Functional yogurt with carrot juice as a natural colorant: Bioactive properties and quality during storage

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Abstract

Carrot (*Daucus carota* L.) is one of the most popular vegetables consumed and recognized as a natural source of provitamin A due to its high carotenoid content. This study aimed to characterize the physicochemical and antioxidant properties of carrot juice and to evaluate its application as a functional ingredient in stirred yogurt. Samples were fortified with carrot juice at four concentrations EY1 (10%), EY2 (20%), EY3 (30%), and EY4 (40%). The overall quality of the product was monitored during 21 days of refrigerated storage at 4°C compared to a control plain yogurt (CY). All yogurt formulations remained stable and complied with physicochemical and microbiological standards during storage. The incorporation of carrot juice enriched the yogurts with bioactive compounds and increased their antioxidant activity. Among the formulations, EY4 (40%) exhibited the highest DPPH radical scavenging activity of 92.56 mg ET/100 g, a better reducing power of 40.09 mg EAA/100 g, and a good total antioxidant activity of 65.65 mg EAA/100 g, compared to the CY. Sensory evaluation revealed high acceptability of the enriched yogurts, and the EY1 was the most preferred formulation with a rate of 75.69%, due to their mild taste, attractive color, and desirable texture. In conclusion, developing a stirred yogurt enriched with carrot juice as natural colorant is not only feasible but also offers a real opportunity to promote a local plant-based ingredient with high nutritional and functional potential. Its development on an industrial scale could meet current consumer expectations for healthier, more natural, and diversified dairy products.

Introduction

Carrots (*Daucus carota* L.) are widely consumed crop in the *Apiaceae* family and are produced annually worldwide for food purposes [1, 2]. They are rich source of plant nutrients, including antioxidants, β-carotene, minerals and vitamins [3, 4]. Several epidemiological studies have reported an inverse relationship between increased carrot consumption and a decreased risk of various diseases, such as chronic disorders, cardiovascular diseases, age-related macular degeneration, and some types of cancer [5, 6]. These health benefit effects are mainly stem to the wide variety of bioactive compounds, also known as phytochemicals, presents in carrots including carotenoids, phenolics, flavonoids, vitamins and anthocyanins [7]. Carrot juice is one of the main products derived from carrots and is recognized for its substantial health benefits [8]. The main carotenoids responsible for the color of carrot juice are β-carotene, lutein, and zeaxanthin. Carotenoids are known for their antioxidant properties, i.e. they are able to neutralize free radicals in the body [9]. Carotenoids derived from carrot juice show great promise for use as functional components and natural colorants in development of novel functional food products such as yogurt [10].

Yogurt is one of the most popular consumed fermented dairy products, known for centuries and being globally recognized worldwide for its nutritional value and health benefits [11]. Yogurt or Yoghurt is a fermented milk product obtained by fermentation of milk through the action of suitable microorganisms (*Streptococcus thermophilus* and *Lactobacillus delbrueckii subsp. Bulgaricus*) and resulting in reduction of pH with coagulation (iso-electric precipitation) [12]. Yogurt is an interesting source of essential nutrients, including high-quality protein, calcium, potassium, phosphorus, and vitamins [13] and it is available in a wide range of flavors, colors and shapes [14]. The color of yogurt is one of the most important sensory attributes that plays a key role in attracting consumers and influence their overall acceptance of the product. Growing interest in natural food additives has stimulated the development of plant-based alternatives to synthetic colorants. This trend is driven by increasing consumers regarding food safety, as well as negative perceptions associated with the use of certain synthetic colorings [15, 16]. In this context, carrot juice is a promising source of carotenoid pigments, particularly β-carotene, which can impart a stable yellow-orange color to fermented dairy products like yogurt.

The aim of this study was to develop an alternative approach to coloring yogurt using carrot juice as a natural coloring agent. The effect of stirred yogurt fortification by four different levels of carrot juice (10%, 20%, 30%, and 40%) was evaluated during 21 days of the storage at 4°C on the physicochemical properties, microbiological quality, and sensory attributes in order to establish the optimal quantity of carrot juice addition based on consumer preference. Furthermore, the content of bioactive compounds and the antioxidant properties of carrot juice and the fortified yogurts were estimated compared to those of control plain yogurt. Research results of this study contribute to the development of a novel functional dairy products enriched with natural ingredient as a colorant.

Materials and methods

Chemicals

Folin-Ciocalteu phenol reagent, Sodium carbonate, Gallic acid, Trolox, Aluminum chloride, Ammonium molybdate, and Sulfuric acid were attained from Biochem Chemopharma (Montreal, Quebec). Quercetin, Ascorbic acid, 2,2-Diphenyl-picrylhydrazyl (DPPH•) stable radical were got from Sigma Chemical Co. (St. Louis, MO, USA). Methanol, ethanol, and acetone were purchased from Merck (Darmstadt, Germany). All reagents are of analytical grade.

Sample preparation

Carrot juice preparation

A sample of carrots (2 kg) *Touchon* variety was purchased on March 2025 from the local market in Bejaia district. The collected unpeeled carrots were trimmed of their inedible ends, after being washed under running water to remove any impurities, followed by rinsing with distilled water for an optimal cleaning. Then, 200 g of unpeeled orange carrots was combined with 100 mL of distilled water and blended in an electric mixer until smooth. The juice obtained was filtered through a sieve to remove solid particles. The collected juice was then pasteurized in a thermostatic water bath at 60 ± 1°C for 5 min to inactivate enzymes and enhance its stability. Finally, the resultant carrot juice was cooled and preserved at 4 ± 2°C for later analysis and incorporation into the stirred yogurt.

Yogurt preparation

Yogurt samples were prepared in a traditional way for a standard yogurt followed within the same company with a modification relating to the proportions of carrot juice according to protocol established by [17] with slight adjustments (Table 1). The whole milk sterilized at high temperature was heated to a temperature of 90 ± 1°C for 20 min while constantly stirring in order to prevent the formation of a cream layer. After adding 1% (w/v) sugar, the milk pan was removed from the heater and cooled. When the temperature was around 45°C, 0.1% (w/v) starch and 3% (w/v) starter culture were added to the milk. After that, previously pasteurized carrot juice added for different portions divided into five batches, the first batch: control plain yogurt (CY) made without addition of carrot juice and the other batches as enriched yogurt with different percentage of carrot juice as a natural colorant: 10% (EY1), 20% (EY2), 30% (EY3) and 40% (EY4) (v/v) with a suitable label. Then, each mixture was putted into a sterile 100 mL jars. For approximately 8 h, the samples were incubated at 45 ± 1°C to make yogurt. Finally, the yogurts were cooled, stirred and stored at 4 ± 2°C for quality analysis.

Table 1
Yogurt formulations.

Formulation	Milk (1 L)	Starch (g)	Sugar (g)	Lactic ferments (g)	Carrot juice (mL)
CY	1	1	100	0.03	-
EY1	1	1	100	0.03	100
EY2	1	1	100	0.03	200
EY3	1	1	100	0.03	300
EY4	1	1	100	0.03	400

Physicochemical analysis

Physicochemical analysis of carrot juice

The pH of carrot juice was measured using a *Hanna* pH meter at 20°C. Acidity was determined by titration with NaOH (0.1 N) in the presence of a few drops of 1% phenolphthalein until the appearance of a persistent pink color [18]. Humidity and dry matter were determined by drying a quantity of carrot juice in an oven set at 105°C, followed by a weight measurement taken every 2 h until constant weight [18]. The Brix degree was measured using a refractometer bas on the refractive index of the sample [19]. Total sugars and reducing sugars were quantified according to the AFNOR method [18]. Finlly, the ash and organic matter contents were determined by incineration of a known quantity of carrot in a porcelain capsule in a muffle furnace at 550 ± 15°C for 5 h, until greyish or whitish ash was obtained [18]. All results were expressed in percentage g/100 g of the carrot juice.

Physicochemical analysis of yogurts

The fortified yogurts and plain yogurt were analyzed fresh (0 day) and after 7, 14 and 21 days of storage at 4 ± 2°C. At each sampling day, physicochemical analysis was carried out in triplicate.

The pH of yogurt was determined by inserting the electrode of a *Hanna* pH-meter into a beaker containing 10 mL yogurt. The pH value was then displayed directly on the pH meter screen and noted [18].

The Total Acidity (TA) was measured after titration of a volume yogurt with NaOH in the presence of a few drops of phenolphthalein as a colored indicator using the method of [20]. Result are expressed in Dornic degree (∘D).

The Total Dry Extract (TDE) was measured by difference in weight after drying a quantity of yogurt in an oven at 105 ± 2∘C for 4 h, until constant weight. Results are expressed in percentage (g/100 g) [18].

Microbial analysis

Yogurt samples were analyzed according to the standard of the Official Journal of Algerian Republic (OJAR), n° 39 of July 2, 2017 for total coliforms, fecal coliforms, *Staphylococcus aureus, Salmonella*, yeasts and molds. The microbiological analyzes are carried out with the aim of ensuring that the prepared yogurt has a higher hygienic, a commercial quality and a stability of microbiological quality during 21 days of storage at 4 ± 2°C.

Sensory analysis

A tasting session was organized in a Food Engineering laboratory of Technology Faculty-Bejaia university in order to evaluate the organoleptic quality of the produced yogurts. Five samples of yogurts were formulated and prepared under the same conditions: enriched yogurt with carrot juice « EY » and the control plain yogurt « CY ». The samples are coded: A (CY), B (EY1), C (EY2), D (EY3) and E (EY4) then presented with a cup of water for a jury composed of 10 trained experts. The sensory evaluation was performed using a nine-point hedonic score (**1**: Extremely unpleasant; **2**: Very unpleasant; **3**: unpleasant; **4**: Quite unpleasant; **5**: Neither pleasant nor unpleasant; **6**: Quite pleasant; **7**: Pleasant; **8**: Very pleasant; **9**: Extremely pleasant) based on acceptance of the product in order to evaluate the degree of likeliness for selected quality attributes (Odor, Color, Flavor, Texture, Consistency and Overall acceptability). The total mean scores of the yogurt products were obtained by calculating the average of the scores obtained for the different attributes.

Bioactive compounds

Preparation of extracts

An aliquot of 25 g of carrot juice was homogenized with 200 mL of methanol 80%. The mixture was stirred for 40 min and then filtered to obtain the methanolic extract.

From fortified yogurts, the extraction was carried out according to the method described by [21] with slight modifications. It consists of dissolving 25 g of yogurt in 200 mL of methanol 80%. The pH of this solution was adjusted to 4.0 with a HCl (1N) solution. The mixture was incubated at 45°C for 10 min followed by centrifugation (10 000 rpm, 20 minutes, 4°C). The supernatant was collected and its pH was adjusted to 7 with NaOH (1N) solution, then centrifuged (10 000 rpm, 20 minutes, 4°C). The methanolic extract was collected and stored at 4°C for further analysis.

The collected methanolic extracts are used for antioxidant quantification and antioxidant activity assessment.

Phytochemical content

Total phenolic contents (TPC)

The total phenolic content (TPC) was assessed using the method described by [22]. A volume of 200 µL of methanolic extracts was added to 800 mL of sodium carbonate (75 g/L) and 1 mL of Folin-Ciocalteu reagent (1/10). The absorbance of the mixture was measured at 765 nm. The results were expressed as milligrams of Gallic Acid Equivalent per 100 grams (mg GAE/100 g).

Total flavonoid contents (TFC)

The estimation of flavonoid content was carried out using the method reported by [23]. A volume of 1 mL of methanolic extract was mixed with the same volume of chloride aluminum (2%). After a 15 min incubation, the absorbance of the reaction mixture was measured at 420 nm. The results were expressed as milligrams of Quercetin Equivalents per 100 grams (mg QE/100 g).

Flavonols Contents (FLC)

Flavonol contents was determined according to the method of [23]. A mixture containing 500 µL of the extract, 500 µL of distilled water, 500 µL of aluminum chloride (2%), and 500 µL of sodium acetate (50 g/L) was incubated for 30 minutes. The absorbance was measured at 440 nm. The FLC were expressed as micrograms of Quercetin Equivalent per 100 grams (µg QE/100 g).

Condensed tannins contents (CTC)

The condensed tannin contents were estimated using the butanol HCl assay as described by [24]. A volume of 200 µL of the extracts was added to 2 mL of butanol HCl (95:5; v/v) and 0.1 mL of iron sulfate (2%). After 60 min of incubation at 90°C, the absorbance was measured at 530 nm. The results were calculated using the Beer Lambert law ($A = \varepsilon * L*C$) with molar extinction coefficient of cyanidin ε = 34,700 L mol^{-1} cm^{-1}. The CTC were expressed as micrograms of Cyanidin Equivalent per 100 grams (µg CE/100 g).

Total Carotenoids contents (TCC) and Lycopene Contents (LC)

The carotenoids were extracted from the samples using the method of [25]. In brief, 20 mL mixture hexane-acetone-ethanol (2:1:1, v: v: v) were added to 2 g of homogenized carrot juice or formulated yogurt samples. After 30 min agitation, the supernatant was collected and the residue was mixed with 10 mL hexane for a second extraction. The absorbance of the combined hexane layers was measured at 450 nm. The TCC were expressed as microgram β-Carotene Equivalent per 100 grams (µg βCE/100 g).

The LC were determined after measuring the absorbance of the supernatant at 472 nm. The results were reported as microgram Lycopene Equivalent per 100 grams (µg LE/100 g).

Ascorbic Acid Contents (AAC)

The AAC was determined as described by [26]. Five grams of each sample was extracted with 20 mL of oxalic acid 1% (w/v) for 45 min at room temperature and filtered. The filtrate (3 mL) was mixed with 1 mL of 2,6-dichloroindophenol and the absorbance was measured within 15 Sec at 515 nm against a blank. The vitamin C contents were expressed as microgram Ascorbic Acid Equivalent per 100 grams (µg AAE/100 g).

Antioxidant activity

Free Radical Scavenging Activity DPPH (FRSA-DPPH)

The FRSA-DPPH was evaluated using the method reported in our previous study [27]. A volume of 100 µL of extract was added to 2.9 mL of DPPH in methanol (6.10^{-5}M). The absorbance was measured at 517 nm after 30 min of incubation at room temperature. The DPPH radical reduction percentage was determined by applying the formula as follows:

$$DPPH\ \% = [(Abs_C - Abs_S) / (Abs_C)].100$$

Where Abs_C represents the absorbance of the DPPH solution without the sample, and Abs_S represents the absorbance of the DPPH solution with the sample extract. The percentages of inhibition were expressed in milligrams Trolox Equivalent per 100 grams (mg TE/100 g).

Total Antioxidant Activity (TAA)

The phosphomolybdenum method of [28], was used to evaluate the TAA of the extracts. A volume of 100 µL of extracts was added to 1 mL of the phosphomolybdenum solution (sulfuric acid 0.6 M, sodium phosphate 28 mM and ammonium molybdate 4 mM). The absorbance of the mixture was measured at 695 nm after 1 hour of incubation at 90°C. The results were expressed as milligrams of Ascorbic Acid Equivalent per 100 grams (mg AAE/100 g).

Ferric Reducing Antioxidant Power (FRAP)

The method described by [27] was used to estimate the free reducing power of the samples. Equal volume of extract, phosphate buffer (0.2 M, pH 6.6), and potassium ferricyanide solution (1%) were mixed. After incubation at 50°C for 20 min, the same volume of trichloroacetic acid (10%) were added. After centrifugation at 3000 rpm for 10 min, 1.25 mL of supernatant was added to 1.25 mL of distilled water and 0.25 mL of ferric chloride (0.1%). The absorbance was measured at 700 nm. The results were expressed as milligrams of Ascorbic Acid Equivalents per 100 grams (mg AAE/100 g).

Statistical analysis

The results were presented as a mean ± standard deviations (n = 3) calculated with Microsoft Office Excel 2016. One-way analysis of variance (ANOVA) was used in order to highlight significant differences between the yogurts produced at 5% significance level ($\alpha = 0.05$) and was performed using Statistica 5.5 Software. The means were compared and the differences were revealed using LSD test.

Results and discussion

Physicochemical properties of carrot juice

Carrot juice used as a functional ingredient in yogurt formulation exhibited a pH of 4.78 ± 0.02 and a titratable acidity of 0.73 ± 0.10% (Table 2), reflecting the presence of organic acids, mainly citric and malic acid, and to a lesser extent ascorbic acid.

Table 2
Physicochemical properties of carrot juice.

Sample	Result
pH	4.78 ± 0.02
Acidity (%)	0.73 ± 0.10
Moisture (%)	88.44 ± 0.38
Dry Matter (%)	11.56 ± 0.38
Brix (%)	9.73 ± 0.15
Total Sugars (%)	139.17 ± 5.77
Reducing Sugars (%)	3.59 ± 0.12
Ash (%)	0.33 ± 0.01
Organic matter (%)	99.66 ± 0.01

The carrot juice showed a high moisture content of 88.44 ± 0.38% (or 11.56% ± 0.38% dry matter) and a °Brix value of 9.73 ± 0.15%, indicating a significant concentration of total soluble solids, mainly simple sugars (glucose, fructose, sucrose), along with organic acids, mineral salts, and water-soluble vitamins. The total sugar content of carrot juice was 139.17 ± 5.77%, with reducing sugar accounting for 3.59 ± 0.12%, reflecting a moderate concentration of glucose and fructose, two monosaccharides naturally present in the root and derived from primary metabolism depending on the variety, stage of maturity, and processing conditions [29]. The ash content was 0.33 ± 0.01%, consistent with the values typically observed in plant matrices, and correspond to a high proportion of organic matter (99.66 ± 0.01%). This composition profile contributes to the organoleptic quality and functional stability of carrot juice, while preserving its nutritional properties.

Quality of fortified yogurts

Physico-chemical quality

The different levels of carrot juice fortification of yogurt significantly affected various physicochemical properties such as pH, acidity and total dry extract.

The pH evolution kinetics demonstrate a gradual acidification of the various yogurt samples during 21 days of refrigerated storage. The initial values (D_0), ranging from 4.05 to 4.20, correspond to the levels expected for freshly fermented yogurt (Fig. 1).

The pH decrease, reaching thresholds between 3.95 and 4.05 at the end of the period (D_{21}), remains in accordance with microbiological safety requirements, with the critical threshold set at 4.6. A low pH value can prevent the growth of pathogenic microorganisms in yogurt such as *Salmonella typhimurium*, *Escherichia coli*, and *Staphylococcus aureus* [30]. The same trend was demonstrated by [17, 19, 31–34]. Moreover, [35] and [36] reported that the pH of the formulated yogurt gradually decreased due to the production of lactic acid by the ongoing growth of lactic acid bacteria during the storage period. This behaviour can be attributed to the residual metabolic activity of lactic acid bacteria, particularly *Lactobacillus delbrueckii subsp. bulgaricus* and *Streptococcus thermophilus*, which are capable of continuing to produce organic acids even at low temperatures. Furthermore, [19] have reported that the decrease in pH of yogurt enriched with different concentration of prickly pear during storage can be explained by the effect of lactic acid bacteria (favored by the availability of nutrients) which acidify the environment by the production of lactic acid hence the drop in pH. This can be also explained by microbial activity in fruit-added yogurts. Yeasts also use sugar and organic acids; therefore, pH value can decrease. However, [32] reported the decrease of pH in enriched yogurt due to the phenolic compounds from enrichment matrix have various hydroxyl and carboxyl groups which can have an impact on pH values.

In this context, the addition of carrot juice, a natural source of simple sugars, vitamins and bioactive compounds, to the formulation may have promoted sustained fermentation activity, resulting in a more pronounced decrease in pH than that observed in the control sample. The reason for the decline in pH over time in yogurt samples can be attributed to the lactic acid production by lactic acid bacteria. Besides, the presence of lactic acid bacteria and nutrient compounds such as sugar in carrot juice caused higher acid production and pH reduction in yogurt samples containing a higher concentration of carrot juice. This addition has been demonstrated to enhance the functionality of the final product during the fermentation process, while concomitantly improving its nutritional value.

The evolution of titratable acidity over storage time are shown in Fig. 2. The acidity of yogurts enriched with carrot juice was found to be lower than those of control. There were significant differences ($p < 0.05$) in titratable acidity between plain yogurt and the yogurts containing carrot juice with varying concentrations from 10% to 40%. This variation can be probably due to the nature of acidity produced by carrot juice added to the yogurts. A significant ($p < 0.05$) decrease in acidity was observed after 7 days of the storage particularly in fortified yogurt comparatively to the CY, reflecting rapid consumption or transformation of organic acids in this period. Subsequently, between D_7 and D_{14}, a slight increase in acidity was noted in all samples, suggesting a metabolic recovery or a second slow phase of fermentation. Furthermore, the titratable acidity of plain and enriched yogurt between the D_{14} and D_{21} showed a certain stability and/or a slight increase of acidity. This dynamic indicates an initial phase of acid consumption, followed by partial regeneration of organic acids, probably linked to the prolonged activity of lactic ferments. This fermentation profile is indicative of an active secondary metabolism, capable of producing lactic acid or other acidic compounds after a delay. Our results are consistent with those of [37], [38] and [17], who observed an increase of acidity during storage in enriched bio-yogurt with sucrose, date and beetroot juices, respectively. This increase is attributed to the high fermentable sugar content of enriched matrix, which promotes prolonged microbial activity. According to [35], the differences between the recorded acidity values may be explained by the composition of the fermentative environment and acidifying activity of starter culture.

Total dry matter and/or moisture are fundamental parameters in assessing the physical stability of fermented dairy products. They reflect not only water retention in the matrix, but also the system's ability to resist syneresis (exudation of liquid). The TDE values of the formulated yogurt ranged from 14.33% to 20.11% (D_0) (Fig. 3). The inclusion of carrot juice in the yogurts significantly ($p < 0.05$) increased the dry extract from D_0 to D_{21} in all fortified yogurt with a rate of 1.6 to 34.88%. The EY4 showed a notable change in TDE, increasing from 15.67% (D_0) to 18.89% (D_{21}), reflecting better water retention over time. Similarly, the TDE of EY3 raised from 14.33% to 19.33%. This increase suggests a change in the structure of the protein or polysaccharide matrix, probably linked to the production of exopolysaccharides (EPS) by the ferments during storage. The EPS can form a hydrophilic network that effectively retains water in the gel, thereby reducing syneresis. In contrast, the TDE of CY remained stable 20.11% on D_0 to 19.78% on D_{21}, reflecting the absence of additional microbial mechanisms to improve water retention. These observations are consistent with the findings of [39], [38], who observed a significant reduction in moisture content in enriched yogurt, where natural sugars and soluble fiber contributed to reduced syneresis and improved water retention.

Furthermore, the study by [40] showed that the use of encapsulated probiotic ferments ensured more stable moisture content throughout storage by strengthening the structure of the milk gel, indicating that microbiological intervention plays a key role in the structuring and hydration of the final product. This property could be exploited in industrial formulations aimed at improving consistency, reducing liquid losses and extending shelf life without the use of texturing additives. Generally, as considered by many researchers, the more the total solids content increases the syneresis phenomenon [19, 36, 41].

Microbiological quality

The results of the microbiological quality of carrot juice fortified yogurts are reported in Table 3, showed clearly their perfect compliance with the standards. As it can be seen, there was no colonies were found for the total coliforms, fecal coliforms, *Staphylococcus aureus*, *Salmonella*, yeasts, and molds in samples of CY, EY1, EY2, EY3 and EY4 until the 21st day of storage; while the regulatory standard as per O.J.A.R n° 39 is < 10/g, < 1/g, < 10/g, Absence, < 100 cfu/g and Absence for total coliforms, fecal coliforms, *Staphylococcus aureus*, *Salmonella*, yeasts, and molds, respectively.

Table 3
Results of microbiological analyses of formulated yogurts.

Day	**D_0, D_7, D_{14}, and D_{21}**					
Researched Germs/Sample	**CY**	**EY1**	**EY2**	**EY3**	**EY4**	**Standard (OJAR) n° 39**
Total Coliforms	Abs	Abs	Abs	Abs	Abs	< 10 germes/g
Fecal Coliforms	Abs	Abs	Abs	Abs	Abs	< 1 germe/g
Staphylococcus aureus	Abs	Abs	Abs	Abs	Abs	< 10 germes/g
Salmonella	Abs	Abs	Abs	Abs	Abs	Abs
Yeasts	Abs	Abs	Abs	Abs	Abs	< 100 germes/g
Molds	Abs	Abs	Abs	Abs	Abs	Abs

OJAR: *Official Journal of Algerian Republic;* **CY**: *Control yogurt;* **EY1**: *Enriched yogurt with 10% of carrot juice;* **EY2**: *Enriched yogurt with of 20% carrot juice;* **EY3**: *Enriched yogurt with 30% of carrot juice; and* **EY4**: *Enriched yogurt with 40% of carrot juice.*

These results indicate that the yogurts were produced under good sanitary conditions. Similar findings were described by [35], who discovered a stability of microbiological quality of the fortified yogurt with lentil during 21 days of the storage at 4°C. According to [32] and [42], these results stated the raw materials quality, adequate heat treatment applications and/or hygienic production process.

Sensory quality

Organoleptic quality is a key parameter in assessing the commercial value of food products. This expert approach aims to provide relevant data on the acceptability of the enriched yogurt, in relation with the changes brought by the addition of carrot juice.

Product Characterization

The sensory characteristics of the yogurts produced before and after storage are illustrated in Figure 4. All the formulated yogurts have an average odor that is moderately appreciated. In addition, the color of all samples is well appreciated; sample A (CY) has a white color, samples B (EY1) and C (EY2) have a pink color, while samples D (EY3) and E (EY4) are characterized by a pale orange color. Sample A (CY) is identified by the absence of the identified fruit, a sour flavor and weak aroma, a moderately sweet flavor and a very smooth texture compared to the other samples (Figure 4.a).

After 21 days of storage à 4°C, a clear improvement was observed in the enriched yogurts in terms of odor, color, flavor, and aroma (Fig. 4.b). The results of the sensory analysis revealed that the enriched yogurts with the carrot juice were the more appreciated than the control one. This can be explained by the fact that their color was more appreciated compared to the plain yogurt which plays a crucial role in consumers' food choices [17].

Overall preference

The Table 4 shows the preference percentages assigned to the different samples of processed yogurts, as expressed by the panel of experts during the sensory analysis. These percentages reflect the overall assessment of the juries, taking into account all the organoleptic criteria evaluated (visual appearance, smell, taste, texture and overall acceptability), and enable the most popular formulations among the enriched yogurts to be identified. The results show that the fortified yogurts are appreciated at fluctuating rates of 60 to 80%. The most popular yogurt is the one enriched with 10% carrot juice (75.69%), and the least popular is the one enriched with 40% carrot juice (62.50%). The different yogurts are ranked in descending order of preference as follows: *EY1 (B) > EY2 (C) > CY (A) > EY3 (D) > EY4 (E)*.

Table 4
Overall preference for the fortified yogurts.

Sample	Percentage (%)	Hedonic score
A	72.22	Pleasant
B	75.69	Pleasant
C	73.61	Pleasant
D	70.14	Quite pleasant
E	62.50	Quite pleasant

A: *Control yogurt;* **B**: *Enriched yogurt with 10% of carrot juice;* **C**: *Enriched yogurt with of 20% carrot juice;* **D**: *Enriched yogurt with 30% of carrot juice; and* **E**: *Enriched yogurt with 40% of carrot juice.*

The Samples A (CY), B (EY1) and C (EY2) were rated 72.22%, 75.69% and 73.61%, respectively, corresponding to the characteristic "Pleasant" (Table 4). However, samples D (EY3) and E (EY4) were the least appreciated, with rating of "Quite pleasant" and percentages of 70.14% and 62.50%, respectively. These results indicate that enriched yogurts are highly appreciated by tasters.

Parameters influencing preference

The differences between the CY (A) and the enriched yogurts are very noticeable, with the enriched yogurts having the best color, smell and texture. Table 5 shows that the parameters that motivated the preference of the tasters of the fortified yogurts were color, with the highest rate of 87.5%, followed by smell, with a percentage of 68.75%, and taste and consistency, with the same rate of 56.25%. However, texture recorded the lowest proportion with a rate of 50%. The role of color in the selection of foods is very important, as it constitutes the primary sensory aspect that consumers encounter, frequently exerting a significant influence on their preferences [32, 43]. Finally, according to [44], the integration of plant nutraceuticals into fermented matrices optimizes their antioxidant potential without compromising their sensory qualities or microbiological stability.

Table 5
Characteristic influencing the preferences for formulated yogurts.

Characteristic	Percentage (%)
Color	87.50
Odor	68.75
Taste	56.25
Texture	50.00
Consistency	56.25

Bioactive compounds

Total Phenolic Content (TPC)

The TPC of the different extracts varies significantly ($p < 0.05$) between the samples studied (Table 6). The TPC of carrot juice (CJ) used as an enriching agent and natural colorant is around 52.12 ± 0.18 mg EAG/100 g. This value is close to the results reported by [45], who recorded polyphenol contents between 40 and 57 mg EAG/100 g in Algerian carrots, confirming the high antioxidant potential of this root vegetable.

Enriched yogurts (YE1 to YE4) have intermediate values ranging from 26.39 to 45.77 mg EAG/100 g of the sample, reflecting a positive correlation between the carrot juice content and the final concentration of phenolic compounds. In particular, YE3 (44.76 mg EAG/100 g Ech) and YE4 (45.77 mg EAG/100 g Ech) are very proximate to the value noted in carrot juice, indicating the enrichment of the fermented matrix with bioactive molecules. However, the YE1 and YE2 contains 26.39 ± 0.81 mg EAG/100 g Ech and 29.54 ± 0.42 mg EAG/100 g Ech, respectively. According to [34], this increase can be related to the existence of high amounts of phenolic compounds. Furthermore, these results are consistent with those of [46] and [47] who revealed that combining carrot juice with fermented dairy products enhances the bioactivity of the final product. In addition, [39], [19], [17], [48] and [34] have demonstrated that the incorporation of antioxidant-rich plant matrices, such as oats, prickly pears betalains (2 to 8%), beetroot juice (4 to 10%), carrot powder (3 to 9%) and black raspberry juice (3 to 5%), into fermented milks significantly increases the phenolic content.

In contrast, the results reported by [49] showed relatively low phenolic compound contents in enriched yogurts with walnut shell. This decrease can be due to the interactions between yogurt proteins and polyphenols and by the formation of insoluble complexes which results in decreasing the total phenolic contents [34]. These data, compared with our results, reinforce the idea that carrot juice, rich in soluble phenolic compounds, is an effective vector for improving the antioxidant potential of yogurt.

Table 6
Antioxidant contents of carrot juice and fortified stirred yogurts.

Sample /Antioxidants	**TPC (mg GAE/100 g)**	**TFC (mg QE/100 g)**	**FLC (µg QE/100 g)**	**CTC (µg CE/100 g)**	**TCC (µg βCE/g)**	**LC (µg LE/100 g)**	**AAC (mg AAE/100 g)**
CJ	52.12 ± 0.18^{a}	28.90 ± 1.16^{a}	1513.77 ± 24.77^{a}	42.22 ± 4.97^{a}	19.89 ± 0.08^{a}	10.29 ± 0.09^{a}	3.63 ± 0.10^{a}
CY	25.77 ± 0.82^{d}	8.67 ± 0.98^{e}	297.35 ± 33.76^{f}	14.35 ± 2.66^{d}	17.02 ± 0.14^{f}	7.83 ± 0.12^{f}	1.59 ± 0.04^{f}
EY1	26.39 ± 0.81^{d}	13.33 ± 0.13^{d}	491.97 ± 24.78^{e}	15.73 ± 0.83^{d}	18.09 ± 0.06^{e}	8.52 ± 0.06^{e}	1.63 ± 0.01^{e}
EY2	29.54 ± 0.42^{c}	13.72 ± 0.14^{c,d}	546.04 ± 25.00^{d}	20.69 ± 0.84^{c}	18.24 ± 0.08^{d}	8.81 ± 0.07^{d}	1.66 ± 0.02^{d}
EY3	44.76 ± 1.22^{b}	14.49 ± 0.13^{b,c}	610.91 ± 24.80^{c}	22.90 ± 0.48^{b,c}	18.83 ± 0.02^{c}	9.37 ± 0.03^{c}	1.74 ± 0.02^{c}
EY4	45.77 ± 0.54^{b}	15.40 ± 0.12^{b}	735.26 ± 40.82^{b}	26.76 ± 2.08^{b}	19.28 ± 0.06^{b}	9.78 ± 0.07^{b}	1.91 ± 0.01^{b}

Different letters indicate a significant differences at $p < 0.05$. The results are ranked in ascending order; a > b>c > d>e > f.

TPC: *Total Phenolic Content;* **TFC**: *Total Flavonoid Content;* **FLC**: *Flavonol Content;* **CTC**: *Condensed Tannin Content;* **TCC**: *Total Carotenoid Content;* **LC**: *Lycopene Content;* **AAC**: *Ascorbic Acid Content.*

CJ: *Carrot Juice;* **CY**: *Control yogurt;* **EY1**: *Enriched yogurt with 10% of carrot juice;* **EY2**: *Enriched yogurt with of 20% carrot juice;* **EY3**: *Enriched yogurt with 30% of carrot juice; and* **EY4**: *Enriched yogurt with 40% of carrot juice.*

Total Flavonoid Content (TFC)

The TFC of the different samples varies significantly at $p < 0.05$ between CJ and fortified yogurt samples (Table 6). The TFC recorded for CJ was 28.90 ± 0.61 mg EQ/100 g, indicating high antioxidant potential, attributable to the natural richness of carrots in these bioactive compounds. Furthermore, [45] confirmed the intrinsic richness of carrots, particularly Algerian varieties, in flavonoids, thus reinforcing the relevance of their use in functional dairy products.

Furthermore, the control yogurt (CY), formulated without carrot juice, has a significantly lower concentration (8.67 ± 0.54 mg EQ/100 g), reflecting the limited contribution of flavonoids from the milk matrix. The gradual enrichment with carrot juice in formulations EY1 to EY4 led to a proportional increase in flavonoid content, reaching 13.33 mg EQ/100 g, 13.72 mg EQ/100 g, 14.49 mg EQ/100 g and 15.40 mg EQ/100 g, respectively, reflecting a direct relationship between the proportion of juice incorporated and the final flavonoid content. These results are confirmed by [39], [50], [48] and [51]. Furthermore, [41] were found that the content of quercetin in the yogurt significantly increased ($p < 0.05$) with increasing black garlic polyphenols addition (0.1–0.4%). However, [49] and [34] reported lower levels of flavonoids in enriched yogurts, highlighting the decisive role of nature of the plant and its compatibility with the milk matrix.

So, the TFC changes in carrot juice fortified yogurt were similar to the TPC tendency of the yogurt. Therefore, TFC were key functional components contributing to the antioxidant properties of yogurt. Thus, the results obtained illustrate the effectiveness of enriching yogurt with carrot juice to increase its functional value, while maintaining good physicochemical stability and beneficial potential for metabolic and cardiovascular health.

Flavonol Content (FLC)

The FLC of the different fortified yogurt extracts varies significantly between the samples studied at $p < 0.05$ (Table 6). The FLC recorded in carrot juice (1513.77 ± 24.77 µg EQ/100 g) confirms the exceptional richness of this plant matrix in these bioactive compounds, particularly quercetin, kaempferol and their glycosylated derivatives, which are known for their powerful antioxidant properties [52]. Conversely, the lowest FLC (297.35 ± 33.76 µg/100 g) was recorded in the control yogurt (CY), reflecting the low contribution of milk to flavonols. However, the gradual incorporation of juice into the enriched yogurts (EY1 to EY4) led to a significant increase, reaching up to 735.26 µg EQ/100 g in EY4, highlighting a positive correlation between the dose of juice added and the final FLC. These results are consistent with those of [53], who showed an increase of more than 60% in flavonols in functional yogurts enriched with black carrot concentrate. Similarly, [54] confirmed the stability of flavonoids in fermented dairy products enriched with citrus extracts, even after refrigeration. To the best of our knowledge, there is no published data regarding the FLC in carrot juice fortified yogurt.

Condensed Tannin Content (CTC)

The Table 6 shows a significant variation ($p < 0.05$) in the proanthocyanidin content of the different samples studied. The CTC measured in carrot juice is estimated at 42.22 ± 4.97 µg EC/100 g, indicating the presence of proanthocyanidin type polyphenols, known for their antioxidant, antimicrobial and anti-inflammatory effects.

In comparison, the control yogurt (CY) has a lower content (14.35 ± 2.66 µg/100 g) than that recorded in carrot juice and enriched yogurts, reflecting the low content of condensed tannins in milk. However, the enrichment of the yogurt led to a gradual increase in this content in samples EY1 to EY4, reaching a higher level of around 26.76 ± 2.08 µg/100 g in EY4, illustrating a dose-dependent relationship. These results are similar to those reported by [55] who showed that adding grape juice to dairy matrices can triple the condensed tannin content, confirming the results observed in the present study.

In addition, [56] emphasized that condensed tannins interact strongly with milk proteins via hydrophobic bonds and hydrogen bonds, leading to the formation of non-covalent complexes that can influence both the availability of tannins and the structure of the protein matrix. These complexes can stabilize tannins against oxidation, while modifying the functional properties of the dairy product.

In this study the gradual increase in condensed tannins in the enriched samples suggests effective post-fermentation retention, as well as stable incorporation into the yogurt structure, without any notable destabilization of the matrix cohesion. This observation indicates a favorable technological compromise, in which enrichment confers functional and antioxidant added value while maintaining the integrity of the fermented product.

Total Carotenoid Content (TCC) and Lycopene Content (LC)

As expected, the quantitative analysis revealed that CJ exhibited a high total carotenoid content (19.89 ± 0.08 µg EβC/g) (Table 6). This result is comparable approximate to that recorded for carrots by [45] (18 µg/g).

The TCC recorded for carrot juice is significantly ($p < 0.05$) higher than that noted in the CY (17.02 ± 0.14 µg EβC/g); while the enriched yogurts (EY1 to EY4) showed a significant and gradual increase depending on the percentage of juice incorporated, with contents of 18.09 ± 0.06 µg/g, 18.24 ± 0.08 µg EβC/g, 18.83 ± 0.02 µg EβC/g and 19.28 ± 0.06 µg EβC/g for EY1, EY2, EY3 and EY4, respectively, indicating effective pigment transfer into the yogurt matrix during fermentation.

These findings are supported by those of [47], who reported a significant increase in β-carotene content in yogurts (from 0.94 to 4.43 mg/100 g) with a gradual increasing carrot juice fortification (10–50%). Similarly, [48] noticed that lutein content increased from 0.04 to 0.42 µg/g as the carrot powder concentration increased from 3% to 9%, while β-carotene levels rose to 1.67 µg/g and 2.23 µg/g at 6% and 9%, incorporation, respectively.

The lycopene content follows a similar dynamic to that of the TCC; the highest level was recorded in CJ (10.29 ± 0.09 µg LE/g) compared to a lower level in CY (7.83 ± 0.12 µg LE/g) (Table 6). Furthermore, the enriched samples showed a gradual increase in lycopene content, with respective levels of 8.52 ± 0.06 µg LE /g (EY1), 8.81 ± 0.08 µg LE /g (EY2), 9.37 ± 0.02 µg LE /g (EY3), and 9.78 ± 0.06 µg LE /g (EY4). These outcomes align with those reported by [57], who noted an increase in lycopene content in yogurt fortified with 2–4% tomato powder derived from food waste, rising from 1.37 to 2.10 mg/100g. According to [58], this increase is due to the lipid environment of milk matrices which optimize the stability and bioavailability of carotenoids such as β-carotene and lycopene.

The results of this study confirm that carrot juice is an effective natural source of bioactive fat-soluble pigments, mainly β-carotene and lycopene, which is recognized for its dual nutritional and technological function. From a sensory perspective, carotenoids play a decisive role in the pink or orange coloring of yogurt, contributing to its visual appearance. This property justifies the traditional use of carrots as a natural food coloring which is a promising alternative to the use of artificial colorings. All the results obtained highlight the dual benefits of enriching yogurt with carrot juice: on the one hand, a notable improvement in its antioxidant potential through the addition of bioactive compounds such as carotenoids and lycopene; on the other hand, an intensification of its visual qualities through an attractive natural color. This approach is fully in line with the new directions of Agri-Food development, focused on the creation of high value-added fermented products that are healthier, more sensorially rewarding and aligned with clean-label requirements, favoring natural, identifiable ingredients free from synthetic additives.

Ascorbic Acid Contents (AAC)

The AAC differed significantly ($p < 0.05$) between carrot juice and the formulated yogurt samples (Table 6). As expected, carrot juice presented the highest level, with a content of 3.63 ± 0.10 mg EAA/100 g. This value was approximate to the results reported by [45] for two varieties of Algerian carrots (*Daucus carota* L.).

According to the current findings, the control yogurt (CY) exhibited the lowest AAC, significantly lower than that of carrot juice and the fortified yogurts (1.59 ± 0.04 mg EAA/100 g), which is justified by the absence of the enrichment matrix. Progressive enrichment of yogurts (EY1 to EY4) with carrot juice resulted in a proportional increase in ascorbic acid content, reaching 1.91 ± 0.01 mg EAA/100 g in EY4. This augmentation of vitamin C is due to the presence of higher amount (3.63 ± 0.10 mg/100 g) of vitamin C present in carrot juice. The current results mirrored those of [59] and [17], who registered a substantial increase in vitamin C content of yogurt with the increasing levels of cabbage outer leaf powder (from 3.27 to 16.35 mg/100 g) and beetroot juice (from 0.387 to 2.250 mg AA/100 g), respectively.

Moreover, [14] have noted that the content of vitamin C was gradually increased (from 0.34 to 3.15 mg/100 g) as the concentration of red beet puree, strawberry juice, and pomegranate juice were increased in the formulated yogurt.

So, the addition of carrot juice to yogurt effectively contributed to its micronutrient enrichment, increasing antioxidant levels without altering the stability of the milk matrix and the sensory attributes. These observations confirm the technological and functional benefits of this enrichment strategy, which makes it possible to promote a locally available plant ingredient as a natural colorant while meeting the requirements of a functional and preventive diet.

Antioxidant Activity

Free Radical Scavenging Activity against DPPH (FRSA-DPPH)

The DPPH° (2,2-diphenyl-1-picrylhydrazyl) antiradical activity of the different samples studied varies significantly (*P < 0.05*) (Table 7). The results recorded reveal a clear improvement in the antioxidant power of yogurt following enrichment with carrot juice. Carrot juice (CJ) has the highest antioxidant activity with a rate of 98.01 ± 0.52 mg ET/100 g, confirming its richness in bioactive compounds of plant origin, such as phenolic compounds, carotenoids and ascorbic acid.

Table 7
Antioxidant activities of carrot juice and fortified stirred yogurts.

Sample	FRSA-DPPH (mg TE/100 g)	TAA (mg AAE/100 g)	FRAP (mg AAE/100 g)
CJ	98.01 ± 0.52^{a}	83.04 ± 1.67^{a}	43.40 ± 0.42^{a}
CY	59.51 ± 2.22^{f}	1.71 ± 0.89^{e}	23.33 ± 0.91^{f}
EY1	75.64 ± 2.46^{e}	27.64 ± 3.27^{d}	33.26 ± 0.73^{e}
EY2	84.61 ± 5.70^{d}	49.80 ± 1.07^{c}	36.71 ± 0.44^{d}
EY3	89.72 ± 1.10^{c}	63.35 ± 3.27^{b}	39.07 ± 0.63^{c}
EY4	92.56 ± 2.77^{b}	65.65 ± 1.01^{b}	40.09 ± 0.17^{b}

Different letters indicate significant differences at p < 0.05. The results are ranked in ascending order; a > b>c > d>e > f.

FRSA-DPPH: *Free Radical Scavenging Activity against free radical DPPH;* **TAA**: *Total Antioxidant Activity;* **FRAP**: *Ferric Reducing Antioxidant Power.*

CJ: *Carrot Juice;* **CY**: *Control yogurt;* **EY1**: *Enriched yogurt with 10% of carrot juice;* **EY2**: *Enriched yogurt with of 20% carrot juice;* **EY3**: *Enriched yogurt with 30% of carrot juice; and* **EY4**: *Enriched yogurt with 40% of carrot juice.*

In addition, the control yogurt (CY) has a relatively low antiradical capacity (59.51 ± 2.22 mg ET/100 g of Ech), while the enriched samples (YE1 to YE4) show increasing values, reaching 92.56 ± 2.77 mg ET/100 g for YE4, reflecting a positive correlation between the concentration of added juice and the final antioxidant activity. The results are in accordance with hose obtained in previous studies for yogurt enriched with 0.5–2.5% cabbage outer leaf powder [59], 0.2–0.6% Moringa oleifera leaf powder [51], 3–9% carrot powder [48], 4–10% beetroot juice [17], 0.25–0.75% fermented edible bird's nest [30], 10–50% carrot juice [47], 4% lentil flour [39], 1–5% pomegranate juice powder [60] and 40% pomegranate juice [61]. This observation is confirmed by [62], who demonstrated a significant improvement in antioxidant capacity in yogurts enriched with paprika juice, due to the notable contribution of water-soluble compounds such as vitamin C. The results clearly confirm that adding carrot juice significantly enhances the functional properties of yogurt due to its richness in phenolic compounds, in particular vitamin C.

Thus, these data confirm that adding carrot juice is an effective strategy for enhancing the functional properties of yogurt, improving its ability to neutralize reactive oxygen species, while meeting growing consumer demand for natural, functional products that comply with the principles of proper labeling and food safety.

Total Antioxidant Activity (TAA)

The TAA of the different extracts varies significantly ($p<0.05$) between the different samples studied (Table 7). The results show that the TAA of the fortified yogurt is significantly higher than that registered for CY.

Carrot juice (CJ) has the highest TAA, reaching 83.04 ± 1.67 mg EAA/100 g, which demonstrates its exceptional richness in water-soluble antioxidants, such as polyphenols, flavonoids and vitamin C. However, the control yogurt (CY), without carrot juice, exhibited the lowest TAA (1.71 ± 0.89 mg EAA/100 g Ech), highlighting a low level of bioactive compounds involved in TAA. Furthermore, TAA activity in the enriched yogurt increases proportionally with increasing levels of CJ incorporation, from 27.64 ± 3.27 mg EAA/100 g (EY1) to 65.65 ± 1.01 mg EAA/100 g (EY4). This dynamic demonstrates not only the effective incorporation of the juice's bioactive compounds, but also their preservation within the fermented matrix. These results correspond to those found by [41], [19], [32], [47] and [39], who demonstrated the beneficial effect of incorporating plant matrices into yogurt to enhance its antioxidant potential.

The increase in TAA in enriched yogurts compared to control yogurt is a major functional argument in favor of using CJ as a nutraceutical ingredient in fermented dairy products.

Ferric Reducing Antioxidant Power (FRAP)

Table 7 shows that there are significant differences ($p < 0.05$) in reducing power between the extracts from the different samples analyzed. CJ has the highest value, 43.40 ± 0.42 mg EAA/100 g, reflecting its intrinsic ability to donate electrons and neutralize oxidizing species, which demonstrates its richness in natural reducing compounds such as carotenoids, flavonoids and vitamin C confirmed in our previous study [45].

In contrast to carrot juice, the control yogurt (CY) has the lowest reducing power (23.33 ± 0.91 mg EAA/100 g Ech), typical of a dairy matrix with a low concentration of endogenous antioxidants. The gradual incorporation of juice into the enriched samples (EY1 to EY4) leads to a significant increase in reducing power, reaching a value of 40.09 ± 0.17 mg EAA/100 g for EY4, which is very close to that recorded for carrot juice. This development illustrates a functional synergy between the antioxidants in carrot juice and the fermented matrix. Similar results were noted by [34], [48], [30] and [63], who demonstrated in their study an improvement in antioxidant capacity in the enriched yogurts.

All of these results reinforce the technological relevance of enriching yogurt with carrot juice, not only for its nutritional value, but also for its protective effects against oxidation.

CONCLUSION

The addition of plant-based ingredients into fermented dairy products represents an innovative approach for meeting consumers' growing demand for health, nutrition and natural food. This study focuses on the development of a stirred yogurt enriched with carrot juice (*Daucus carota* L.), a vegetable that is renowned for its high bioactive compounds content and antioxidant activity, as well as its attractive color.

The primary objective was to evaluate the impact of incorporating carrot juice at different proportions (10, 20, 30 and 40%) on the physicochemical, microbiological, and sensory qualities of stirred yogurt during a 21-days of refrigerated storage at 4°C. Additionally, the antioxidant properties of both carrot juice and the enriched yogurts were evaluated. The physicochemical quality of yogurt samples is complied with the established standards and as accompanied by satisfactory microbiological quality. The organoleptic analysis revealed a high level of acceptance for the enriched yogurts. The fortified yogurt with 10% (EY1) of carrot juice was the most appreciated with a level of 75.69% which can be attributed to their mild taste, attractive color and pleasant texture. Moreover, gradually enriching yogurt with carrot juice increases the level of bioactive compounds and significantly enhances proportionally the antioxidant activity from the sample EY1 (10%) to EY4 (40%). These data reinforce the idea that carrot juice is an effective and natural carrier of phenolic compounds, is an effective vector for improving the antioxidant potential of yogurt while maintaining its physicochemical stability and sensory acceptability with high functional added value. Thus, the combination of carrot juices and yogurt improve the nutritional and functional food characteristics of the yogurt.

In conclusion, the results indicate that the enrichment with carrot juice is a relevant and promising strategy for enhancing the nutritional, functional, and sensory attributes value of stirred yogurt, as carrot juice serves a dual purpose; it functions as a natural colorant agent and a source of antioxidant compounds with high antioxidant properties, while concurrently preserving the physicochemical stability, microbiological safety, and organoleptic quality of the product throughout storage.

Declarations

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Author Contributions: L. Arkoub-Djermoune conceived and designed the study, and undertook the literature research. All authors participated in the experiment and data acquisition. L. Bensafia and L. Haddar performed the data analysis. L. Arkoub-Djermoune and F. Benmeziane prepared, reviewed, and drafted the manuscript. All authors approved the final version before submission. All authors have read and agreed to the published version of the manuscript.

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Figures

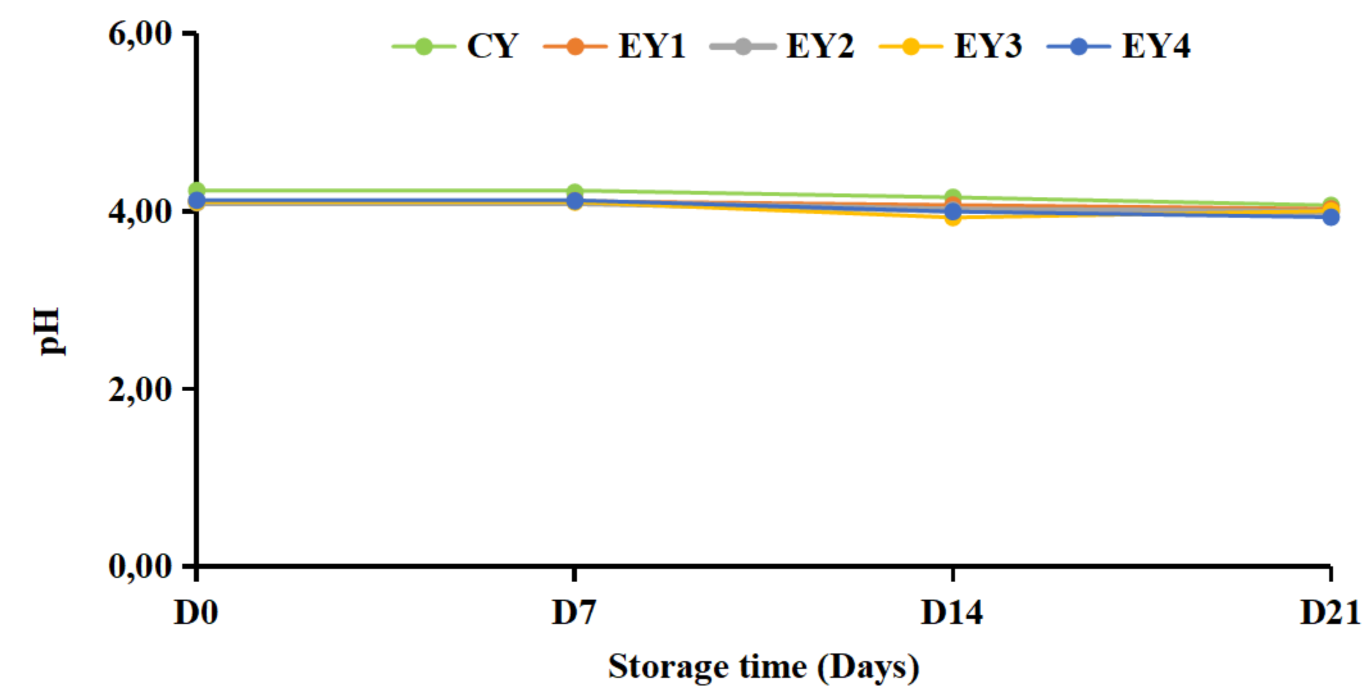

Figure 1

Evolution of the pH of formulated yogurts during storage at 4°C.

CY: *Control yogurt;* ***EY1:****Enriched yogurt with 10% of carrot juice;* ***EY2:****Enriched yogurt with of 20% carrot juice;* ***EY3:****Enriched yogurt with 30% of carrot juice; and* ***EY4:*** *Enriched yogurt with 40% of carrot juice.*

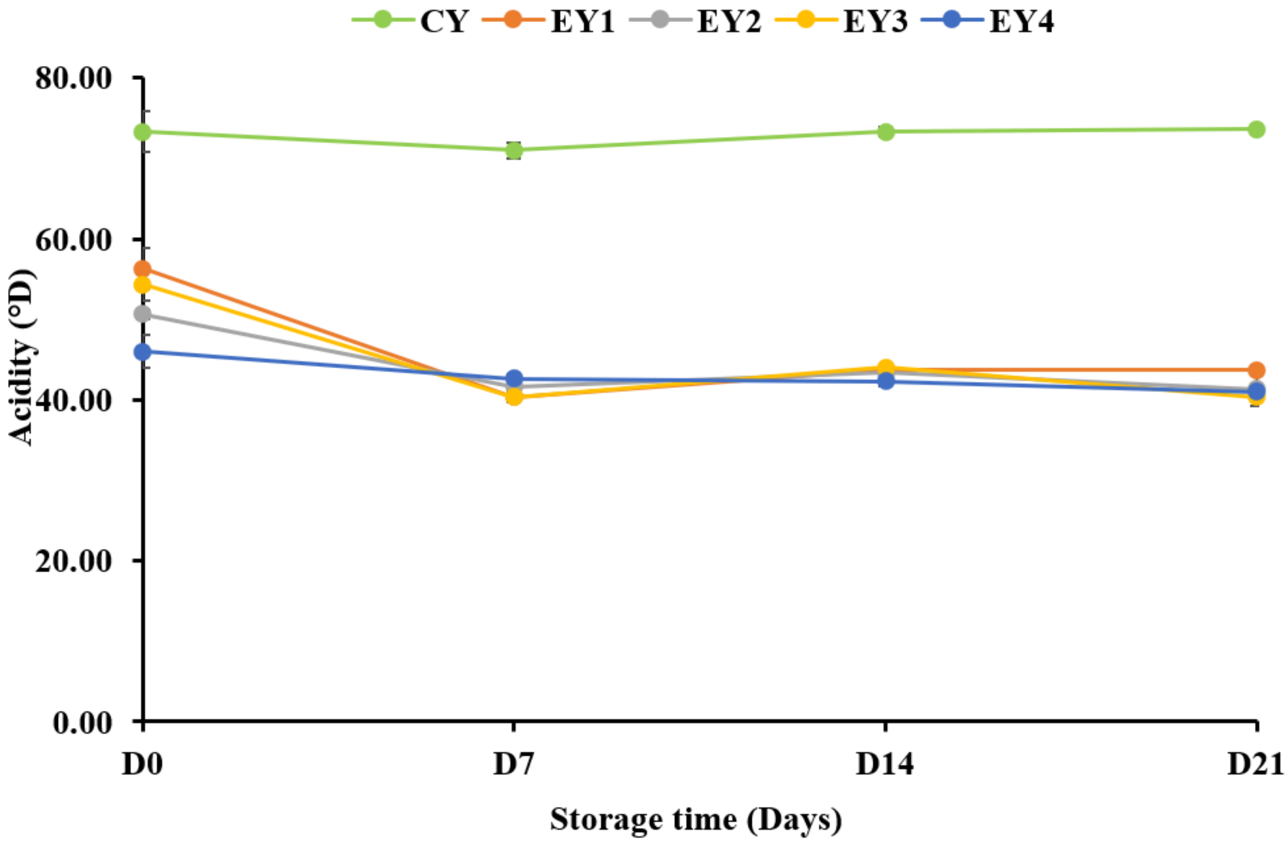

Figure 2

Evolution of the acidity of the formulated yogurts during storage at 4°C.

CY: *Control yogurt;* ***EY1:****Enriched yogurt with 10% of carrot juice;* ***EY2:****Enriched yogurt with of 20% carrot juice;* ***EY3:****Enriched yogurt with 30% of carrot juice; and* ***EY4:*** *Enriched yogurt with 40% of carrot juice.*

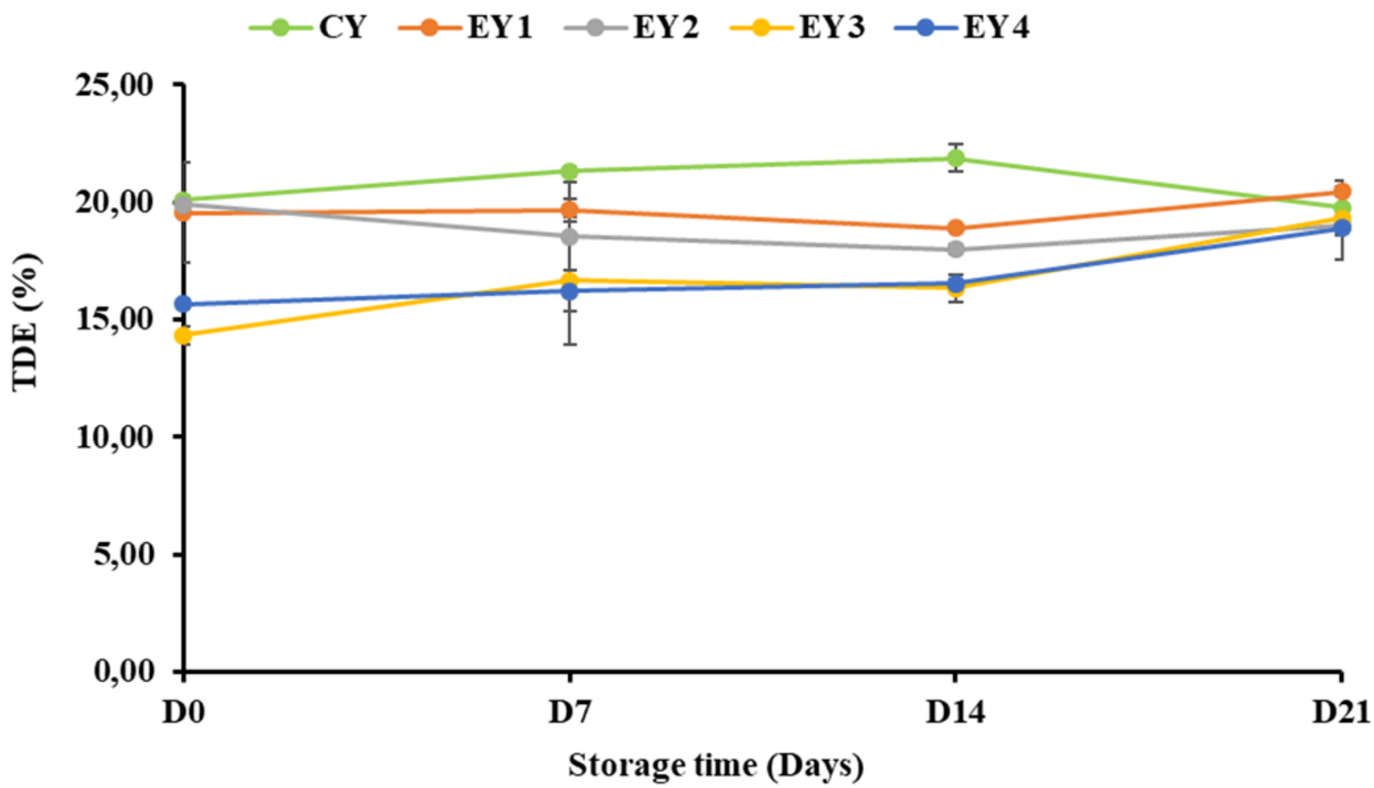

Figure 3

Evolution of the Total Dry Extract of the formulated yogurts during storage at 4°C.

CY: *Control yogurt;* ***EY1:****Enriched yogurt with 10% of carrot juice;* ***EY2:****Enriched yogurt with of 20% carrot juice;* ***EY3:****Enriched yogurt with 30% of carrot juice; and* ***EY4:*** *Enriched yogurt with 40% of carrot juice.*

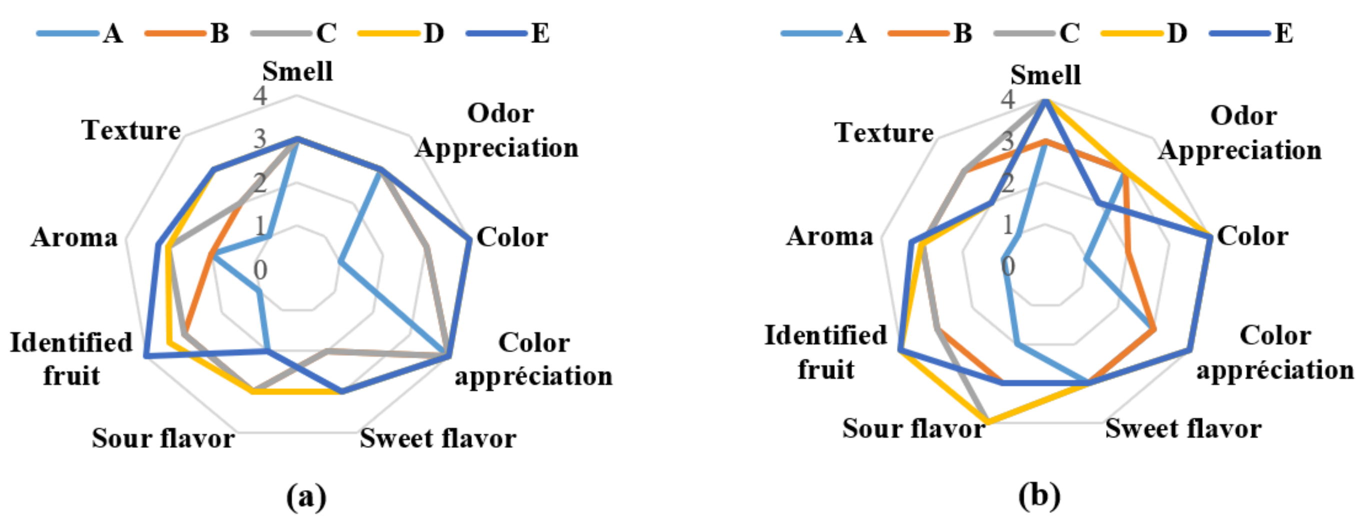

Figure 4

Characterization of fortified yogurts during storage. ***(a):*** *Day 0;* ***(b):****Day 21*.

A: *Control yogurt;* ***B:*** *Enriched yogurt with 10% of carrot juice;* ***C:*** *Enriched yogurt with of 20% carrot juice;* ***D:****Enriched yogurt with 30% of carrot juice; and* ***E:*** *Enriched yogurt with 40% of carrot juice.*