time (d)	SSC (%)	TA (g L^{-1})	pH
15 days	V1	0	14.5 ± 0.0 Aa	3.9 ± 0.2 Aa	5.9 ± 0.0 Ab
		3	14.6 ± 0.1 Aa	3.1 ± 0.2 Bb	5.9 ± 0.0 Aa
		7	14.2 ± 0.1 Ab	2.7 ± 0.1 Cb	5.7 ± 0.0 Bb
		10	14.6 ± 0.4 Aa	3.4 ± 0.1 Ba	5.8 ± 0.0 Ab
	V2	0	9.9 ± 0.1 Bb	2.7 ± 0.0 Aa	5.9 ± 0.0 Ab
		3	9.8 ± 0.0 Bb	2.0 ± 0.0 Cb	5.8 ± 0.0 Cb
		7	9.8 ± 0.0 Bb	1.9 ± 0.2 Ca	5.8 ± 0.0 Db
		10	11.7 ± 0.1 Aa	2.3 ± 0.1 Ba	5.9 ± 0.0 Bb
	V3	0	12.3 ± 0.0 Ab	1.6 ± 0.1 Ab	5.8 ± 0.0 ABb
		3	11.9 ± 0.1 Bb	1.6 ± 0.0 Ab	5.8 ± 0.0 Bb
		7	11.2 ± 0.0 Cb	1.7 ± 0.2 Aa	5.7 ± 0.0 Bb
		10	10.7 ± 0.2 Db	1.8 ± 0.0 Ab	5.8 ± 0.0 Ab
	V4	0	10.9 ± 0.1 Bb	2.3 ± 0.1 Aa	5.8 ± 0.0 Bb
		3	10.9 ± 0.0 Bb	2.1 ± 0.2 Aa	5.8 ± 0.0 Ba
		7	10.0 ± 0.0 Cb	1.6 ± 0.2 Bb	5.8 ± 0.0 Cb
		10	11.6 ± 0.1 Aa	2.0 ± 0.2 ABb	6.0 ± 0.0 Aa
30 days	V1	0	13.9 ± 0.0 Bb	4.0 ± 0.2 ABa	6.0 ± 0.0 Aa
		3	13.3 ± 0.1 Cb	3.7 ± 0.3 Ba	5.8 ± 0.0 Db
		7	14.4 ± 0.1 Aa	4.3 ± 0.1 Aa	5.9 ± 0.0 Ca
		10	13.4 ± 0.0 Cb	3.6 ± 0.1 Ba	5.9 ± 0.0 Ba
	V2	0	10.1 ± 0.1 Ca	2.4 ± 0.3 Aa	6.0 ± 0.0 Aa
		3	11.3 ± 0.1 Aa	2.4 ± 0.2 Aa	5.9 ± 0.0 Ba
		7	10.4 ± 0.1 Ba	2.1 ± 0.1 Aa	5.9 ± 0.0 Ba
		10	10.4 ± 0.0 Cb	2.4 ± 0.2 Aa	6.0 ± 0.0 Ba
	V3	0	11.3 ± 0.1 Da	1.9 ± 0.1 Ba	5.9 ± 0.0 ABa
		3	12.4 ± 0.0 Aa	2.0 ± 0.1 Ba	5.8 ± 0.0 Ca
		7	11.8 ± 0.1 Ca	1.9 ± 0.1 Ba	5.8 ± 0.0 BCa
		10	12.2 ± 0.0 Ba	2.3 ± 0.0 Aa	5.9 ± 0.0 Aa
	V4	0	11.8 ± 0.1 Aa	2.0 ± 0.0 Ab	6.0 ± 0.0 Aa
		3	11.2 ± 0.1 Ba	2.5 ± 0.4 Aa	5.9 ± 0.0 Ba
		7	10.4 ± 0.0 Ca	2.3 ± 0.3 Aa	5.9 ± 0.0 Ba
		10	11.1 ± 0.1 Bb	2.5 ± 0.2 Aa	5.9 ± 0.0 Bb

Different capital letters in the same column and sample indicate significant differences between refrigerated storage times (P<0.05) for each sample. Different lower case letters in the same refrigerated storage day indicate significant differences between postharvest storage times (P<0.05) for each sample

Figure 1

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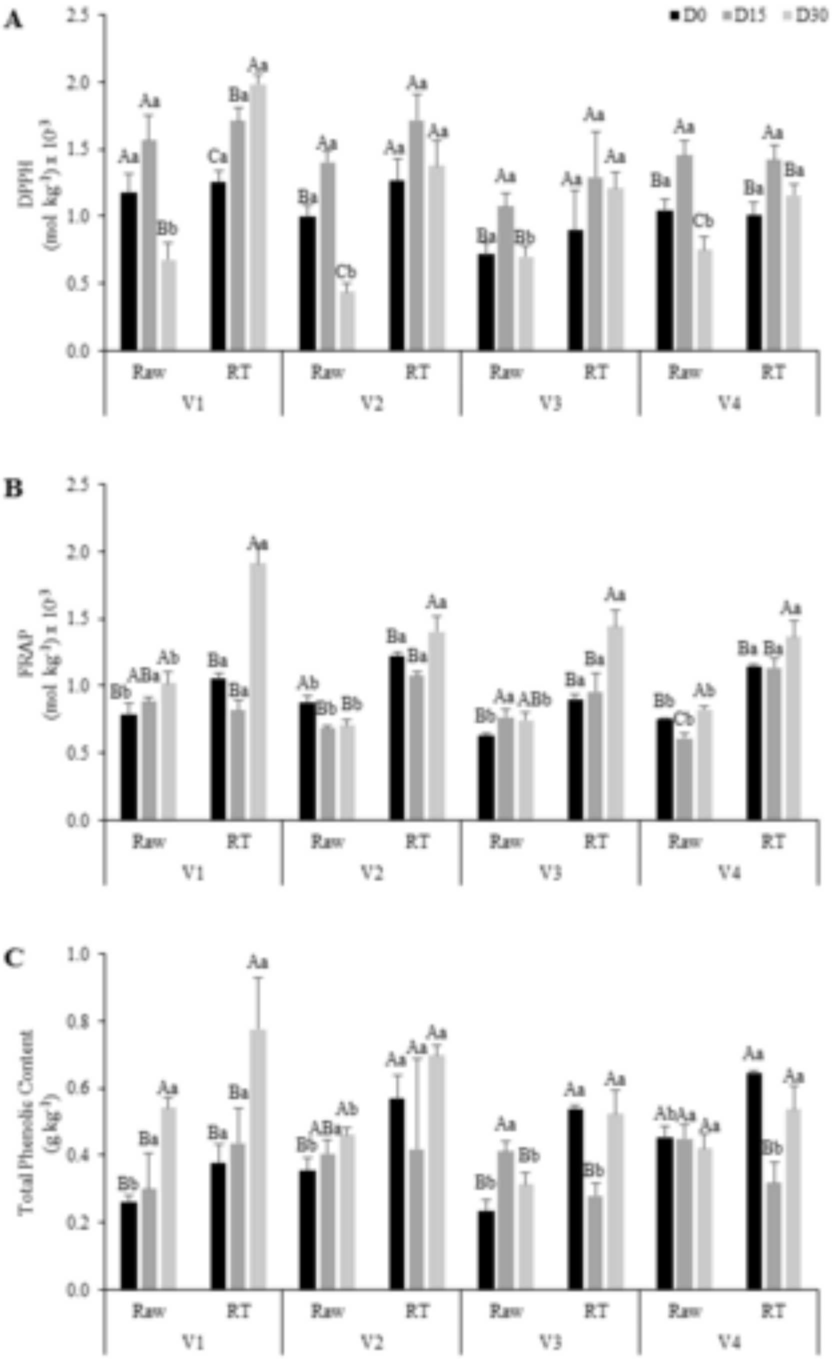

Figure 2
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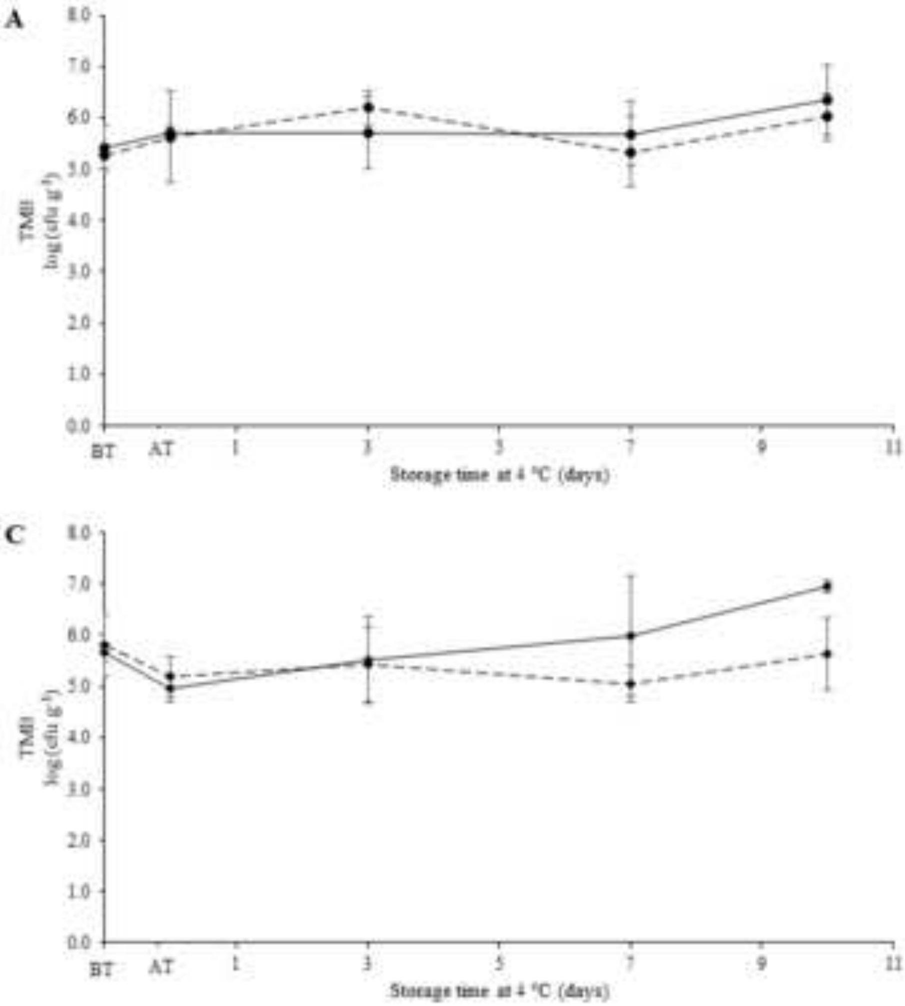

Figure 3

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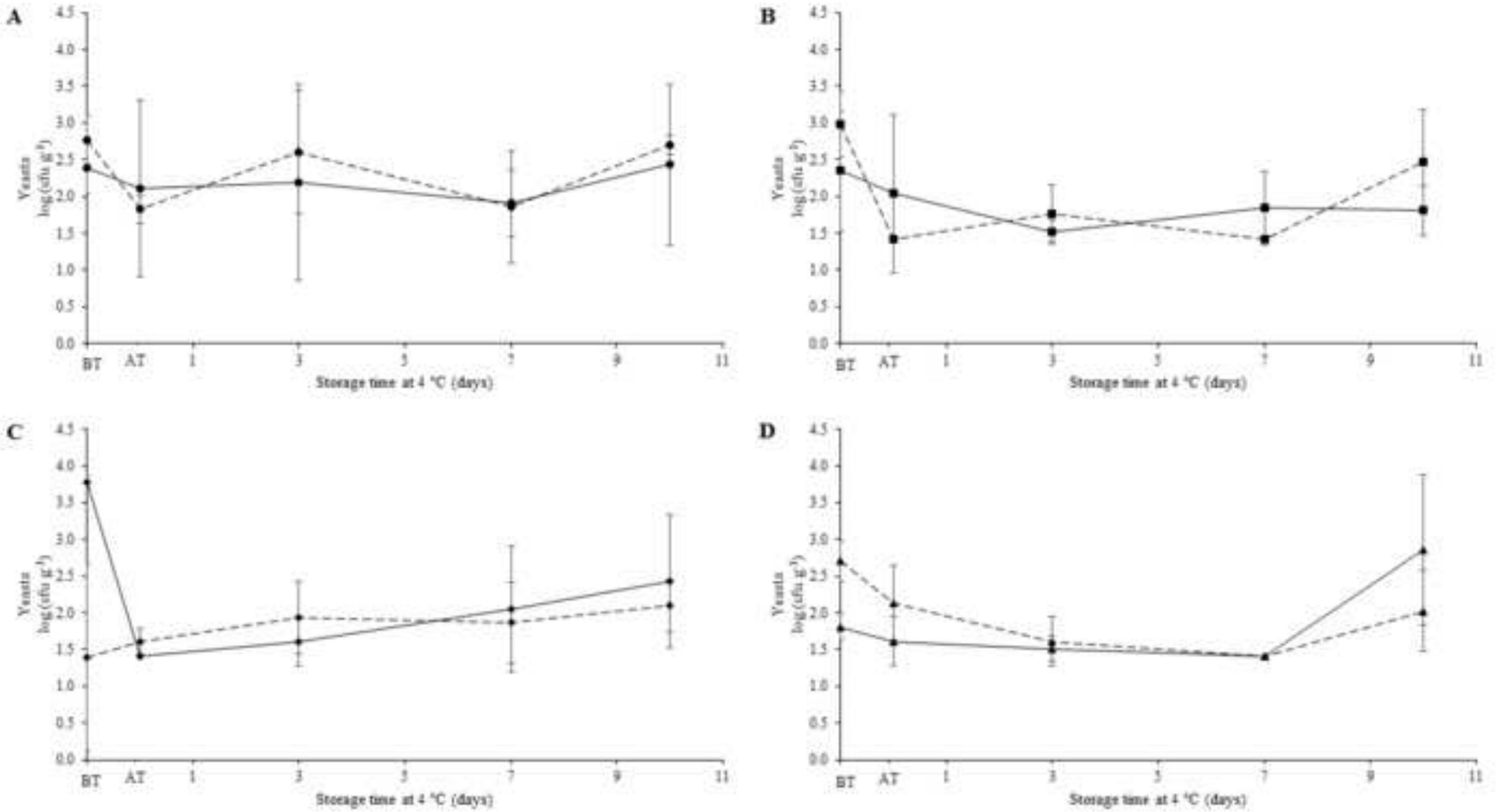

Figure 4

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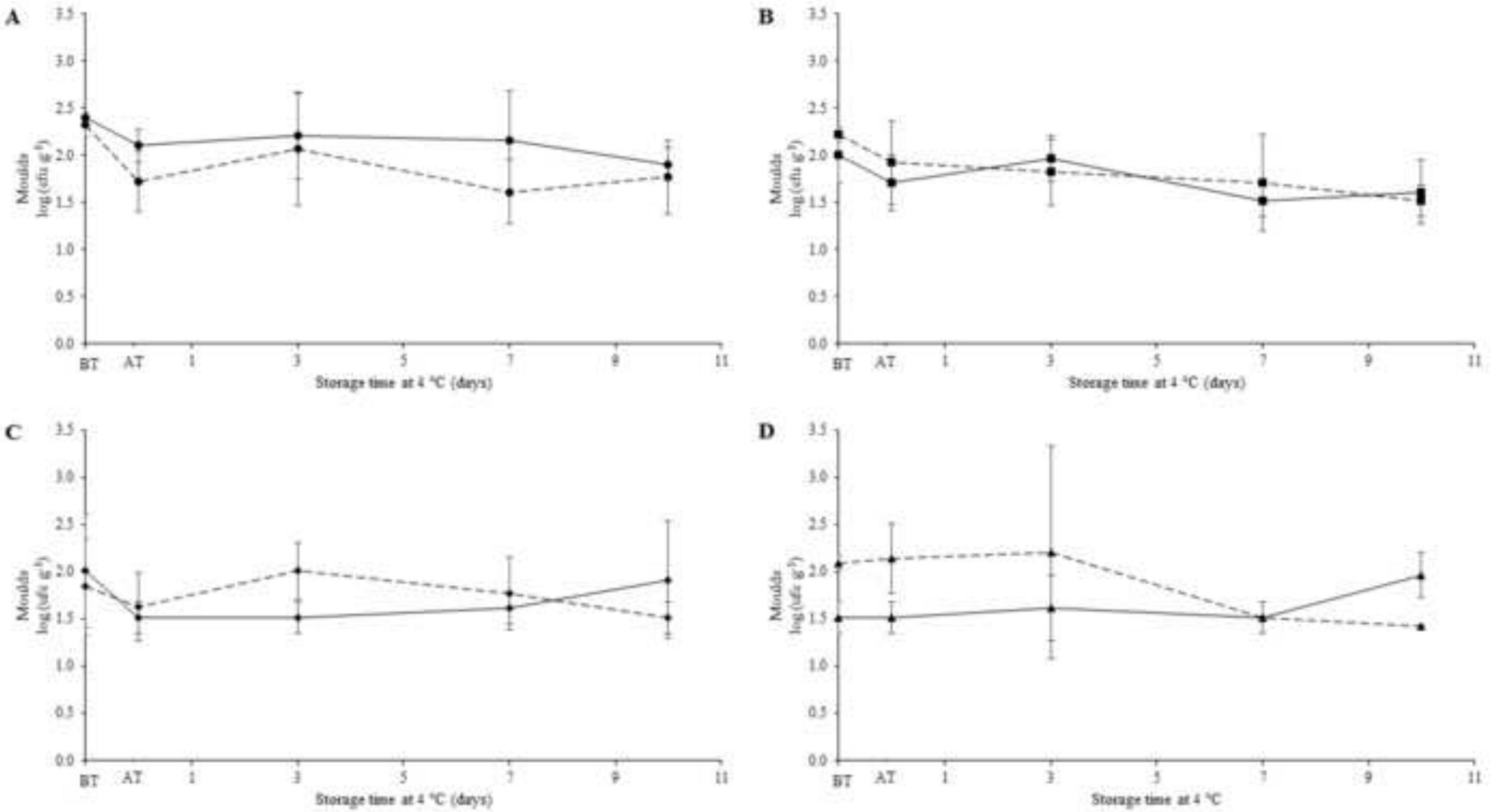

Supplementary Material - FIG1

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Supplementary Material - FIG2

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