



Research article

Geographical indication (GI) branded quality: a study case on the homogeneity of the Carota Novella di Ispica Region

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Abstract: Quality criteria for fresh produce are often underestimated in the industry, as the majority of parameters regulated are visual. Consequentially, this negatively affects the physicochemical, nutraceutical and organoleptic properties of the end product offered to the consumer. To deal with this, more information is required about the pre- and postharvest development of quality-related parameters. The aim of this work was to evaluate the postharvest quality of four different carrot cultivars of the Carota Novella di Ispica brand. The brand is protected by geographical indication and is well known around Italy for its high quality. Carrots were exposed to standard commercial storage conditions for 6 weeks. Samples were collected at the beginning, after 3 weeks and at the end of the period. At each time point, physicochemical, nutraceutical and organoleptic parameters were evaluated. The results show that the four cultivars are of high overall quality and are generally homogenous among parameters.

Keywords: *Daucus carota*; variety; brand; quality; storage

1. Introduction

Globalization leads to the breakdown of barriers and to free international trade. In the context of the agricultural industry, this means that food is no longer seasonal, as imports and exports allow year-round availability of fruits, vegetables, grains and other products of the industry. This globalization of the trade and marketing of fruit and vegetable (F&V) products can negatively affect

sustainable land use, small-scale producers, and the authenticity and tradition of products coming from a specific geographical territory [1]. To satisfy the desires of some of the most demanding consumers in the world, different governments such as Italy, Spain and France strictly follow the DOP-IGP system, in which importance is placed not on high yields but on the organoleptic quality of the product [2] and its linkage with the ‘terroir’. The literature shows that protection of geographical indications (GIs) can be a direct driver for food safety as it promotes transparency of the production process [3]. It also ensures stricter regulation of all production steps as protected products normally fall into their specific, more restrictive, regulations. Moreover, it has been shown that IGP schemes improve local ecosystems and biodiversity, suggesting more sustainable use of arable land. All this affects the customers’ perception and they are typically more prone to pay more for an exclusive brand [3,4]. Considering F&V products, for a territorial brand to meet GI standards, it is essential that all the varieties that are marked with the same name are of homogenous quality; this is also fundamental in management of the product’s postharvest storage. The quality criteria of fresh products are often underestimated in the industry, as the majority of parameters regulated are visual. Consequentially, this negatively affects the physicochemical, nutraceutical and organoleptic properties of the end product offered to the consumer. To deal with this, more information is required about the pre- and postharvest development of quality-related parameters.

1.1. Case study: Carota Novella di Ispica

The main focus of this study was to assess the postharvest quality of different varieties of whole raw carrots (*Daucus carota* L.) that take part in the GI brand of Ispica territory (RG), Italy. One reason for the focus on *D. carota* is that literature provides limited information about the overall quality and deterioration of whole raw carrots [5–7]; further research is important as carrots are in the top 10 most consumed vegetables across the world and seventh in the list of the top dietary contributors of nutrition [6,8]. Most research has focused on ready-to-eat cut carrots or processed carrot products such as purees, canned product and carrot-based baby food. Important parameters of carrot quality are colour and crunchiness, although many authors suggest that the most important is sweetness [8]. As mentioned above, information about whole raw carrots is scarce; however, it is known that the sugar (e.g. sucrose) concentration increases over time even though it is variable between cultivars and affected by other factors such as inadequate agronomical practices or inappropriate temperature during storage [6]. These factors also affect the nutraceutical value of the vegetables. Carrots are rich in phenolic compounds—potent antioxidants with anti-inflammatory properties, and carotenoids—precursors of vitamin A, important in vision [9]. Analysing these quality parameters in a shelf-life study will be valuable for investigating how sensorial and physicochemical characteristics relate to the nutrition of the crop. Moreover, this may help the industry to develop new, cost-efficient and non-destructive protocols for evaluating quality. By assessing carrots from the Carota Novella di Ispica brand protected by IGP, this work focused on a type of product that is characterized by a traditional production region (the Ispica region in south-eastern Sicily, Italy) and has specific and consolidated agronomical practices and distinct morphological, physical, chemical-nutritional and organoleptic quality. The Ispica area is on a plain (up to an altitude of 550 m above sea level) and includes 16 municipalities, between the provinces of Ragusa, Siracusa, Catania and Caltanissetta. The growing area is characterized by a semi-arid Mediterranean climate with mild winters, often rainless springs, and hot and dry summers.

Soils (with a sandy loam texture and good availability of organic matter) are generally well exposed to light between September and March. All of this is described in the related standard imposed by the Italian Ministry of Agriculture [10]. Ispica carrots must be from the extra or class I categories of varieties with a semi-long root type or their hybrids. Currently, the varieties allowed in the specification are Exelsa, Dordogne, Nanco, Naval, Chambor and Selene. New varieties can be added only if they comply with the specific requirements. Morphologically, carrots must be uniform in colour and shape, ranging in diameter from 15 mm (50 g in weight) to 40 mm (150 g). Chemically and nutritionally, fresh roots must have a total sugar content in the range of 3% to 10% of the dry weight (DW) [11] and a β -carotene content of more than 4 mg/100 g fresh weight. The minimum organoleptic quality should be in the middle of the scale, with values of 2.5 (on a 1–5 scale) for attributes such as colour intensity, typical carrot smell, herbaceous aroma and crunchiness [10]. Furthermore, unpublished information shows that Dordogne, the cultivar that is typically used as a reference of excellent quality and is a classical variety for the Ispica brand, is now experiencing problems such as susceptibility to biotic stress and thus lower yields. Furthermore, the same variety presents a high number of roots not compliant with size requirements and its seed is not available to growers who are commercializing carrots on large scale. In practice, this means that producers need to know how Dordogne compares to other cultivars so they are able to replace it effectively. The Ispica carrots under investigation are offered by a major Italian supermarket chain under a premium private label (PPL). The GI and PPL proposal is to raise the quality bar for the carrots, suggesting a unique and indeed premium quality to customers. However, poor and indiscriminate postharvest management of PPL products by retail platforms and stores may lead to a severe loss of quality during shelf life, leaving the customer with Ispica carrots not compliant with the standards. This could result in a negative perception of the product or the retailer's image as the customer will have a negative experience of the product. This is why it is important to know how the product evolves over time. Moreover, marketing of the carrots is limited to February, March, April and May, so producers and distributors are interested in varieties that would allow extension of the marketing period. Considering these topics, in this study, four different cultivars (Namibia, Novara, Soprano, Dordogne) were compared in the postharvest period to evaluate brand homogeneity and extrapolate different correlations between quality parameters.

2. Materials and methods

Four cultivars of *Daucus carota* L. (Namibia, Novara, Soprano, Dordogne) were provided by the Carota Novella di Ispica Consortium (Ragusa, Italy). Samples were harvested at random and on the same date, ensuring that there was no bias involved in the process. Any safety washing treatments (cold running water at +8 °C to remove dirt from the surface) were performed before the qualitative analysis. Samples were stored at the Department of Agricultural, Forest and Food Sciences (Disafa) of the University of Torino for up to 6 weeks at 4 °C, at 98% RH in dark conditions. Qualitative analysis was performed at T0 (before storage), T1 (after 3 weeks of storage) and T2 (at the end of the storage period).

2.1. Qualitative analysis

The total soluble solids content (TSS/°Brix) was determined by digital refractometer (Atago,

PAL-1). Juice from each sample was extracted and five independent measurements were recorded for each variety. Sample hardness was quantified by a GUSS Fruit Texture Analyser (FTA) using a 2 mm standard penetration head. The FTA was set at 68 g trigger threshold, 10 mm/s measure speed and 10 mm measure distance. Reverse and forward speeds were set at 40 and 30 mm/s, respectively. The data were recorded by FTA standard software. Dry matter (DM) was estimated by drying three replicates of approximately 20 g of material in an oven at 70 °C for 24 h. The fresh weight (FW) and dry weight data were used to calculate the respective DM percentage. Colour was detected with a colorimeter (Konica Minolta, mod. CR-400). Each sample was measured six times along the whole root body and on both sides. The L^* , a^* and b^* parameters were recorded with Konica Minolta software (SpectraMagic NX). Deriving from L^* , a^* and b^* , other colour indexes as chroma difference (ΔC) (Eq.1), previously tested were calculated to enhance the sensitivity of the colour evaluation [12].

$$\Delta C = \sqrt{(a - a_{\text{ref}})^2 + (b - b_{\text{ref}})^2} \quad (1)$$

where a is the redness-yellowness on the tristimulus colour scale, a_{ref} is the a value of raw material, b is the greenness-blueness on the tristimulus colour scale, and b_{ref} is the b value of raw material.

2.2. Total starch content

The extraction phase was prepared as follows: 6 g of fresh carrot sample was homogenized in 60 mL of dimethyl sulfoxide (DMSO) (Sigma-Aldrich) for 1 min (or until complete homogenization). Homogenates were stirred for 24 h (room temperature). Next, 90 mL of DMSO was added to each sample to reach a final volume of 150 mL; 5 mL of the DMSO solution (in three replicates) was mixed with 15 mL of 80% ethanol (v/v) (VWR Chemicals). Ethanol solutions were centrifuged for 15 min at 3000 rpm. To prepare the final extraction solution, the supernatant was discarded and the resulting pellet was dissolved in 5 mL of 0.1 M NaOH (Alfa Aesar). The starch was digested using a modified phenol-sulphuric method [13,14]. The reaction mixture contained 0.05 mL of extraction solution, 0.45 mL of NaOH, 0.5 mL of phenol (5%) (Alfa Aesar) and 2.5 mL of sulphuric acid (Sigma-Aldrich). Samples were incubated for 30 min (or until room temperature was reached). Starch was determined colorimetrically using a spectrophotometer (UV-1800, Shimadzu Corp., Japan) at 490 nm. The blank was prepared as a reference sample in which the extraction solution was replaced with 0.05 mL of NaOH.

2.3. Carotenoids and nutraceutical compounds

Carotenoids were extracted and quantified according to a modified Lichtenthaler method [15]. One gram of sample was incubated for 24 h (4 °C) in 5 mL of acetone (> 99.5%; VWR Chemicals). After incubation, the absorbance of the supernatant at 470 nm was recorded. Total polyphenolics and antioxidant capacity were analysed following the protocol of Slinkard and Singleton (1977) using the same extraction solution; 12.5 mL of extraction solvent (500 mL of methanol, 23.8 mL of H₂O, 1.4 mL of HCl) was added to 5 g of fresh sample. Samples were incubated for 1 h at room temperature in the dark. Next, samples were homogenized for 1 min with an Ultra-Turrax T-25 tissue homogenizer (Janke and Kunkel, IKA®-Labortechnik, Saufen, Germany) followed by centrifugation

for 15 min at 3000 rpm. The resulting supernatant was kept at $-20\text{ }^{\circ}\text{C}$ until further analysis. Polyphenolics were analysed as follows: 250 μL of sample was added to 18.5 mL of H_2O , 1.25 mL of Folin-Ciocalteu reagent (Sigma-Aldrich) and 5 mL of 15% Na_2CO_3 followed by incubation for 2 h at room temperature. Absorbance was recorded at 765 nm. The results were calculated as gallic acid equivalents (GAE) (mg GAE/100 g of fresh carrots). Antioxidant capacity was determined via the FRAP test method. All reagents were prepared fresh prior to the experiment according to the Slinkard and Singleton protocol [16]. In brief, 900 μL of FRAP reagent (25 mL of 0.3 M pH 3.6 acetate buffer, 2.5 mL of 10 mM 2,4,6-tripyridyl-s-triazine in 40 mM HCl and 2.5 mL of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$; incubated for 15 min at $37\text{ }^{\circ}\text{C}$ in a water bath prior to use) was added to 90 μL of H_2O . Next, 30 μL of sample extract solution was added. Samples were incubated for 15 min in a $37\text{ }^{\circ}\text{C}$ water bath. Absorbance was measured at 595 nm. Results were expressed as $\text{mmol Fe}^{2+}/\text{kg}$ of fresh sample. Blank samples were prepared as shown for the respective analysis using extraction solvent instead of sample.

2.4. Sensorial analysis

Ten panellists from SATA srl (Alessandria, Italy) (five men and five women, 25–60 years old) were selected and trained in sensory evaluation in accordance with ISO 8586 [17]. The sensorial analysis was done between 4 p.m. and 6 p.m. The parameters evaluated (odour, crunchiness, herbaceous aroma, colour intensity, sweetness and overall liking) were ranked on a scale from 1 to 5 (1 = very low; 5 = very high). Peeled samples were cut into 10 cm-long pieces from the equatorial part of the carrots.

2.5. Statistical analysis

All statistical analyses were performed using SPSS Statistics 24 (2017, IBM, Milan, Italy) for Mac. The data were treated using analysis of variance (ANOVA) and the means separated using Tukey's test ($p \leq 0.05$). To obtain more integrated information about cultivar homogeneity, shelf-life degradation and correlation between analytical parameters, multiple factor analysis (MFA) was conducted.

3. Results and discussion

3.1. Qualitative analysis

TSS in Dordogne, Soprano and Namibia cultivars changed significantly between T0 and T2 ($p < 0.05$), while that of Novara remained stable during the whole experiment (Figure 1A). At the beginning of storage, TSS was highest in Novara and Namibia: 8.96 and 8.35 °Brix, respectively. At the end of the storage period, Novara accumulated the highest TSS (9.05 °Brix), followed by Dordogne (8.9 °Brix), Namibia (8.35 °Brix) and Soprano (7.8 °Brix). A general trend of increased TSS was observed in all cultivars, which agrees with the literature. Authors generally find that TSS increases during storage; however this effect is cultivar- and environment-dependent [7].

Carrot hardness decreased dramatically in the first part of the study (Figure 1B). At the beginning of storage, the best-performing cultivar was Novara; however by the end of the

experimental period, there was no significant difference between cultivars. Considering hardness measured by FTA as the analytical tool used to evaluate crunchiness, is it possible to affirm that the sensorial panel was in disagreement once again, as the panellists did not identify any difference in crunchiness between cultivars within the same time point and over time (Table 2). It was also proved that increased hardness will not always lead to increased crunchiness; as well as that, it is known that fresh produce, especially vegetables, can become fibrous during storage, which negatively influences the perception of crunchiness [18]. Another important attribute evaluated was the DM content (Figure 1C). In freshly harvested material, all varieties had a DM content of approximately 13%. Soprano and Novara samples showed no significant alteration of the parameter over time, while the DM content of Dordogne and Namibia decreased significantly, to 10.6% and 11.4%, respectively. Changes in percentages of dry matter content in carrot roots could be depending to the high sensitivity to low different fertilization doses that could had been apported in the field.

The trend for total starch in the postharvest experiment was different. Soprano accumulated starch towards T2, ranging from 13 g/100 g FW (at T0) to 19 g/100 g FW (at T2). In Novara and Namibia, concentrations decreased, ranging from 14 to 13 g/100 g FW and 15 to 10 g/100 g FW at T0 and T2, respectively. Dordogne accumulated starch from T0 to T1, 11 to 19 g/100 g FW, followed by a significant drop at T2 to 14 g/100 g FW (Figure 1D).

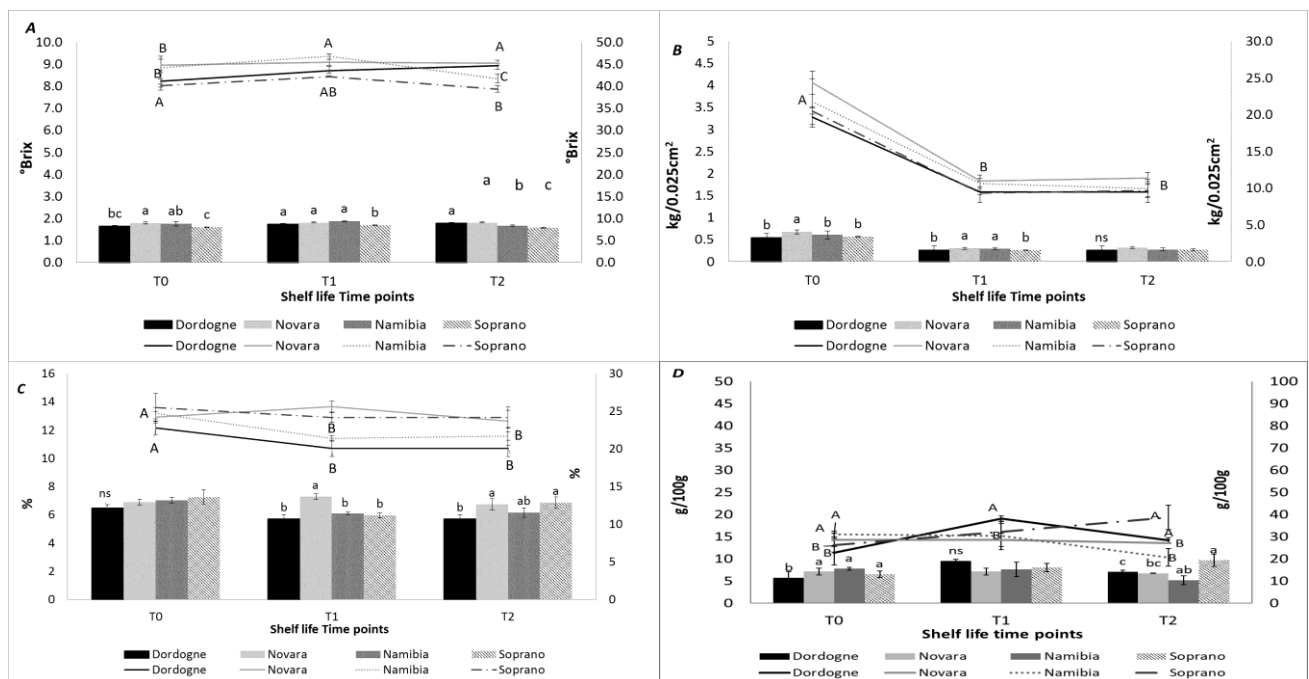


Figure 1. Physicochemical analysis of Carota Novella di Ispica brand: total soluble solids (TSS) (A), hardness (B), dry matter (C), starch content (D). Histograms depict comparisons between different cultivars within the same time point (ANOVA, Tukey HSD, $p \leq 0.05$) (scale on the left). Linear graphics present the evolution of each of the cultivars over time (ANOVA, Tukey HSD, $p \leq 0.05$) (scale on the right).

Inconsistent with predictions, the amounts of starch did not decrease. One explanation is that the amount of starch in carrots is limited and thus the analytical method adapted from Oh et al. [14]

was not rigorous enough to detect the possible changes across all samples [19]. It is well known that this method was first proposed for determining total sugars [13] and the DMSO solubilization step followed by ethanol addition could have led to the presence of other sugar compounds in the pellet and thus an interfering of the concentration.

The evaluation of pH showed that carrot acidity increased as shelf life progressed (data not shown). This trend was observed in all cultivars. The most pronounced net change of pH was observed in Dordogne. The pH changed from 5.9 to 6.5 for T0 and T2, respectively.

Considering FW, there was no statistically significant difference between varieties or within varieties. Dordogne carrots had the highest FW (76 g), followed by Namibia (57 g), Soprano (54 g) and Novara (50 g). An average water loss of 3% during storage for was found all cultivars; however, the results were statistically insignificant. This could be due to the carrots being kept at high humidity. Another reason could be that the shelf-life study was too short to allow critical water loss [18].

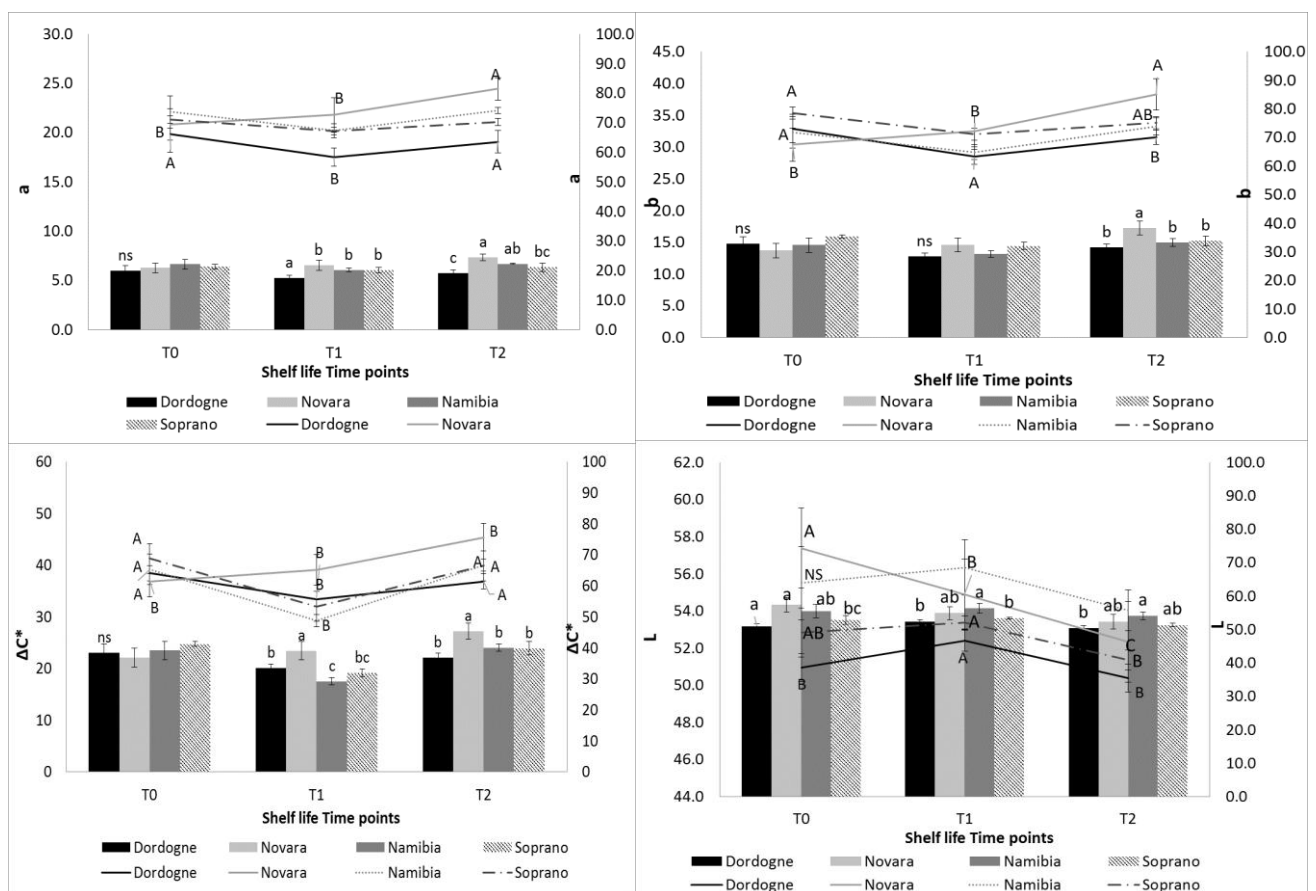


Figure 2. Colorimetric analysis of Carota Novella di Ispica brand over time (T0, T1, T2) for the following attributes: a^* (tendency to redness) b^* (tendency to yellowness), L^* (luminosity) and ΔC^* (chroma). Histograms depict comparisons between different cultivars within the same time point (ANOVA, Tukey HSD, $p \leq 0.05$) (scale on the left). Linear graphics present the evolution of each of the cultivars over time (ANOVA, Tukey HSD, $p \leq 0.05$) (scale on the right).

Colour, measured by colorimeter, showed significant changes for most parameters (Figure 2).

The tendency to redness (a*) and yellowness (b*) was significantly different within the same cultivar over time; however, between cultivars the most important difference was observed at T2. For both parameters, Novara manifested the highest values at the end of the study. Luminosity (L*) decreased in all cultivars. At the start of the experiment, there was no significant difference in colour intensity between cultivars. At T1 and T2, Dordogne, Namibia and Soprano were statistically similar, while Novara was positively and significantly superior. Regarding colour, it was hypothesized that after 6 weeks of storage, carrots would lose chroma intensity. This was partly seen in Dordogne, Soprano and Namibia, but only up to 3 weeks of storage. After that, the chroma saturation value increased again, probably due to limited loss of water and changes of pigment concentration. Interestingly, the sensorial panel did not agree with this finding, as the test subjects found that Novara and Namibia had lower intensity at T2 than Soprano and Dordogne (Table 2). Colour is difficult to evaluate by eye as it is subject to many environmental factors such as natural and artificial lighting, the human eye, etc. [20]. Therefore, assessment with a colorimeter may give more accurate results than human judgement.

Table 1. Carotenoids and nutraceutical compounds of Carota Novella di Ispica brand.

Quality control measure	Variety	T0	T1	T2
Carotenoids (mg/100 g)	Dordogne	3.22 ± 0.2 ns*	3.25 ± 0.4 ns	3.18 ± 0.3 ns
	Novara	3.08 ± 0.4 ab	2.66 ± 0.1 b	3.44 ± 0.1 a
	Namibia	3.82 ± 0.5 a	2.23 ± 0.1 b	2.92 ± 0.1 b
	Soprano	2.67 ± 0.3 b	2.58 ± 0.2 b	3.50 ± 0.1 a
Total polyphenolics (mg GAE/100 g)	Dordogne	20.11 ± 1.7 b	44.62 ± 1.8 a	44.61 ± 1.8 a
	Novara	28.01 ± 1.6 ns	24.30 ± 1.1 ns	22.91 ± 3.7 ns
	Namibia	14.70 ± 2.3 b	23.12 ± 1.7 a	21.82 ± 2.1 a
	Soprano	22.91 ± 0.9 ns	23.40 ± 0.8 ns	22.63 ± 1.0 ns
Antioxidant	Dordogne	4.69 ± 0.4 a	2.93 ± 0.1 b	2.89 ± 0.4 b
	Novara	3.72 ± 0.4 ns	3.27 ± 0.3 ns	3.38 ± 0.3 ns
	Namibia	3.75 ± 0.1 ns	3.68 ± 0.6 ns	3.73 ± 0.3 ns
	Soprano	3.28 ± 0.5 ns	3.57 ± 0.1 ns	3.50 ± 0.5 ns

Note: *For each variety, different lowercase letters show significant differences among samples for Tukey's test ($p \leq 0.05$) for each sampling point. ns = no statistically significant difference.

3.2. Carotenoids and nutraceutical compounds

Total carotenoids increased significantly over time only in Soprano (from 2.67 to 3.50 mg/100 g). The carotenoid concentration in Dordogne followed a stable trend. The results for Novara and Namibia were inconsistent, but still significant (Table 1). Regarding β -carotene, we cannot be conclusive as we measured total carotenoids, the levels of which were found to be below the required 4 mg/100 g FW. Here it should be noted that the protocol used was not developed for carrots and most certainly did not yield optimal results, because it was not β -carotene-specific. Even though considerably longer and resource-intensive, if β -carotene determination is essential and the chromatography method is not an option, Biehler et al. suggested using the method of Hornero-Méndez and Míguez-Mosquera [21]. While our method measured carotenoids at 470 nm

with no steps to remove possible contaminants, the proposed protocol eliminates possible contaminants and measures at both 472 nm (yellow fractions) and 508 nm (red fractions). Surprisingly, even though pigment secondary metabolites were found to change significantly over time, the antioxidant capacity results were not in agreement, presenting no statistically significant differences during the storage period for Soprano, Namibia and Novara (Table 1). The change of total phenolic content over time was insignificant for Novara (25 mg GAE/100 g averaged for all time points) and Soprano (21 mg GAE/100 g averaged), while an increase was observed for Dordogne (from 20 to 44 mg GAE/100 g) and Namibia (from 14 to about 22 mg GAE/100 g) (Table 1).

3.3. Sensorial analysis

Table 2. Progression of organoleptic parameters during storage of Ispica carrots.

Control	Variety	Colour intensity	Odour	Crunchiness	Sweetness	Herbal aroma	Overall liking
T0	Dordogne	2.9 ±0.7	2.9 ±0.7	3.8 ±0.8	3.0 ±0.8	2.7 ±0.9	3.0 ±0.9
	Novara	3.2 ±0.7 ns*	2.7 ± 0.7 ns	3.6 ±1.0 ns	3.2 ±0.9 ns	2.9 ±0.9 ns	3.0 ±1.1 ns
	Namibia	2.9 ±0.7	2.6 ±0.5	3.9 ±0.7	3.6 ±0.9	3.0 ±1.1	3.5 ±1.0
	Soprano	3.5 ±0.8	2.7 ±0.5	3.4 ±0.7	3.6 ±0.7	3.2 ±0.8	3.3 ±0.7
T1	Dordogne	2.4 ±0.4 a	2.1 ±0.5	3.1 ±1.0	2.8 ±0.9	2.8 ±0.7	2.7 ±0.9 b
	Novara	2.6 ±0.8 ab	2.7 ± 0.9 ns	3.6 ±1.0 ns	3.0 ±0.7 ns	2.4 ±0.5 ns	3.1 ±0.9 ab
	Namibia	2.6 ±0.8 ab	2.4 ±0.9	3.3 ±0.6	3.3 ±0.6	3.0 ±0.8	3.8 ±0.4 a
	Soprano	3.2 ±0.9 b	2.5 ±0.4	3.3 ±0.8	2.9 ±1.1	2.5 ±0.9	2.9 ±0.9 ab
T2	Dordogne	2.4 ±0.4 b	2.1 ±0.5	3.1 ±1.0	2.8 ±0.7 ab	2.8 ±0.7 ab	2.7 ±0.9
	Novara	1.7 ±0.6 a	2.0 ± 0.9 ns	3.5 ±0.7 ns	2.9 ±1.0 ab	2.9 ±1.0 ab	2.8 ±0.9 ns
	Namibia	1.8 ±0.6 a	2.2 ±0.9	3.4 ±0.9	3.0 ±0.9 a	3.0 ±0.9 a	3.0 ±0.7
	Soprano	3.0 ±0.6 b	2.2 ±1.0	3.2 ±1.0	2.1 ±0.8 b	2.1 ±0.8 b	3.1 ±1.2

Note: Values are the mean ± SD (standard deviation of the mean). *Different lowercase letters show significant differences among sample variety ($p \leq 0.05$) for each storage point. ns = no statistically significant difference.

No significant differences in the evolution of sensory parameters during storage were detected between cultivars. Heterogeneity between cultivars was detected for each time point ($p > 0.05$) (Table 2). The sensorial analysis showed that all cultivars scored over 2.5 (1–5 scale) for all parameters at T0. No significant difference was detected between cultivars. At T1, after 3 weeks of storage, produce was still scored at or over 2.5 for all parameters. Panellists' responses showed that Dordogne and Soprano differed significantly in colour. Concerning overall liking, Namibia scored highest (3.8) and Dordogne lowest (2.7). After 6 weeks of storage, carrots scored over 2.5 for crunchiness, sweetness, herbal aroma and overall liking, but not for colour intensity and odour. Statistical significance between cultivars was found for colour, Dordogne (2.4) and Soprano (3.0) being superior; for aroma, Namibia (3.0) performed best, closely followed by Novara (2.9) and Dordogne (2.8). The EU standard requires Ispica carrots to achieve a minimum score of 2.5 in trained sensorial panels (1–5 scale). In our case, after 3 weeks of storage, Dordogne was the only one that scored below that for

typical carrot odour. After 6 weeks, most cultivars scored less than 2.5 for odour and colour. The results show a correlation between sensorial overall liking and the colorimetric data, but there was none considering the sensorial colour data. This is not surprising as measuring colour by eye is not precise despite the training of panellists.

3.4. Multiple factor analysis

To validate the results and to obtain more integrated information about the cultivars' homogeneity, degradation during storage, and correlation between analytical parameters, MFA was conducted. Dimensions 1 and 3 were chosen for the data analysis as they constituted 50% of the meaningful sample variance with the best representation quality (meaning that there were more loadings close to the axis, especially for shelf life and overall liking, leading to easier interpretation of the analysis and better structure of the space). Group representation results (Figure 3A) showed that overall liking and cultivar categorical groups were explained by dimension 1 ($p < 0.05$), while shelf life was explained by dimension 3 ($p < 0.05$). Evaluating the possible correlations between different parameters (Figure 3B), the MFA correlation circle showed correlations between sensorial sweetness, crunchiness and hardness, which were well explained through dimension 1 representing overall liking and cultivars. In fact, it was possible to observe that Dordogne samples were positioned mainly on the left side of dimension 1, while the other varieties were positioned mainly on the right side. The construct showed that overall liking was also correlated with starch content, antioxidant capacity and hardness, even though these parameters had a weak overall influence on the analysis, considering the lower values for loadings in the correlation circle. Moreover, overall liking was correlated to carrot luminosity, sensorial colour intensity and carrot odour. Regarding the correlation between shelf life (mainly represented by dimension 3) and the parameters tested, it is possible to observe that few parameters were well explained by this construct, and their loadings are shorter compared to dimension 1. In particular, the colorimetric parameters and carotenoid content were the parameters most related to dimension 3, meaning that cultivars had a major change in colour during storage compared to other parameters. Interestingly, luminosity was conversely correlated to chroma, a^* and b^* , which were correlated with each other. The carotenoid content was correlated more with b^* and chroma values than with other colorimetric indices. Evaluating the homogeneity and shelf-life deterioration between and within cultivars, MFA confidence ellipses (Figure 4A) showed that Namibia and Soprano were most homogeneous considering the attributes of interest. Soprano data fell within the most compact confidence ellipse, suggesting that this variety was most homogenous during storage. The proximity of sample scores indicates that Novara quality at T0 and T1 was homogenous with that of Namibia and Soprano; however, it clearly deviated at T2. Regarding Dordogne, which in this work was used as a high-quality reference, MFA showed heterogeneity of T1 and T2 Dordogne carrots compared to all other varieties for all time points. The shelf life construct (Figure 4B) showed that the results for the experimental time points were not homogenous in relation each other, which was not surprising considering that evolution over time was observed (the ellipse intervals hardly overlapped, especially T0 and T2). The sample quality was much more homogenous at T0 than at T1. The greatest quality heterogeneity was observed at T2.

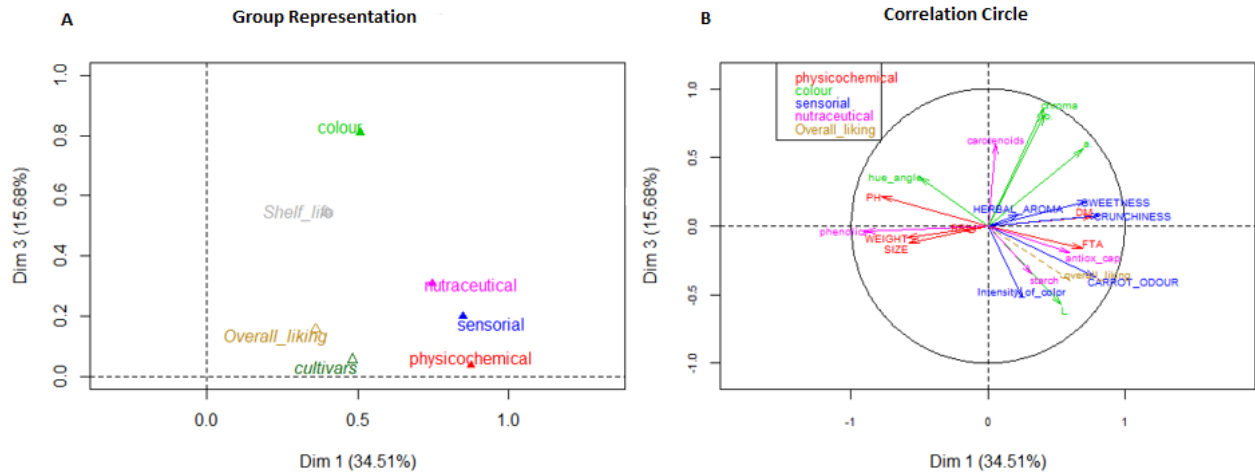


Figure 3. Multiple factor analysis. (A) Representation of experimental groups. Main groups considered for building the MFA construct: physicochemical, cultivar, nutraceutical, colour and sensorial (filled triangles). Supplementary groups: overall liking, shelf-life time point, carrot cultivar (open triangles). (B) Correlation circle for all parameters within an analytical group.

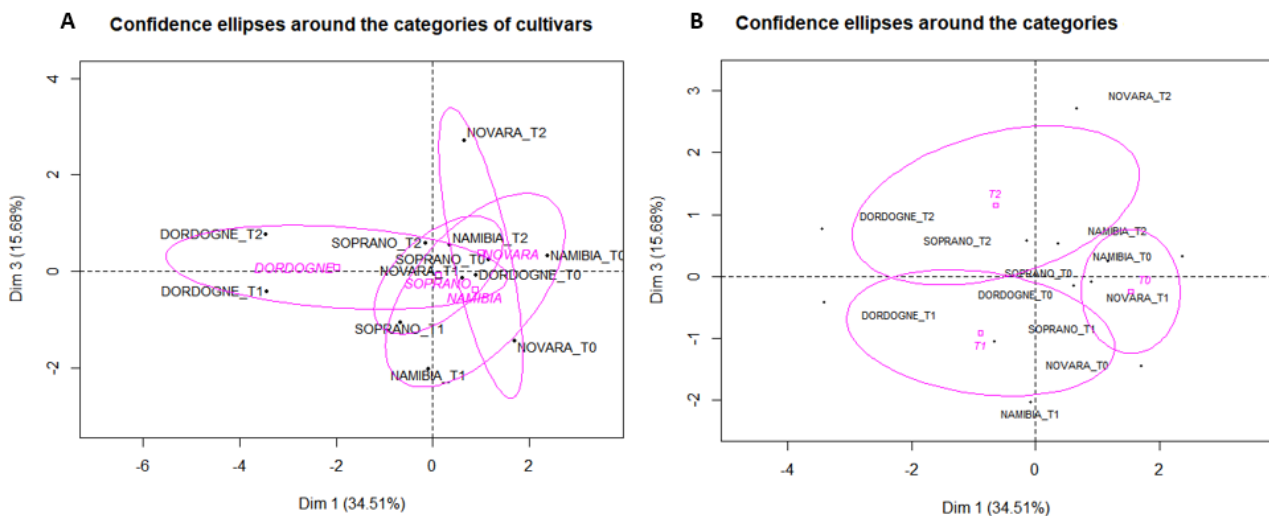


Figure 4. Multiple factor analysis confidence ellipses. (A) Confidence ellipses around the cultivar category. (B) Confidence ellipses around the shelf life category (95% confidence).

4. Conclusions

In the current work, the focus was placed on determining the postharvest quality of whole raw carrots of the Carota Novella di Ispica brand. The brand is protected by GI and is well known around Italy for its high quality. For Carota Novella di Ispica management, it is essential that all cultivars marketed under the brand are homogenous in quality. Considering the proximity of sample scores,

the MFA showed that Namibia and Soprano were the most homogenous at all time points. Surprisingly, even though Dordogne was included as a high-quality reference, those samples deviated from the required overall quality after the initial time point. This agreed with the sensory evaluation, in which Dordogne was given lower scores on the overall liking scale at T1, while at T2 this difference was no longer evident due to the low quality of samples of other cultivars. Furthermore, the nutraceutical data for Dordogne showed higher concentrations of total phenolic compounds, but lower antioxidant capacity. Higher concentrations of phenolic compounds, even if observed together with low antioxidant capacity, are a typical response to cold storage and postharvest senescence. Another outlier from the overall quality homogeneity was Novara; it was consistent with the other cultivars up to the third week of storage (T0 and T1) but deviated at T2. This could be explained by the fact that for some of the attributes measured at T2 (e.g. colour parameters and TSS), Novara was superior in comparison to the other cultivars evaluated at the same time points. This would suggest that the respective Novara attributes deteriorate at a slower rate; however, such results were not depicted in the sensorial analysis, and thus such slight superiority probably would not be of interest to the producer. The data suggest that inclusion of the Novara, Namibia and Soprano cultivars in the Carota Novella di Ispica brand would be beneficial and has the potential to improve the overall quality of the brand given it is already established that all varieties follow similar deterioration rates. Based on physicochemical, organoleptic and nutraceutical analysis, the cultivars evaluated are of interest and perform well during storage. They are compliant with the respective IGP standard up to 6 weeks of cold-temperature storage.

Conflict of interest

The authors declare no conflict of interest.

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