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Impact of Flower Head Order and Phenolic Content on the Quality of Three Different Artichoke Cultivars for Fresh-Cut Products

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Abstract: The growing consumer interest in healthy and convenient food has led to an increased demand for fresh-cut vegetables, including artichokes, which are known for their bioactive compounds like antioxidants and polyphenols. However, artichokes are highly susceptible to browning, as their high phenol content complicates processing into ready-to-eat products. This study evaluated the suitability of three artichoke cultivars ('Lorca', 'Tupac', and 'Green Queen') for fresh-cut processing, focusing on flower head order (main, secondary, tertiary). Artichokes were processed as fresh-cut hearth slices, stored for 7 days at 2 °C and 85% relative humidity, and assessed for total phenolic content (day 0) and browning index (days 0, 1, 3, 5, 7). Sensory analysis was performed until day 3. Results revealed that tertiary heads, especially from the 'Green Queen' cultivar, exhibited the highest phenolic content but also greater susceptibility to browning, whereas main heads, lower in polyphenols (particularly from the 'Lorca' and 'Tupac' cultivars), showed minor browning indices and higher consumer acceptability. These parameters displayed a strong negative correlation coefficient (>−0.9), indicating that an increase in browning directly impacts sensory rejection. This study highlights the importance of cultivar and flower head order selection, providing valuable insights to enhance the quality and commercial viability of minimally processed artichoke products.

Keywords: ready-to-eat; shelf life; browning; sensory evaluation; post-harvest; polyphenols; correlation coefficient

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1. Introduction

Artichokes (*Cynara cardunculus* L. var. *scolymus* (L.)) are a vital crop in the Mediterranean region, known not only for their culinary uses but also for their high nutritional and medicinal value [1]. They are a rich source of bioactive compounds, particularly polyphenols, flavonoids [2–5], inulin, vitamins, minerals, and fiber [6–10], which contribute to their antioxidant, anti-inflammatory, and hepatoprotective properties [11–13]. The health benefits associated with artichokes, such as promoting cardiovascular health, aiding digestion, and supporting liver function [14–16] have increased their demand in the global market, particularly in the form of fresh-cut, ready-to-eat products [17]. However, due to the morphology of artichokes, the preparation of this type of products may be quite challenging since the most used part is the heart of the artichoke. When peeling an artichoke to obtain only the heart, a significant portion of the plant (approximately 80–85% of the total harvested biomass) is discarded as waste [18,19] in the processing of fresh-cut artichoke products. This waste typically consists of inedible components, such as the outer external bracts, stem, leaves, and fuzzy choke [18,20–22]. The larger, globe-type artichokes tend to have a slightly lower waste percentage due to their thicker, meatier hearts, while smaller or more fibrous varieties may result in higher waste. In this sense, the development of processed artichokes as fresh-cut products would serve a dual purpose. On the one hand, it would increase the convenience of using this product for consumers by reducing the waste generated from its use in the home, which, in turn, would increase its consumption by avoiding the high percentage of discarded plant waste, complexity of preparation, and trimming operations. On the other hand, these same residues generated from processing could be used as by-products in the food industry.

As previously indicated, artichokes are highly abundant in bioactive compounds. Although the health-promoting benefits mentioned earlier cannot be attributed to a single compound, several active compounds provide additive or synergistic pharmacologic effects. In this sense, polyphenols, especially hydroxycinnamic acid derivatives, represent a significant fraction of the whole secondary metabolites. As reported by several authors, 5-O-caffeoylquinic acid (5-CQA) or chlorogenic acid is the most abundant compound within the caffeoylquinic derivatives, followed by 3,5-di-O-caffeoylquinic acid (3,5-diCQA) and 3,4-di-O-caffeoylquinic acid (3,4-diCQA). Regarding the minor hydroxycinnamic acids, 3-O-caffeoylquinic acid (3-CQA) or neochlorogenic acid, 1,3-di-O-caffeoylquinic acid (1,3-diCQA) or cynarine, and 4,5-di-O-caffeoylquinic acid (4,5-diCQA) are also present in artichoke cultivars [3,10,23–25]. Furthermore, luteolin derivates are also present in artichokes, with luteolin 7-O-glucuronide (Lut 7-gluc) being a major compound identified in artichoke cultivars, followed by luteolin 7-O-glucoside (Lut 7-glc) and luteolin 7-O-glucuronide 3-O-glucoside (Lut 7-gluc 3-glc), as has been described by other authors [3,7,25].

The intricate relationship between these phenolic compounds, their biological activity, and their susceptibility to browning remains insufficiently understood due to the complexity of these interactions. Nonetheless, it is well established that despite their exceptional nutritional value, artichokes are particularly prone to browning, as their elevated phenol content complicates processing into ready-to-eat products [26–33]. Artichokes present considerable challenges in post-harvest management due to their rapid perishability and susceptibility to quality deterioration, particularly when processed for fresh-cut consumption [26–28]. One of the primary issues with fresh-cut artichokes is enzymatic browning, a reaction caused by polyphenol oxidase (PPO) that occurs when plant tissues are damaged during processing [29,30]. The exposure of polyphenolic compounds to oxygen leads to oxidation and the formation of brown pigments, significantly affecting the visual quality of the product [26,28,30–33]. This browning not only reduces the marketability of fresh-cut artichokes but also compromises their perceived freshness and nutritional value, which are key factors in consumer preferences for minimally processed products [33–36]. In addition to browning, other post-harvest challenges include microbial growth, which can be exacerbated by the high moisture content of artichokes [37]. The combination of enzymatic browning and microbial spoilage further complicates the maintenance of visual and microbiological quality during storage [38]. Furthermore, the structural integrity of artichoke tissues is compromised during cutting, leading to moisture loss, texture degradation, and an accelerated decline in sensory attributes such as taste and color [26–28,30]. These factors severely limit the shelf life of fresh-cut artichokes, making it challenging to maintain their quality over extended periods of storage.

Therefore, the increasing demand for convenient, ready-to-eat products has driven research efforts toward developing innovative post-harvest technologies to extend the shelf life of fresh-cut artichokes while preserving their sensory and nutritional qualities. Approaches such as the use of controlled atmosphere packaging, chemical treatments, anti-browning agents, edible coatings, and innovative packaging (used separately or in combination) [26,30,34,35,37,39–42] have been explored to mitigate browning and delay the degradation processes. However, the effectiveness of these treatments may vary depending on factors such as the cultivar, the harvest date, the agronomic management, and the environmental conditions, among others [3,13,23,43–45] which determine the phenolic content, a key factor in browning. In this sense, some researchers have evaluated the genetic variation among artichoke genotypes that may affect their suitability for fresh-cut products and overall quality [26,35,38,46,47]. In addition, some studies have reported that flower head order has a profound impact on their biochemical composition, particularly phenolic compounds, which are critical determinants of post-harvest quality [3–5,28].

Understanding the physiological and biochemical changes that occur in artichokes after cutting and storage is crucial for optimizing post-harvest interventions and ensuring the successful commercialization of minimally processed artichokes. In this sense, one previous study [28] focused on the characterization of the 'Lorca' cultivar's aptitude for minimally processed products. While this earlier study identified key factors influencing phenolic content (such as flower head order and internal development stage), it only evaluated entire artichokes and measured browning over a very short timeframe (up to 180 s) using PPO activity and initial browning index values. No extended refrigerated storage or fresh-cut processing was assessed, nor was sensory analysis conducted. In the research of Giménez et al., (2021) [5], the focus shifts to the cultivar 'Blanca de Tudela.' This study evaluated whole artichokes across different flower head orders and harvest times during a full growing season, with a particular emphasis on long-term storage (up to 21 days). However, it did not involve fresh-cut processing, which limits its direct applicability to minimally processed product development. Therefore, as far as we are concerned, our study is the first to integrate these findings with sensory acceptance data for fresh-cut artichokes stored under refrigerated conditions for up to 7 days.

This study aimed to address these knowledge gaps by evaluating the performance of three different artichoke cultivars ('Lorca', 'Tupac', and 'Green Queen'), attending to their flower head order to determine the suitability of each for the potential development of a fresh-cut products, with particular attention to phenolic content, browning evolution, and overall quality preservation over time.

2. Materials and Methods

2.1. Plant Material and Experimental Design

For this experiment, three different seed-propagated white artichoke cultivars with green heads were selected: 'Green Queen', which is a hybrid cultivar, and 'Lorca' and 'Tupac', which are both open-pollinated cultivars. For the trial, the artichokes were classified for every cultivar according to the flower head order: main, secondary, and tertiary heads. Standard agronomic practices common in Southeast Spain were followed, including the use of fungicides and insecticides throughout the growing cycle, and the application of fertilizers (250 kg N, 120 kg P_2O_5, and 300 kg K_2O per ha) via drip irrigation. Gibberellic acid was not applied.

Artichokes from each cultivar were harvested when the flower heads were firm and tightly closed and reached their typical commercial size. Therefore, different harvest dates were conducted according to the availability of artichokes. Main and secondary heads of the three cultivars were harvested on 22 February 2022. Tertiary heads of the 'Lorca' and 'Tupac' cultivars were collected on 4 March 2022, and finally tertiary heads of the 'Green Queen' cultivar were collected on 14 March 2022.

2.2. Post-Harvest Processing

After harvest, artichokes were transported to the laboratory of Miguel Hernandez University and 10 artichokes of each cultivar and head order were separated to perform the total phenolic content analysis.

The rest, attending to the cultivar and the flower head order, were peeled until obtaining the artichoke hearts, which were cut into slices. Then, they were disinfected using a solution of water and food-grade bleach of sodium hypochlorite (NaClO) at a concentration of 100 ppm where they stayed for 5 min to remove any possible surface contaminants. After disinfection, the artichoke hearts were carefully rinsed with abundant water, centrifuged using a manual centrifuge to remove excess moisture, and air dried. Once dry, they were placed in polyethylene plastic trays. In this way, 10 trays of each cultivar and flower head order were filled, with 12 slices of artichoke hearts each, making a total of 90 trays. Finally, the trays were stored under controlled conditions at a temperature of 2 °C and a relative humidity of 85% for a period of 7 days (Figure 1).

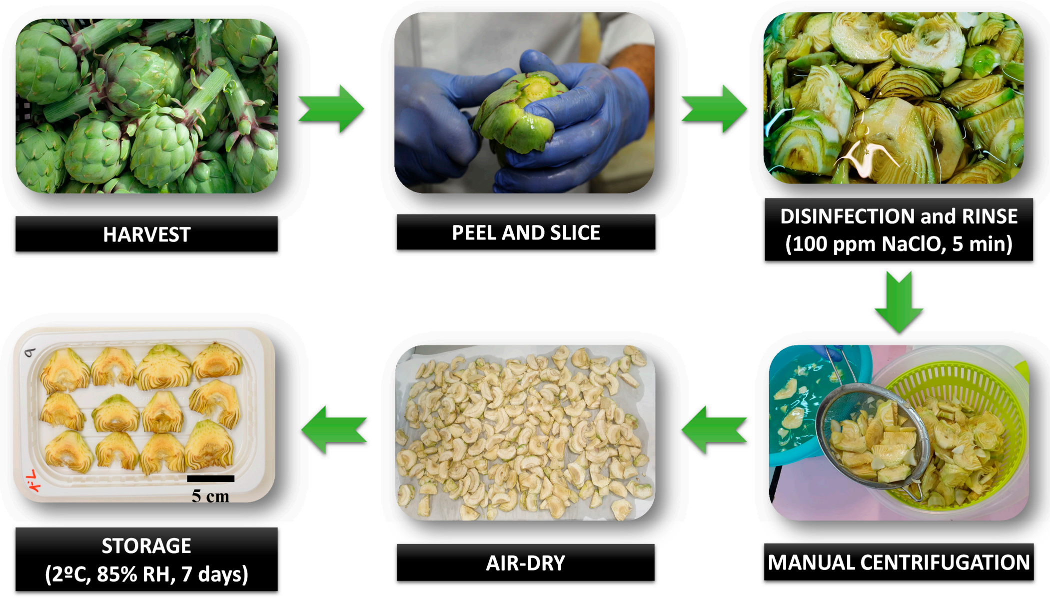

Figure 1. Flowchart of fresh-cut artichoke processing.

2.3. Extraction and Quantification of Total Phenolic Compounds

Phenolic compounds were extracted following the method described by Giménez-Berenguer et al. [28]. In short, 5 g of the edible portion of each sample (including the heart and inner bracts) were blended with 15 mL of 80% methanol solution containing 2 mM sodium fluoride (NaF) to deactivate polyphenol oxidase and prevent phenolic degradation. The homogenization was conducted for 2 min using an Ultra-Turrax® homogenizer (model TP 18, IKA, Staufen, Germany). After that, the samples were centrifuged at 10,000× *g* for 15 min at 4 °C. The resulting supernatant was used for quantification of total phenolic content using the Folin–Ciocalteu reagent according to Giménez-Berenguer et al. [28]. Briefly, duplicate replicates were prepared alongside a blank containing 500 µL of phosphate buffer. For the samples, 300 µL of phosphate buffer and 200 µL of the extract were added to each test tube. In cases where necessary, the extracts were diluted with phosphate buffer to ensure optimal absorbance readings. A 2.5 mL of a 1:10 diluted Folin–Ciocalteu reagent was then added to each tube, followed by thorough mixing. After 3 min of reaction time, 2 mL of sodium carbonate solution was introduced to the mixture. The tubes were mixed again and incubated in a water bath at 50 °C for 5 min. The absorbance of the samples was measured at 760 nm using a spectrophotometer UV-1700 PharmaSpec (Shimadzu, Kyoto, Japan) with plastic cuvettes of 2.5 mL capacity. The blank sample was used to zero the instrument. The results (mean ± standard error) were expressed as grams of gallic acid equivalent per kilograms of fresh weight (FW).

2.4. Evaluation of Fresh-Cut Artichoke Browning

The color of each slice of artichoke was measured individually on both sides using a Minolta colorimeter (CR-400; Konic Minolta, Osaka, Japan) in triplicate. The L*, a*, and b* values that corresponded to the lightness, greenness/redness, and blueness/yellowness, respectively, of the samples were evaluated at room temperature, after calibrating the instrument using a white plate.

Browning evaluation was performed using the browning index (% BI), which was calculated with Equation (1) [48,49] presented below, and the results were expressed as mean ± SE.

$$\%\text{ browning index }(\%\text{ BI}) = \frac{\{100(x - 0.31)\}}{0.17} \quad (1)$$

where (in Equation (1)) x:

$$x = \frac{(a^* + 1.75\,L^*)}{5.645L^* + a^* - 3.012b^*}$$

2.5. Photographic Image-Based Assessment

To record the visual evolution during the conservation, images of the ready-to-eat artichoke were captured using a digital camera (Nikon D3400, Minato, Tokio, Japan) in a light box with a white background. The camera settings were as follows: light provided by two LEDs with a color temperature of 5600 K, ISO−100, speed of 1/5 s, length of 35 mm, and focal aperture (f) of 20. For each artichoke sample, images on both sides were taken post-processing and on days 1, 3, 5, and 7 of refrigerated storage.

2.6. Sensory Evaluation of General Acceptability

An evaluation of general acceptability of different artichoke head orders (main, secondary, and tertiary heads) of 'Lorca', 'Tupac', and 'Green Queen' cultivars was performed in triplicate by a trained panel of 10 judges (5 males and 5 females) from the Department of Agri-Food Technology of Miguel Hernández University (Orihuela, Alicante, Spain) on day 0, day 1, and day 3 of storage at 2 °C. The overall acceptability assessment was scored using a 6-point hedonic scale with increments of 0.5, based on a visual scale made with photos taken previously for this trial (Figure 2). The description of each sensory score is defined in Table 1. A score of 3 or less indicates the end of its shelf life, since the visual appearance does not meet the quality criteria. Results were expressed as mean ± SE.

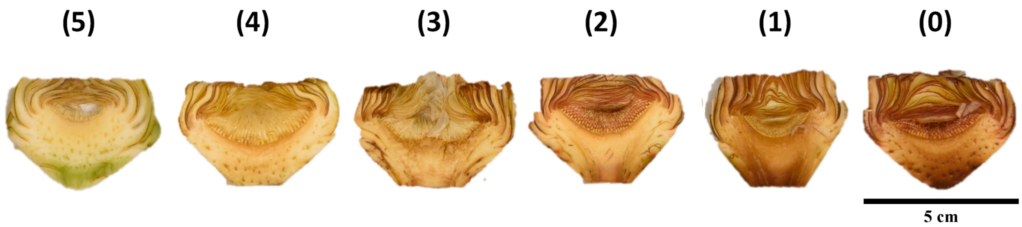

Figure 2. General acceptability scale: (**5**) optimum quality; (**4**) moderate quality; (**3**) insufficient quality; (**2**) poor quality; (**1**) very poor quality; (**0**) extremely poor quality.

Table 1. Description of the characteristics of each sensory score used to evaluate fresh-cut artichokes.

Sensory Score	Description
(5) = Optimum quality	No Browning—Excellent Freshness: Artichoke heart slice appears in perfect condition, entirely free of browning, retaining its original pale green color. There are no visible signs of dehydration, and the surface looks plump and moist. This indicates excellent freshness and quality.
(4) = Moderate quality	Slight Browning—Good Freshness: Artichoke heart slice shows a very slight brown tinge, barely noticeable. Browning is minimal, with only a few spots showing any darkening. There are no signs of severe dehydration or deterioration, and the surface still looks relatively moist.
(3) = Insufficient quality	Light Brown—Not Fresh: The artichoke heart slice displays a light brown color, but it is spread throughout all the sample. The color suggests initial quality deterioration and not freshness. A score of 3 or less indicates the end of the shelf-life.
(2) = Poor quality	Moderate Brown—Slight Deterioration: The artichoke heart slice exhibits a moderate brown color, indicating mild browning. Browning is present and extensive, with some areas showing more intense coloration than others. The surface shows slight signs of quality deterioration.
(1) = Very poor quality	Dark Brown—Moderate Deterioration: The artichoke heart slice shows a deep brown color, indicating moderate browning. Browning is noticeable across the surface, suggesting high levels of oxidation. The surface appears moderately deteriorated.
(0) = Extremely poor quality	Very Dark Brown—Severe Deterioration: The artichoke heart slice appears very dark brown, almost black, with extensive browning throughout the surface. This indicates severe oxidation and deterioration. The surface looks highly deteriorated. This suggests poor freshness and a very unappealing visual appearance.

2.7. Statistical Analysis

All data were subjected to an analysis of variance (ANOVA). For total phenolic content, a two-way factorial combination design was applied, considering cultivars (3) and flower head orders (3). For browning index and sensory evaluation data were examined using a three-way factorial combination design, incorporating cultivars (3), flower head orders (3) and days of storage (5). Results were expressed as mean square (percentage of total) per each source of variation (% MS). Significant differences were presented with F-values (** $p \leq 0.05$ and *** $p \leq 0.01$). When ANOVA assumptions were found to be valid, mean comparisons were performed using Duncan's multiple-range test to detect significant differences ($p \leq 0.05$). Pearson's test was also conducted to determine the correlation coefficient between the browning index and sensory analysis. All analyses were performed with SPSS software package v. 20 for Windows (IBM Corp., Armonk, NY, USA).

3. Results

3.1. Total Phenolic Content at Harvest

The ANOVA results indicated that both the cultivar and the flower head order significantly influenced the total phenolic content of artichokes (Table 2). The cultivar explained 50.8% of the variation, while flower head order contributed 41.4%, both highly significant, with F-values of 89.691 and 73.053, respectively (*** $p \leq 0.01$). In contrast, the interaction between cultivar and head order contributed 7.8% to the overall variance. This suggests that the phenolic content is primarily determined by genetic factors, although the position of the flower head also plays a substantial role.

Table 2. Mean square (percentage of total) per each source of variation (% MS) resulting from analysis of variance of the total phenolic content.

Source of Variation	Total Phenolic Content		
	% MS	**F-Value**	**Significance Level**
Cultivar (C)	50.8	89.691	***
Flower Head Order (H)	41.4	73.053	***
(C) x (H)	7.8	13.824	***

Significant differences are presented, with F-values and asterisks denoting the significance level (*** $p \leq 0.01$).

As shown in Table 3, the 'Green Queen' cultivar exhibited the highest mean total phenolic content (3.73 g kg^{-1} FW), which was significantly higher than that of 'Lorca' (2.36 g kg^{-1} FW) and 'Tupac' (2.34 g kg^{-1} FW). When considering the mean values of the flower head order, regardless of the cultivar, the tertiary heads presented the highest phenolic content (3.48 g kg^{-1} FW), followed by secondary heads (2.66 g kg^{-1} FW) and main heads (2.13 g kg^{-1} FW). These results underscore the importance of selecting both cultivar and flower head order for achieving better results in the industrial process.

Table 3. Mean total phenolic content at harvest (g kg^{-1} FW) for each cultivar and mean total phenolic content for each flower head order of all three cultivars together, respectively.

	Total Phenolic Content (g kg^{-1} FW)		
CULTIVAR	Lorca	Tupac	Green Queen
	2.36 ± 0.08 a	2.34 ± 0.09 a	3.73 ± 0.16 b
FLOWER HEAD ORDER	Main	Secondary	Tertiary
	2.13 ± 0.07 a	2.66 ± 0.10 b	3.48 ± 0.16 c

Data are the mean ± SE. Different lowercase letters show significant differences in the phenolic content of each cultivar and mean flower head order respectively, according to Duncan test at $p \leq 0.05$.

The interaction between cultivar and head order (Figure 3) further highlights this trend, as tertiary heads of 'Green Queen' contained the highest phenolic levels (4.83 g kg^{-1} FW), while main heads of 'Lorca' and 'Tupac' had the lowest (1.95 and 1.93 g kg^{-1} FW, respectively). In addition, the statistical analysis reveals that the main heads of the 'Green Queen' cultivar (2.49 g kg^{-1} FW), which have the lowest phenolic content within this cultivar, were comparable to the tertiary heads of the 'Lorca' and 'Tupac' cultivars, which exhibit the highest phenolic content in their respective cultivars (2.75 and 2.63 g kg^{-1} FW, respectively). This indicates that the phenolic content of the least phenolic-rich heads of 'Green Queen' is on par with the most phenolic-rich heads of 'Lorca' and 'Tupac', highlighting a noteworthy difference in phenolic content between these cultivars despite their flower head order. Nevertheless, the significant interaction between these factors indicates that both genotype and head order should be carefully considered when selecting artichokes for their suitability as fresh-cut products.

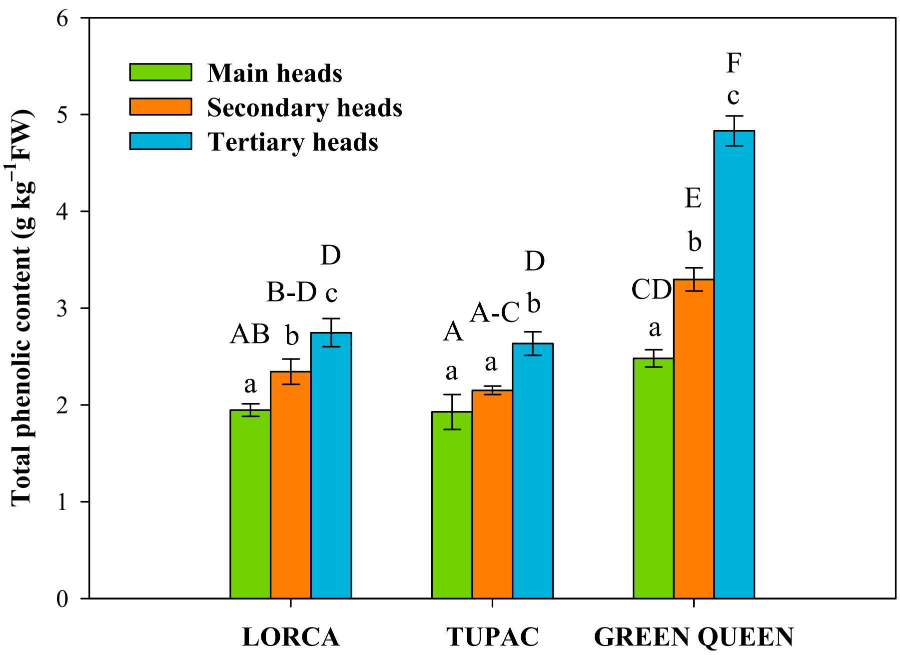

Figure 3. Total phenolic content (g kg^{-1} FW) for different artichoke head orders (main, secondary, and tertiary heads) of 'Lorca', 'Tupac', and 'Green Queen' cultivars at harvest. Different lowercase letters show significant differences between flower head orders of each cultivar individually, according to Duncan test at $p \leq 0.05$. Different capital letters show significant differences between the interaction of flower head orders and all cultivars, according to Duncan test at $p \leq 0.05$. Data are the mean ± SE.

3.2. Browning Evolution of Fresh-Cut Artichokes During Storage

The browning evolution, expressed as the browning index (%), is a critical factor that affects the visual quality and marketability of fresh-cut artichokes, limiting their shelf life. Analysis of variance shows that the browning index was significantly influenced by cultivar, flower head order, and storage duration (Table 4). The cultivar explained 35.72% of the variation, with 'Green Queen' having the highest mean browning index (52.92%), significantly greater than 'Lorca' (45.18%) and 'Tupac' (44.32%) (Table 5). Flower head order accounted for 35.24% of the variation (Table 4), with tertiary heads showing the most browning (52.82%), followed by secondary heads (45.51%) and main heads (44.36%) (Table 5). Storage time also played a significant role in browning progression, contributing 27.93% of the variation (Table 4). Browning increased progressively over 7 days of storage, with significant differences observed at each time point (Table 5). On day 0, the browning index was the lowest (40.50%), and it increased steadily to 54.29% by day 7.

Table 4. Mean square (percentage of total) per each source of variation (% MS) resulting from analysis of variance of the percentage of browning index.

Source of Variation	% Browning Index		
	% MS	F-Value	Significance Level
Cultivar (C)	35.72	393.859	***
Flower Head Order (H)	35.24	388.587	***
Days of Storage (D)	27.93	307.990	***
(C) x (H)	0.35	3.853	***
(C) x (D)	0.30	3.259	***
(H) x (D)	0.21	2.281	**
(C) x (H) x (D)	0.25	2.733	***

Significant differences are presented, with F-values and asterisks denoting the significance level (** $p \leq 0.05$ and *** $p \leq 0.01$).

Table 5. Browning evolution (% mean browning index) for different artichoke flower head orders (main, secondary, and tertiary heads), cultivars ('Lorca', 'Tupac', and 'Green Queen'), and day of storage, respectively, and for the interaction of cultivars and flower head orders.

	% Browning Index		
Cultivar	Lorca	Tupac	Green Queen
	45.18 ± 0.31 b	44.32 ± 0.35 a	52.92 ± 0.36 c
Head Order	Main	Secondary	Tertiary
	44.36 ± 0.32 a	45.51 ± 0.33 b	52.82 ± 0.38 c
Days of Storage	D0	40.50 ± 0.35 a	
	D1	44.59 ± 0.44 b	
	D3	47.31 ± 0.44 c	
	D5	51.07 ± 0.42 d	
	D7	54.29 ± 0.43 e	
Cultivar x Flower Head Order	Lorca	Tupac	Green Queen
Main	43.15 ± 0.47 a	40.20 ± 0.51 a	49.74 ± 0.52 a
Secondary	43.48 ± 0.51 a	42.35 ± 0.45 b	50.42 ± 0.55 a
Tertiary	49.31 ± 0.55 b	50.23 ± 0.59 c	58.96 ± 0.61 b

Data are the mean ± SE. Different lowercase letters show significant differences between cultivars and flower head orders, according to Duncan test at $p \leq 0.05$.

The browning evolution resulting from the interaction between cultivars ('Lorca', 'Tupac', and 'Green Queen'), head orders (main, secondary, tertiary), and storage days (D0–D7), exhibited significant differences (Table 6, Figure 4). On day 0, the main heads of 'Tupac' (33.76%) presented the lowest browning index, significantly differing from the main heads of 'Lorca' (37.81%) and 'Green Queen' (41.43%). In contrast, the tertiary heads of 'Green Queen' at D0 had the highest browning index (51.38%), indicating a much greater susceptibility to browning after processing compared to both 'Lorca' and 'Tupac' (42.73% and 40.48%, respectively).

Table 6. Browning evolution (% browning index) for the interaction of cultivars ('Lorca', 'Tupac', and 'Green Queen'), artichoke head order (main, secondary, and tertiary heads), and day of storage interrelated.

	% Browning Index								
C x H x D	**Lorca**			**Tupac**			**Green Queen**		
	Main	**Secondary**	**Tertiary**	**Main**	**Secondary**	**Tertiary**	**Main**	**Secondary**	**Tertiary**
D0	37.81 ± 0.52 b–d	37.42 ± 0.74 bc	42.73 ± 0.74 f–h	33.76 ± 0.78 a	36.54 ± 0.61 b	40.48 ± 1.12 d–g	41.43 ± 0.70 fg	42.19 ± 0.58 f–h	51.38 ± 0.98 p–r
D1	39.67 ± 0.80 c–f	40.05 ± 0.63 c–f	45.13 ± 0.90 h–l	35.50 ± 0.54 ab	38.06 ± 0.55 b–e	48.14 ± 0.81 l–o	46.64 ± 0.77 j–l	47.47 ± 0.77 k–n	59.58 ± 1.51 u–w
D3	40.94 ± 0.75 e–g	41.24 ± 0.90 fg	51.08 ± 0.94 o–q	39.95 ± 0.91 c–f	43.39 ± 0.89 g–i	49.91 ± 1.03 m–p	49.69 ± 0.84 m–p	49.78 ± 1.06 m–p	60.14 ± 1.33 vw
D5	47.10 ± 0.96 j–m	46.04 ± 0.86 i-l	53.61 ± 1.02 q–s	44.87 ± 0.91 h–k	44.35 ± 1.00 h–j	54.85 ± 0.90 st	54.07 ± 1.09 r–t	54.93 ± 1.09 st	61.28 ± 1.21 wx
D7	50.26 ± 0.97 n–p	52.66 ± 1.06 p–s	58.30 ± 1.08 uv	46.93 ± 1.09 j–m	47.67 ± 1.07 k–n	57.79 ± 1.12 uv	56.85 ± 0.84 tu	57.74 ± 1.05 uv	63.01 ± 1.00 x

Data are the mean ± SE. Different lowercase letters show significant differences between cultivars and flower head orders at harvest and during 7 days of storage at 2 °C, according to Duncan test at $p \leq 0.05$.

As storage progressed, browning increased significantly in all cultivars. By day 7, the tertiary heads of 'Green Queen' reached the highest browning levels (63.01%), substantially surpassing those of 'Tupac' (57.79%) and 'Lorca' (58.30%). These data show a clear trend where the tertiary heads across all cultivars consistently exhibited higher browning compared to the main and secondary heads.

Among all combinations, the main heads of 'Tupac' showed the slowest increase in browning, with values rising from 33.76% on day 0 to 46.93% on day 7, while the tertiary heads of 'Green Queen' showed the sharpest increase, from 51.38% at harvest to 63.01% by the end of the storage period.

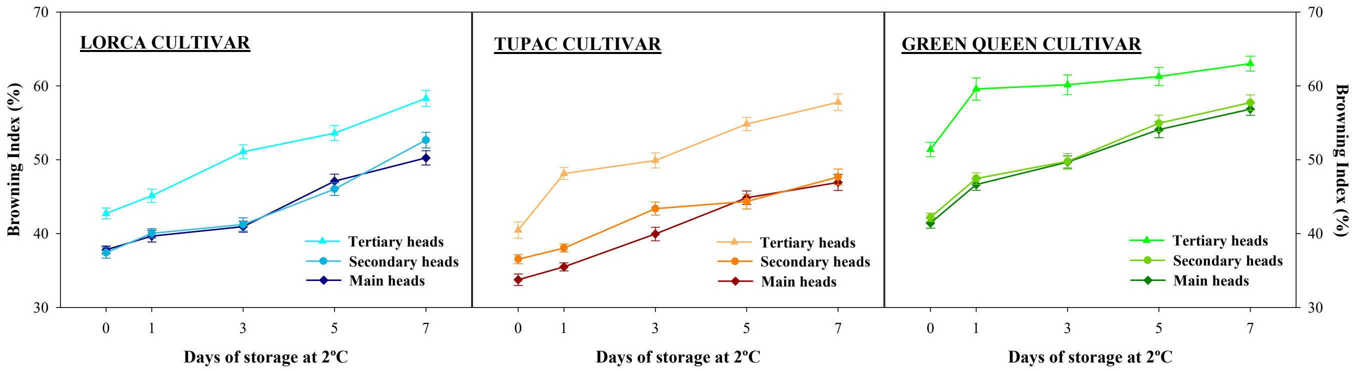

Figure 4. Browning evolution (% browning index) for different artichoke head orders (main, secondary, and tertiary heads) of 'Lorca', 'Tupac', and 'Green Queen' cultivars at harvest and during 7 days of storage at 2 C. Data are the mean ± SE.

Pictures of the progression of browning in artichoke head orders (main, secondary, and tertiary heads) from three cultivars ('Lorca', 'Tupac', and 'Green Queen') over a storage period of 7 days at 2 °C are presented in Figure 5. At the day of processing, all head orders across the three cultivars showed minimal browning, maintaining a fresh appearance (D0—green color). The main heads appeared the most vibrant, followed by secondary and tertiary heads, which were also well-preserved but slightly less uniform in color. On day one, a slight onset of browning was observed, particularly in the secondary and tertiary heads of 'Green Queen' (D1—red color). 'Lorca' and 'Tupac' maintained a relatively fresh appearance, though subtle discoloration was noticeable in tertiary heads (D1—orange color). On the third day, browning became more prominent across all cultivars, with secondary and tertiary heads showing more intense discoloration (D3—red color) than the main heads. 'Green Queen' exhibited a more advanced degree of browning (D3—red color) compared to 'Lorca' and 'Tupac', whose main heads still showed less susceptibility to the browning process (D3—orange color).

On day five, significant browning was observed in all head orders (D5—red color), with the tertiary heads of all cultivars displaying the most severe discoloration. Main heads of 'Lorca' and 'Tupac' maintained the best appearance, although the differences between head orders were becoming more pronounced. On the last day, browning was extensive in all cultivars and head orders (D7—red color). The tertiary heads had darkened considerably, indicating advanced senescence. However, the main heads of 'Lorca' and 'Tupac' still retained some visual appeal, though browning was evident. 'Green Queen' artichokes showed widespread browning, with tertiary heads almost completely brown.

This image-based assessment showed a clear trend: browning intensified with storage time, and tertiary heads were most susceptible to this deterioration across all cultivars. 'Lorca' and 'Tupac' showed the most resistance to browning, while 'Green Queen' experienced more rapid quality loss.

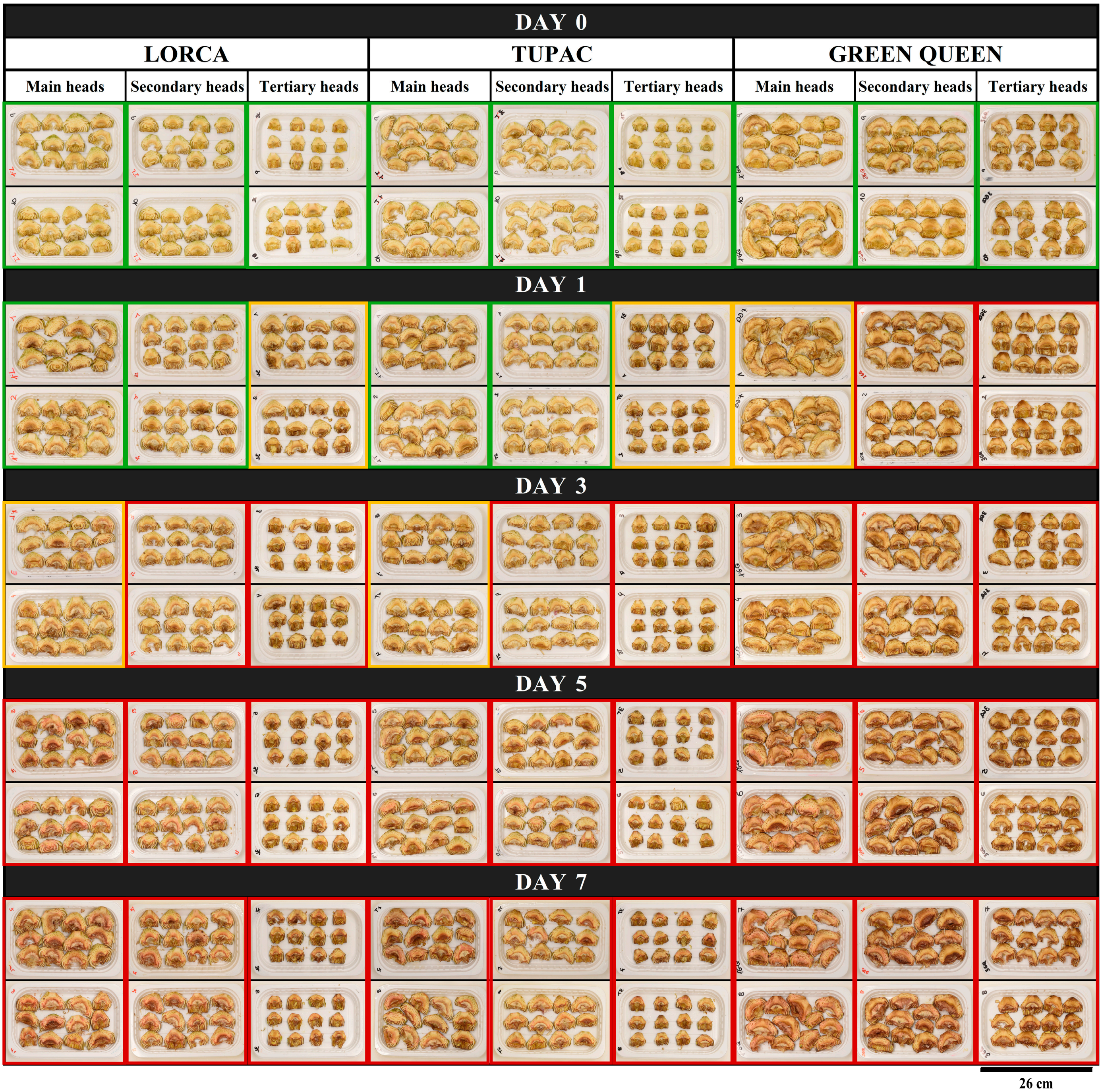

Figure 5. Images of the browning evolution for different artichoke head orders (main, secondary, and tertiary heads) of 'Lorca', 'Tupac', and 'Green Queen' cultivars at harvest and during 7 days of storage at 2 °C. Different frame colors illustrate relevant changes in the browning evolution between cultivars and flower head orders at harvest and during 7 days of storage at 2 °C.

3.3. Sensorial Evaluation of General Acceptability

Sensorial evaluation of general acceptability showed that consumer preference is significantly affected by storage duration, cultivar, and head order (Table 7). Storage days explained 77.39% of the variation, highlighting the importance of freshness in maintaining consumer satisfaction. Cultivar and head order also contributed to differences in acceptability, explaining 13.08% and 8.77% of the variation, respectively.

Table 7. Mean square (percentage of total) per each source of variation (% MS) resulting from analysis of variance of the sensorial evaluation.

Source of Variation	Sensorial Evaluation		
	% MS	F-Value	Significance Level
Cultivar (C)	13.08	1986.059	***
Flower Head Order (H)	8.77	1331.353	***
Days of Storage (D)	77.39	11,747.529	***
(C) x (H)	0.14	21.235	***
(C) x (D)	0.23	34.206	***
(H) x (D)	0.35	52.912	***
(C) x (H) x (D)	0.05	7.162	***

Significant differences are presented, with F-values and asterisks denoting the significance level (*** $p \leq 0.01$).

The sensory results highlight cultivar and head order-dependent differences in the general acceptability of fresh-cut artichokes over storage time (Figure 6), following the same tendency as the browning index, as it was a parameter highly linked to the general acceptability.

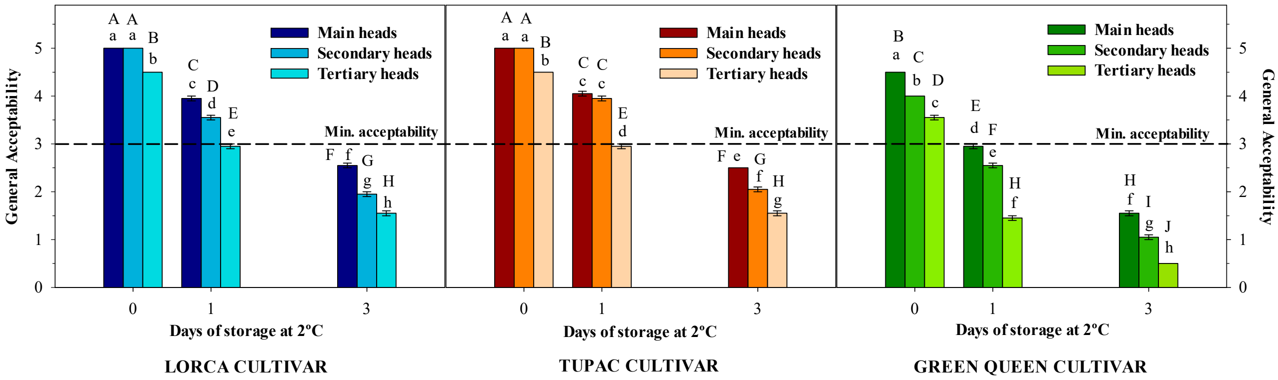

Figure 6. Sensorial evaluation of the general acceptability of different artichoke head orders (main, secondary, and tertiary heads) of 'Lorca', 'Tupac', and 'Green Queen' cultivars on day 0, day 1, and day 3 of storage at 2 °C. Different lowercase letters show significant differences between head orders of each cultivar individually during storage, according to Duncan test at $p \leq 0.05$. Different capital letters show significant differences between the interaction of head orders and all cultivars during storage, according to Duncan test at $p \leq 0.05$. Data are the mean ± SE.

At the day of processing (D0), the 'Lorca' and 'Tupac' cultivars exhibited superior sensory attributes, particularly in the main heads, which maintained the highest quality of all for up to 3 days at 2 °C, compared to the 'Green Queen' cultivar which scored lower in all the flower head orders. On the other hand, tertiary heads showed the greatest decline across all cultivars, with both 'Lorca' and 'Tupac' tertiary heads falling below the acceptable threshold by day 3.

In contrast, the 'Green Queen' cultivar performed poorly across all head orders. Its general acceptability scores for secondary and tertiary heads fell below the minimum threshold as early as day 1. In this sense, none of the samples exceeded the minimum of acceptability on day 3, since no antioxidant was added to delay the degradation process. This was due to the fact that the field of study was the intrinsic aptitude of each sample as a fresh-cut product. Within these outcomes, the 'Green Queen' cultivar obtained the worst results—well below the acceptable quality threshold—indicating significant deterioration.

3.4. Correlation Between Browning and Sensory Evaluation Acceptance

The relationship between the % BI and sensory acceptance scores was evaluated for the three artichoke cultivars ('Lorca', 'Tupac', and 'Green Queen') across all flower head orders (main, secondary, and tertiary) at harvest and during refrigerated storage (D1 and D3). The calculated correlation coefficient (CC) between the % BI and sensory scores, presented in Table 8, reveals a strong negative correlation for all cultivars and head orders throughout the storage period.

Table 8. Correlation coefficient between % BI values and sensory acceptances evaluation scores during D0, D1, and D3 of refrigerated storage.

CC between % BI and Sensory Evaluation								
Lorca			**Tupac**			**Green Queen**		
Main	**Secondary**	**Tertiary**	**Main**	**Secondary**	**Tertiary**	**Main**	**Secondary**	**Tertiary**
−0.982	−0.971	−0.964	−0.994	−0.989	−0.950	−0.993	−0.973	−0.968

Data of the CC are the mean values of % BI and sensory evaluation scores of different artichoke head orders (main, secondary, and tertiary heads) of 'Lorca', 'Tupac', and 'Green Queen' cultivars on day 0, day 1, and day 3 of storage at 2 °C.

For 'Lorca', the CC values ranged from −0.982 to −0.964, with the main heads exhibiting the strongest correlation (−0.982), indicating that increases in browning were closely linked to declines in sensory acceptance. Similarly, for 'Tupac', CC values ranged from −0.994 to −0.950, with the main heads again showing the strongest relationship (−0.994). In 'Green Queen', the CC values followed the same trend, ranging from −0.993 to −0.968. Across all cultivars, the main heads consistently demonstrated the highest sensitivity to the relationship between browning and sensory rejection, while tertiary heads showed slightly weaker correlations. Despite this, a strong negative correlation is evident as all CC values exceeded −0.9, highlighting a significant inverse relationship between % BI and sensory acceptance across all samples.

4. Discussion

This study assessed the total phenolic content, browning evolution, and sensory acceptability of fresh-cut artichokes from three cultivars ('Lorca', 'Tupac', and 'Green Queen') in relation to flower head order (main, secondary, and tertiary heads) and storage duration. The results reveal that both cultivar and head order, as well as their interactions, significantly affect polyphenol concentration at harvest and the overall postharvest quality of the artichokes, providing essential insights into the suitability of these cultivars for fresh-cut applications.

Several studies have reported that phenolic content varies significantly among cultivars, with factors like developmental stage and agronomic and environmental conditions, among others, playing key roles in phenolic accumulation [4,13,23,28,43–45]. Moreover, artichokes are characterized by a hierarchical organization determined primarily by their growth position within the plant structure, which also influences the phenolic content [3–5,28]. This flower head order is categorized by a primary head or capitulum and multiple secondary and tertiary heads. The primary head is typically the largest and terminates the main stem, whereas the secondary and tertiary capitula are smaller and borne on lateral branches [50]. Annual production consists of a single primary head and up to a maximum of twenty secondary and tertiary heads per plant [16,18].

The findings of the present study align with prior studies by Giménez et al. [3,5] and Giménez-Berenguer et al. [4,28]. It has been corroborated that secondary and tertiary heads of artichokes frequently accumulate higher phenolic compounds than primary heads. This may be due to developmental stresses in these later-forming heads which may activate defense responses, increasing phenolic production [4,51]. Additionally, this research expands on earlier work by evaluating three distinct cultivars ('Lorca', 'Tupac', and 'Green Queen') and exploring their suitability for fresh-cut processing based on flower head order. This combination of sensory analysis and browning assessment offers practical insights for producers aiming to optimize the development of fresh-cut artichoke products.

The phenolic variability has notable implications for the nutritional and functional quality of artichokes, including cynarine, chlorogenic acid, and flavonoids [2–4,44,52], which are bioactive compounds with several beneficial properties in human health [11,14–16,18,53]. Studies have shown that the content of 5-CQA, the primary hydroxycinnamic acid in artichokes, is significantly higher in tertiary heads, followed by secondary heads and lastly, main heads. This trend extends to both major and minor hydroxycinnamic acids, demonstrating a consistent distribution pattern among head orders [3]. Variability in caffeoylquinic acid derivative levels has also been linked to harvest timing, which aligns with the classification of heads into main, secondary, and processing categories [7]. In the case of luteolin derivatives, Lut 7-gluc content was notably higher in tertiary heads compared to secondary and main heads. Overall, tertiary flower heads have consistently exhibited significantly greater total amounts of individual luteolin derivatives than their secondary and main counterparts [3]. However, this high phenolic content also predisposes these artichokes to more rapid browning during storage, as phenolic compounds serve as substrates for PPO-catalyzed browning reactions, which compromise the visual quality of fresh-cut products [29,30,32,35].

In this study, TPC was measured on day 0 to establish its baseline correlation with browning susceptibility and flower head order. Our prior research [30] evidences no significant changes in TPC during storage under similar conditions for untreated samples up to nine days. Therefore, the measured TPC on day 0 is expected to remain stable throughout the storage period, and the differences observed between flower head orders and cultivars at the initial stage would likely persist over time. Within this investigation, tertiary heads from all cultivars displayed the highest browning indices, with 'Green Queen' showing the most pronounced darkening. Smaller and later-developing heads, such as tertiary heads, experience greater oxidative stress, which induces PPO activity and accelerates browning. This accelerated oxidation process likely due to high phenolic substrate concentration, with PPO activity further contributing to browning [26,28,31,33,34]. Conversely, the slower browning observed in 'Tupac' and 'Lorca', particularly in main heads, suggests that due to reduced phenolic substrates susceptible to oxidation, these cultivars may have lower PPO activity. This could improve the suitability of these artichokes for fresh-cut processing. Similar results in other fresh-cut produce indicate that cultivars with lower PPO activity tend to brown more slowly, potentially extending shelf life and minimizing the need for anti-browning treatments [26,28,35,38,46,47].

Sensory acceptability, a key factor in commercial viability, was highly influenced by browning rates, with panelists preferring the main heads of 'Tupac' and 'Lorca', which exhibited less browning and retained visual appeal for a longer period. In contrast, the rapid browning of 'Green Queen' reduced its sensory acceptability, especially in tertiary heads, reinforcing the challenge of balancing phenolic content with visual quality. This may indicate that visual factors, including browning, play a more significant role in consumer purchasing decisions than nutritional content alone. This tendency was also confirmed by the strong negative correlations observed, highlighting that browning is a critical determinant of sensory rejection. As the % BI values increased over time, sensory acceptance scores declined significantly, reflecting consumer aversion to visual discoloration. In this sense, Starowicz et al. [54] also reported a generally positive correlation coefficients (0.80) between the TPC and browning, proving the importance of these two parameters in determining the quality and marketability of fresh-cut products. This aligns with the findings of the present study, where samples with lower phenolic content and reduced browning susceptibility, particularly those from the main head orders of 'Lorca' and 'Tupac' cultivars, demonstrated better sensory acceptance. These results emphasize the critical need for selecting appropriate cultivars and processing strategies to minimize browning and maintain sensory appeal, ultimately enhancing the commercial viability of minimally processed artichokes. These outcomes are supported by other studies that have identified browning as a primary factor influencing the marketability of fresh-cut artichokes and, therefore, appearance as a primary determinant of consumer preference [26,28,30,33–36,38,55].

The implications for fresh-cut applications are clear: while higher phenolic content artichokes will have a better nutritional profile, it also may necessitate careful postharvest handling to mitigate browning, especially for high-phenolic cultivars like 'Green Queen', which may require more intensive postharvest treatments to preserve visual appeal. Oppositely, cultivars with slower browning rates, such as 'Tupac' and 'Lorca', could reduce postharvest losses, lower the need for anti-browning agents, and improve marketability, lowering costs for producers and enhancing consumer satisfaction.

5. Conclusions

The challenge of developing fresh-cut artichoke products makes it necessary to define the suitability of the different cultivars and types of artichokes for fresh-cut products. It is essential to characterize and quantify their bioactive compounds, as well as study their browning evolution. The results of this study evidence for the first time that both flower head order and cultivar significantly influence the extent of browning and its impact on sensory perception.

This research underscores the importance of selecting appropriate cultivars and head orders for the development of fresh-cut artichoke products. While 'Green Queen' and tertiary heads offer potential nutritional benefits due to their high phenolic content, their rapid browning limits their applicability in fresh-cut markets and shelf-life without significant intervention.

In contrast, cultivars with lower susceptibility to browning like 'Tupac' and 'Lorca', particularly in their main and secondary heads, may present a more favorable option for extending shelf life and maintaining sensory quality in minimally processed formats. They demonstrated better commercial viability due to their lower browning rates and higher consumer acceptability, making them a more suitable candidate for fresh-cut product applications, diminishing postharvest losses, reducing dependency on anti-browning agents, and increasing market appeal, thereby cutting costs for producers and elevating consumer satisfaction. These findings suggest that choosing cultivars and head orders based on their phenolic content at harvest and browning behavior is essential to optimize the quality and shelf life of fresh-cut artichoke products. Future research should focus on exploring methods to mitigate browning and improve the stability of high-phenolic cultivars like 'Green Queen', and further studying artichokes to allow for the accurate selection of cultivars, and flower heads orders depending on their final destination.

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References

1. Pandino, G.; Lombardo, S.; Mauromicale, G.; Williamson, G. Profile of Polyphenols and Phenolic Acids in Bracts and Receptacles of Globe Artichoke (*Cynara Cardunculus* Var. *Scolymus*) Germplasm. *J. Food Compos. Anal.* **2011**, *24*, 148–153. [CrossRef]
2. Lombardo, S.; Scavo, A.; Pandino, G.; Cantone, M.; Mauromicale, G. Improvement in the Cynaropicrin, Caffeoylquinic Acid and Flavonoid Content of Globe Artichokes with Gibberellic Acid Treatment. *Plants* **2022**, *11*, 1845. [CrossRef] [PubMed]
3. Giménez, M.J.; Giménez-Berenguer, M.; García-Pastor, M.E.; Parra, J.; Zapata, P.J.; Castillo, S. The Influence of Flower Head Order and Gibberellic Acid Treatment on the Hydroxycinnamic Acid and Luteolin Derivatives Content in Globe Artichoke Cultivars. *Foods* **2021**, *10*, 1813. [CrossRef] [PubMed]
4. Giménez-Berenguer, M.; Gutiérrez-Pozo, M.; Serna-Escolano, V.; Giménez, M.J.; Zapata, P.J. Influence of Artichoke Antioxidant Activity in Their Susceptibility to Suffer Frost Injury. *Antioxidants* **2023**, *12*, 1960. [CrossRef]
5. Giménez, M.J.; Giménez-Berenguer, M.; García-Pastor, M.E.; Castillo, S.; Valverde, J.M.; Serrano, M.; Valero, D.; Zapata, P.J. Influence of Flower Head Order on Phenolic Content and Quality of Globe Artichoke at Harvest and during Twenty-One Days of Cold Storage. *Sci. Hortic.* **2022**, *295*, 110846. [CrossRef]
6. Lombardo, S.; Pandino, G.; Mauromicale, G. Minerals Profile of Two Globe Artichoke Cultivars as Affected by NPK Fertilizer Regimes. *Food Res. Int.* **2017**, *100*, 95–99. [CrossRef]
7. Gagliardi, A.; Giuliani, M.M.; Carucci, F.; Francavilla, M.; Gatta, G. Effects of the Irrigation with Treated Wastewaters on the Proximate Composition, Mineral, and Polyphenolic Profile of the Globe Artichoke Heads [*Cynara cardunculus* (L.)]. *Agronomy* **2020**, *10*, 53. [CrossRef]
8. Pandino, G.; Lombardo, S.; Mauromicale, G. Mineral Profile in Globe Artichoke as Affected by Genotype, Head Part and Environment. *J. Sci. Food Agric.* **2011**, *91*, 302–308. [CrossRef] [PubMed]
9. Rocchetti, G.; Lucini, L.; Corrado, G.; Colla, G.; Cardarelli, M.; de Pascale, S.; Rouphael, Y. Phytochemical Profile, Mineral Content, and Bioactive Compounds in Leaves of Seed-Propagated Artichoke Hybrid Cultivars. *Molecules* **2020**, *25*, 3795. [CrossRef] [PubMed]
10. Rouphael, Y.; Colla, G.; Graziani, G.; Ritieni, A.; Cardarelli, M.; De Pascale, S. Phenolic Composition, Antioxidant Activity and Mineral Profile in Two Seed-Propagated Artichoke Cultivars as Affected by Microbial Inoculants and Planting Time. *Food Chem.* **2017**, *234*, 10–19. [CrossRef]
11. Silva, L.R.; Jacinto, T.A.; Coutinho, P. Bioactive Compounds from Cardoon as Health Promoters in Metabolic Disorders. *Foods* **2022**, *11*, 336. [CrossRef]
12. Zayed, A.; Serag, A.; Farag, M.A. Cynara Cardunculus L.: Outgoing and Potential Trends of Phytochemical, Industrial, Nutritive and Medicinal Merits. *J. Funct. Foods* **2020**, *69*, 103937. [CrossRef]
13. Ceccarelli, N.; Curadi, M.; Picciarelli, P.; Martelloni, L.; Sbrana, C.; Giovannetti, M. Globe Artichoke as a Functional Food. *Med. J. Nutr. Metab.* **2010**, *3*, 197–201. [CrossRef]
14. Salem, M.B.; Affes, H.; Ksouda, K.; Dhouibi, R.; Sahnoun, Z.; Hammami, S.; Zeghal, K.M. Pharmacological Studies of Artichoke Leaf Extract and Their Health Benefits. *Plant Foods Hum. Nutr.* **2015**, *70*, 441–453. [CrossRef]
15. Santos, H.O.; Bueno, A.A.; Mota, J.F. The Effect of Artichoke on Lipid Profile: A Review of Possible Mechanisms of Action. *Pharmacol. Res.* **2018**, *137*, 170–178. [CrossRef]
16. de Falco, B.; Incerti, G.; Amato, M.; Lanzotti, V. Artichoke: Botanical, Agronomical, Phytochemical, and Pharmacological Overview. *Phytochem. Rev.* **2015**, *14*, 993–1018. [CrossRef]
17. Muratore, G.; Restuccia, C.; Licciardello, F.; Lombardo, S.; Pandino, G.; Mauromicale, G. Effect of Packaging Film and Antibrowning Solution on Quality Maintenance of Minimally Processed Globe Artichoke Heads. *Innov. Food Sci. Emerg. Technol.* **2015**, *31*, 97–104. [CrossRef]
18. Feiden, T.; Valduga, E.; Zeni, J.; Steffens, J. Bioactive Compounds from Artichoke and Application Potential. *Food Technol. Biotechnol.* **2023**, *61*, 312–327. [CrossRef] [PubMed]
19. Corrias, F.; Arru, N.; Atzei, A.; Milia, M.; Scano, E.; Angioni, A. Determination of Pesticide Residues in IV Range Artichoke (Cynara Cardunculus L.) and Its Industrial Wastes. *Foods* **2023**, *12*, 1807. [CrossRef]
20. Canale, M.; Sanfilippo, R.; Strano, M.C.; Amenta, M.; Allegra, M.; Proetto, I.; Papa, M.; Palmeri, R.; Todaro, A.; Spina, A. Artichoke Industrial Waste in Durum Wheat Bread: Effects of Two Different Preparation and Drying Methods of Flours and Evaluation of Quality Parameters during Short Storage. *Foods* **2023**, *12*, 3419. [CrossRef]

21. Dadalı, C. Artichoke Bracts as Fat and Wheat Flour Replacer in Cake: Optimization of Reduced Fat and Reduced Wheat Flour Cake Formulation. *J. Food Meas. Charact.* **2023**, *17*, 98–107. [CrossRef]
22. Zayed, A.; Farag, M.A. Valorization, Extraction Optimization and Technology Advancements of Artichoke Biowastes: Food and Non-Food Applications. *LWT* **2020**, *132*, 109883. [CrossRef]
23. Petropoulos, S.A.; Pereira, C.; Ntatsi, G.; Danalatos, N.; Barros, L.; Ferreira, I.C.F.R. Nutritional Value and Chemical Composition of Greek Artichoke Genotypes. *Food Chem.* **2018**, *267*, 296–302. [CrossRef] [PubMed]
24. Lombardo, S.; Pandino, G.; Mauromicale, G. The Nutraceutical Response of Two Globe Artichoke Cultivars to Contrasting NPK Fertilizer Regimes. *Food Res. Int.* **2015**, *76*, 852–859. [CrossRef] [PubMed]
25. Martínez-Esplá, A.; García-Pastor, M.E.; Zapata, P.J.; Guillén, F.; Serrano, M.; Valero, D.; Gironés-Vilaplana, A. Preharvest Application of Oxalic Acid Improves Quality and Phytochemical Content of Artichoke (*Cynara scolymus* L.) at Harvest and during Storage. *Food Chem.* **2017**, *230*, 343–349. [CrossRef] [PubMed]
26. Cefola, M.; D'Antuono, I.; Pace, B.; Calabrese, N.; Carito, A.; Linsalata, V.; Cardinali, A. Biochemical Relationships and Browning Index for Assessing the Storage Suitability of Artichoke Genotypes. *Food Res. Int.* **2012**, *48*, 397–403. [CrossRef]
27. Tortosa-Díaz, L.; Saura-Martínez, J.; Taboada-Rodríguez, A.; Martínez-Hernández, G.B.; López-Gómez, A.; Marín-Iniesta, F. Influence of Industrial Processing of Artichoke and By-Products on The Bioactive and Nutritional Compounds. *Food Eng. Rev.* **2025**. [CrossRef]
28. Giménez-Berenguer, M.; García-Pastor, M.E.; García-Martínez, S.; Giménez, M.J.; Zapata, P.J. Evaluation of 'Lorca' Cultivar Aptitude for Minimally Processed Artichoke. *Agronomy* **2022**, *12*, 515. [CrossRef]
29. Amodio, M.L.; la Zazzera, M.; Colelli, G. Floral Vegetables: Fresh-Cut Artichokes. In *Controlled and Modified Atmospheres for Fresh and Fresh-Cut Produce*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 567–576, ISBN 9780128045992.
30. Giménez, M.J.; Giménez-Berenguer, M.; Guillén, F.; Serna-Escolano, V.; Gutiérrez-Pozo, M.; Zapata, P.J. Effect of Cysteine with Essential Oils on Quality Attributes and Functional Properties of 'Blanca de Tudela' Fresh-Cut Artichoke. *Foods* **2023**, *12*, 4414. [CrossRef] [PubMed]
31. Pompili, V.; Mazzocchi, E.; Moglia, A.; Acquadro, A.; Comino, C.; Rotino, G.L.; Lanteri, S. Structural and Expression Analysis of Polyphenol Oxidases Potentially Involved in Globe Artichoke (*Cynara cardunculus var. scolymus* L.) Tissue Browning. *Sci. Rep.* **2023**, *13*, 12288. [CrossRef]
32. Görgüç, A.; Erdoğdu, Ö.; Demirci, K.; Bayraktar, B.; Yilmaz, F.M. Cryoprotective Role of Vacuum Infused Inulin on the Quality of Artichoke: Interactive Effects of Freezing, Thawing and Storage Period. *Cryobiology* **2024**, *116*, 104914. [CrossRef] [PubMed]
33. Ricceri, J.; Barbagallo, R.N. Role of Protease and Oxidase Activities Involved in Some Technological Aspects of the Globe Artichoke Processing and Storage. *LWT-Food Sci. Technol.* **2016**, *71*, 196–201. [CrossRef]
34. Rizzo, V.; Lombardo, S.; Pandino, G.; Barbagallo, R.N.; Mazzaglia, A.; Restuccia, C.; Mauromicale, G.; Muratore, G. Active Packaging-Releasing System with Foeniculum Vulgare Essential Oil for the Quality Preservation of Ready-to-Cook (RTC) Globe Artichoke Slices. *Foods* **2021**, *10*, 517. [CrossRef]
35. Pandino, G.; Barbagallo, R.N.; Lombardo, S.; Restuccia, C.; Muratore, G.; Licciardello, F.; Mazzaglia, A.; Ricceri, J.; Pesce, G.R.; Mauromicale, G. Quality Traits of Ready-to-Use Globe Artichoke Slices as Affected by Genotype, Harvest Time and Storage Time. Part I: Biochemical and Physical Aspects. *LWT-Food Sci. Technol.* **2017**, *76*, 181–189. [CrossRef]
36. Rizzo, V.; Lombardo, S.; Pandino, G.; Barbagallo, R.N.; Mazzaglia, A.; Restuccia, C.; Mauromicale, G.; Muratore, G. Shelf-life Study of Ready-to-cook Slices of Globe Artichoke 'Spinoso Sardo': Effects of Anti-browning Solutions and Edible Coating Enriched with *Foeniculum Vulgare* Essential Oil. *J. Sci. Food Agric.* **2019**, *99*, 5219–5228. [CrossRef] [PubMed]
37. Restuccia, C.; Lombardo, S.; Pandino, G.; Licciardello, F.; Muratore, G.; Mauromicale, G. An Innovative Combined Water Ozonisation/O3-Atmosphere Storage for Preserving the Overall Quality of Two Globe Artichoke Cultivars. *Innov. Food Sci. Emerg. Technol.* **2014**, *21*, 82–89. [CrossRef]
38. Licciardello, F.; Pandino, G.; Barbagallo, R.N.; Lombardo, S.; Restuccia, C.; Muratore, G.; Mazzaglia, A.; Strano, M.G.; Mauromicale, G. 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.* **2017**, *79*, 554–560. [CrossRef]
39. Amodio, M.L.; Cabezas-Serrano, A.B.; Peri, G.; Colelli, G. Post-Cutting Quality Changes of Fresh-Cut Artichokes Treated with Different Anti-Browning Agents as Evaluated by Image Analysis. *Postharvest Biol. Technol.* **2011**, *62*, 213–220. [CrossRef]
40. la Zazzera, M.; Rinaldi, R.; Amodio, M.L.; Colelli, G. Influence of High CO_2 Atmosphere Composition on Fresh-Cut Artichoke Quality Attributes. *Acta Hortic.* **2012**, *934*, 633–640. [CrossRef]
41. García-Martínez, N.; Andreo-Martínez, P.; Almela, L.; Guardiola, L.; Gabaldón, J.A. Microbiological and Sensory Quality of Fresh Ready-to-Eat Artichoke Hearts Packaged under Modified Atmosphere. *J. Food Prot.* **2017**, *80*, 740–749. [CrossRef] [PubMed]
42. Capotorto, I.; Innamorato, V.; Cefola, M.; Cervellieri, S.; Lippolis, V.; Longobardi, F.; Logrieco, A.F.; Pace, B. High CO_2 Short-Term Treatment to Preserve Quality and Volatiles Profile of Fresh-Cut Artichokes during Cold Storage. *Postharvest Biol. Technol.* **2020**, *160*, 111056. [CrossRef]

43. Spanu, E.; Deligios, P.A.; Azara, E.; Delogu, G.; Ledda, L. Effects of Alternative Cropping Systems on Globe Artichoke Qualitative Traits. *J. Sci. Food Agric.* **2018**, *98*, 1079–1087. [CrossRef] [PubMed]
44. Pandino, G.; Lombardo, S.; Mauromicale, G.; Williamson, G. Characterization of Phenolic Acids and Flavonoids in Leaves, Stems, Bracts and Edible Parts of Globe Artichokes. *Acta Hortic.* **2012**, *942*, 413–417. [CrossRef]
45. Palma, A.; Cossu, M.; Deligios, P.A.; Ledda, L.; Tiloca, M.T.; Sassu, M.M.; D'Aquino, S. Organic versus Conventional Globe Artichoke: Influence of Cropping System and Harvest Date on Physiological Activity, Physicochemical Parameters, and Bioactive Compounds. *Sci. Hortic.* **2023**, *321*, 112304. [CrossRef]
46. Todaro, A.; Peluso, O.; Catalano, A.E.; Mauromicale, G.; Spagna, G. Polyphenol Oxidase Activity from Three Sicilian Artichoke (*Cynara cardunculus* L. var. scolymus L. (Fiori)) Cultivars: Studies and Technological Application on Minimally Processed Production. *J. Agric. Food Chem.* **2010**, *58*, 1714–1718. [CrossRef]
47. Lombardo, S.; Restuccia, C.; Pandino, G.; Licciardello, F.; Muratore, G.; Mauromicale, G. Influence of an O3-Atmosphere Storage on Microbial Growth and Antioxidant Contents of Globe Artichoke as Affected by Genotype and Harvest Time. *Innov. Food Sci. Emerg. Technol.* **2015**, *27*, 121–128. [CrossRef]
48. Liu, H.; Jiao, J.; Tian, Y.; Liu, J.; Yuan, P.; Wu, X. Drying Kinetics of *Pleurotus eryngii* Slices during Hot Air Drying. *Open Phys.* **2022**, *20*, 265–273. [CrossRef]
49. Kasim, R.; Kasim, M.U. Biochemical Changes and Color Properties of Fresh-Cut Green Bean (*Phaseolus vulgaris* L. Cv. Gina) Treated with Calcium Chloride during Storage. *Food Sci. Technol.* **2015**, *35*, 266–272. [CrossRef]
50. Lombardo, S.; Pandino, G.; Mauromicale, G. The Influence of Pre-Harvest Factors on the Quality of Globe Artichoke. *Sci. Hortic.* **2018**, *233*, 479–490. [CrossRef]
51. Kumar, K.; Debnath, P.; Singh, S.; Kumar, N. An Overview of Plant Phenolics and Their Involvement in Abiotic Stress Tolerance. *Stresses* **2023**, *3*, 570–585. [CrossRef]
52. Petropoulos, S.A.; Pereira, C.; Tzortzakis, N.; Barros, L.; Ferreira, I.C.F.R. Nutritional Value and Bioactive Compounds Characterization of Plant Parts from *Cynara cardunculus* L. (*Asteraceae*) Cultivated in Central Greece. *Front. Plant Sci.* **2018**, *9*, 459. [CrossRef] [PubMed]
53. Wauquier, F.; Boutin-Wittrant, L.; Viret, A.; Guilhaudis, L.; Oulyadi, H.; Bourafai-Aziez, A.; Charpentier, G.; Rousselot, G.; Cassin, E.; Descamps, S.; et al. Metabolic and Anti-Inflammatory Protective Properties of Human Enriched Serum Following Artichoke Leaf Extract Absorption: Results from an Innovative Ex Vivo Clinical Trial. *Nutrients* **2021**, *13*, 2653. [CrossRef] [PubMed]
54. Starowicz, M.; Ostaszyk, A.; Zieliński, H. The Relationship between the Browning Index, Total Phenolics, Color, and Antioxidant Activity of Polish-Originated Honey Samples. *Foods* **2021**, *10*, 967. [CrossRef]
55. Ghidelli, C.; Mateos, M.; Rojas-Argudo, C.; Pérez-Gago, M.B. Antibrowning Effect of Antioxidants on Extract, Precipitate, and Fresh-Cut Tissue of Artichokes. *LWT* **2013**, *51*, 462–468. [CrossRef]