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Health-Promoting Properties of Fresh and Processed Purple Cauliflower

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Abstract: Plant-based foods should be fresh, safe, and natural, with nutritional value and processed in sustainable ways. Among all consumed vegetables, Brassica vegetables are considered to be the most important ones. As they are eaten in large quantities and frequently, they may constitute an important source of nutrients and bioactive compounds in a daily diet. This work is aimed at assessing the effect of technological processing (blanching and traditional cooking in water and in a convection steam oven) as well as the method of frozen storage (in PE-LD zipper bags and vacuum packing) on the content of selected components in purple cauliflower. The material was examined for the content of dry matter, vitamin C, total polyphenols, anthocyanins, thiocyanates, nitrates, and nitrites, as well as antioxidant activity. All technological processes caused significant changes in the contents of examined nutritive and non-nutritive compounds as well as in antioxidant activity or the level of selected chemical pollutions. A trend was also observed towards lower constituents' losses as a result of convection steaming, compared to traditional cooking in water. Moreover, the reduction in the content of examined compounds was smaller in vacuum-packed and frozen-stored vegetables then in those stored in zipper PE-LD bags.

Keywords: nutritional value; brassica vegetables; antioxidative properties; quality of food; nitrates and nitrites; frozen storage; processing of vegetables

1. Introduction

Sustainable food consumption is a significant aspect of sustainable development. Throughout the last two decades, Brassica crops were of intense interest to many researchers due to their health benefits [1]. Numerous epidemiological and pharmacological works showed a significant role of a diet abundant in Brassica vegetables, which may protect against many chronic diseases, including type II diabetes, cardiovascular disease, age-related macular degeneration, dementia, immune dysfunction, obesity, and some kinds of cancers [2,3]. Cauliflower (*Brassica oleracea* var. *botrytis*) belongs to the very popular Brassica species and is broadly used as a dish or an ingredient of soups or salads. It is rich in vitamins B_1, B_2, B_3, B_5, B_6, folic acid and C, E, K, as well as omega-3 fatty acids, dietary fiber, potassium, phosphorus, magnesium manganese, and iron. Chemical components contents in Brassica vegetables vary among cultivars, which is especially relevant to cauliflower because, in addition to the large group

of white-curded cultivars, breeding techniques have resulted in commercially available genotypes forming green, purple, and orange curds, with enhanced synthesis of chlorophylls, anthocyanins, and carotenoids, respectively. Cauliflower genotypes show differences in the content of bioactive compounds, as well as in the chemical composition [4–6]. In addition, this vegetable contains also a lot of valuable and healthy plant's metabolites, including flavonoids, terpenes, S-methylcysteine sulfoxide, sulfur-containing glucosinolates, coumarins, and other minor compounds. These compounds of cauliflower, and other Brassica vegetables, were found to be effective in the protection of some kinds of cancer as cancer-fighting components [4,7,8]. The number of studies has suggested protective effects of these compounds on human health. Brassica species are commonly present in a diet as additives to meat dishes and other products rich in fat, which constituents favour cell transformation and cancer growth [9]. Therefore, some of Brassica crops are classified as functional foods [7].

Thermal treatment of different types of food products leads to various physical, chemical and biological changes occurring in nutrients as well as non-nutrient compounds. In vegetable processing, cooking is the most commonly used technique; although, the application of high temperature may affect the basic chemical composition of as well as activity of bioactive compounds. Two contrary phenomena may be responsible for changes in the content of bioactive compounds during this process: denaturation of enzymes that are involved in degradation of nutrients and bioactive compounds and softening effect of cooking, which increases the extractability of bioactive compounds. As a result, their amount in cooked products is higher than in the raw material [10]. Therefore, in order to evaluate their accessibility with a diet, more knowledge should be gained about the role and the final concentration of bioactive compounds before and after food processing.

New thermal technologies with higher energy efficiency, less nutrient loss and less environmental impacts are being developed. It is believed that for example the steam blanching is relatively inexpensive and retains more water-soluble ingredients and minerals in comparison to water blanching.

The main drawback to vegetables is that they are perishable and available seasonally. Food technology is focused on the development of such methods of food processing, which will affect its chemical composition to the least extent. In view of this, freezing, which is a simple and fast method, is one the most universal and convenient ways of food preservation. Knowledge about optimization of freezing and storing processes is crucial to preserve beneficial and bioactive compounds of vegetables [6]. In this context, the importance of packaging and its role is huge, especially considering its fundamental role in the product protection against the external conditions as well as mechanical damages. In order to guarantee high product quality in terms of their sensory and nutritional features, selection of suitable packaging materials is required [11].

As for packaging properties, low-density polyethylene (PE-LD) is characterized by low permeability to water vapor and good permeability to gases, especially carbon dioxide [12]. Vacuum packaging, as a static form of hypobaric storage, is widely used in food industry. This method allows oxidative reactions to be reduced effectively in a product, at relatively low cost [13].

Until now, the majority of studies concerned other than examined here *Brassicas* cultivars. In consequence, less information is available about such Brassicas like, for example, colored varieties of cauliflower.

High quality foods obtained with sustainable practices during preharvest need proper postharvest practices, including thermal treatments and storage. The aim of the work was to assess the effect of technological processing (blanching, traditional cooking in water and in a convection steam oven) as well as the method of frozen storage (in PE-LD zipper bags and vacuum packing) on the content of selected components in purple cauliflower.

2. Materials and Methods

2.1. Material

The experimental material was purple cauliflower (*Graffiti* cv.) cultivated at the Producer Cooperative "Traf" in Tropiszów (Poland). The experimental field was located in the northern outskirts of the Krakow. The climate of the region is humid continental (Dfb) according to Köppen's classification. The purple cauliflower was grown in black soil on loess framework with neutral pH. Mineral fertilization was applied according to the fertility of soil and the nutritional requirements of the species and condition treatments (mechanical weed control, diseases, and pests) were carried out during the growing season (depending on soil and weather conditions). Mineral fertilization included 400 kg Polifoski PK (MgS) 15-24-(6-7), 100 kg of Saletrzak NH_4NO_3 + $CaCO_3$ and twice foliar application of Folicare NPK 18:18:18; 5:17:40.

Vegetable samples were prepared for analyses directly after harvest. Properly prepared representative medium samples of vegetables (fresh, blanched, cooked in water, convection steamed and frozen, and stored in different package types for 2 and 4 months), were examined for the content of dry matter, vitamin C, total polyphenols, anthocyanins, thiocyanates, nitrates and nitrites as well as antioxidant activity. In addition, the contents of protein, fat, carbohydrates, ash and fiber were determined in fresh material.

The first step of processing (before thermal treatment) included leaf removing, washing in running water, and dividing the heads into roses 4–6 cm in diameter and 5 cm in length. Then, the vegetables were mixed in order to obtain the representative average laboratory samples (a minimum of three for each analysis performed on the fresh material and the same procedure was on material after cooking). Analyses of fresh vegetables were carried out immediately after the pretreatment.

The blanching of material was carried out in the HENDI steam convection oven (model G715RXSD) for 5 min at 100 °C and then cooking to the consumer's softness in the same oven for 20 min at 100 °C. After blanching, the material was chilled and dried at room temperature for about 20 min. Another part of the fresh material was washed, dried using the filter paper, shredded mechanically, frozen at −22 °C, and, finally, freeze-dried in the Christ Alpha 1–4 apparatus. Afterwards, the material was comminuted in the Knifetec 1095 Sample Mill (Tecator) until reaching a homogenous sample with the possibly smallest diameter of particle. Adequately labelled samples were stored at −22 °C in plastic containers in a Liebherr GTS 3612 chamber freezer (Germany), until analyses of protein, fat, dietary fiber and ash.

Another part of the vegetables was cooked in a stainless steel pot using an electric cooking plate, in unsalted water, and in the initial phase of hydrothermal treatment—without a lid but in accordance with the principle "from farm to fork". The proportion of water to the raw material is 5:1 by weight. The cooking time applied was 15 min. The boiled vegetables were then prepared as described for fresh, blanched and steamed vegetables.

The material blanched in a convection steam oven was divided and packed in two types of packaging: the first batch in the conventional polyethylene (PE-LD) zipper bags (0.915–0.935 g/cm^3 in density and 230 × 320 mm in size); the remainder in the special vacuum bags adapted for this purpose, applying a RAMON vacuum packaging machine (60% vacuum; pressure: 0.10 MPa). Next, hermetically sealed samples were stored at −22 °C in a Liebherr GTS 3612 chamber freezer (Germany). Analyses were carried out on the raw material, the material blanched, cooked and the frozen product. Frozen samples were analyzed after 2 and 4 months of frozen storage. The experimental material, taken from every package (on average: 3 roses differing in diameter—from the smallest up to the largest), was collected and then homogenized using a homogenizer (CAT type X 120) to obtain a mean representative sample.

2.2. Analytical Methods

The experimental material was taken from every container (on average: 3 roses differing in diameter—from the smallest up to the largest) and homogenized using a homogenizer (CAT type X 120) in order to obtain a mean representative sample.

At the same time, 70% methanol extracts have been prepared to determine total polyphenols (calculated per chlorogenic acid) by means of the colorimetric measurement of colorful substances occurring as a result of the reaction between phenolic compounds and a Folin–Ciocalteu reagent (Sigma) [14]. The same extract was also used to measure antioxidant activity based on the $ABTS^+$ free radical scavenging ability by a colorimetric assessment of the amount of the $ABTS^+$ free radical solution, which remained unreduced by the antioxidant in the products [15]. In addition, 70% acidified methanolic extracts (5 g of raw vegetables in 80 mL of 70% acidified methanol solution) were prepared [16], which were then used to determine anthocyanin content.

The amount of total phenols in the extracts was measured by a spectrophotometric method at 760 nm on a RayLeigh UV-1800 spectrophotometer, according to the procedure described by Folin–Ciocalteu. The results were calculated using a chlorogenic acid equivalent (CGA) and expressed in milligrams per 100 g of fresh or dry mass, based on a standard curve.

Antioxidant activity was measured by means of colorimetric determination of the quantity of the colored solution of $ABTS^+$ free radical (2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid)) because of its reduction performed by the antioxidants present in the product examined. Absorbance was measured at 734 nm on a RayLeigh UV-1800 spectrophotometer. The values obtained for every sample were compared to the concentration–response curve of the standard Trolox solution and expressed as micromoles of Trolox equivalent per gram of fresh and dry mass (TEAC).

Anthocyanin content, measured as anthocyanins' absorbance in visible light, was determined in buffer solutions at two pH values: 1 and 4.5. At pH 1 anthocyanins took the form of a red-colored flavic cation, while at pH 4.5 they had changed to the colorless pseudobase. Anthocyanin content was converted to mg of cyanidin-3-glucoside [17].

The dry matter content in the vegetable samples was found in agreement to PN-90/A-75101/03 [18]. The determination principle comprised determining the decrease in mass upon removal of water from the product during thermal drying at the temperature of 105 °C, under normal pressure conditions.

The contents of total ascorbic acid and dehydroascorbic acid were determined using 2,6-dichlorophenoloindophenol in accordance with PN-A-04019:1998 [19]. Extraction of the ascorbic acid was performed using oxalic acid solution. Vitamin C content was expressed as milligrams per 100 g of dry mass (mg/100 g d.m.).

Determination of thiocyanate was based on extraction of the sample with trichloroacetic acid (TCA) and the reaction with ferric ions. Under acidic conditions, blood-red coloration was created due to the formation of $Fe(SCN)^{2+}$ to $Fe(SCN)_6{}^{3-}$ complexes.

Determinations of nitrates and nitrites were carried out in accordance with the Polish standard PN-92/A-75112 [20]. The colorimetric method was used to determine these contaminants based on nitrite colored reaction with Griess I and II. Previously nitrates must be reduced to nitrites. Nitrate content was established using Griess I (sulfanilamide, Sigma-Aldrich) and Griess II (*n*-(1-Naphtyl)ethylene-diamine dihydrochloride, water solution, Sigma-Aldrich). The principle of this method is to induce in acidic conditions, a color reaction of nitrate(III) with *n*-(1-Naphtyl)ethylene-diamine dihydrochloride.

Raw, freshly prepared, lyophilized samples were also examined for protein content using a Tecator Kjeltec 2200; fat content, using a Tecator Soxtec Avanti 2050; ash content, by means of dry mineralisation in muflon oven at 525 °C in accordance with PN-A-79011-8:1998 [21]; and dietary fiber content, with the enzymatic-gravimetry method using the Tecator Fibertec System E.

Protein content was determined by mineralization of the product in concentrated sulfuric acid (IV) (aqueous mineralization), followed by alkalizing the solution, distillation of the ammonia released, and its qualitative determination [22]. As for fat content, at first fat extraction was performed from the dried material with an organic solvent (petroleum ether), then distilling off the solvent, drying the

residue, and determining the mass of the extracted "crude fat" [23]. Analysis of dietary fiber content was conducted according to Polish standard [24] by means of enzymatic and gravimetric methods. Lyophilized samples were subjected to gelatinization with a thermally stable α-amylase, then digested by enzymes involving protease and amyloglucosidase to remove protein and starch present in the sample. Soluble dietary fiber was precipitated by adding ethanol. The sediment was then filtered off, washed in ethanol and acetone, and, after drying, weighed. Half the samples was analyzed for the presence of protein and the remainder incinerated. Total dietary fiber has been calculated as the mass of sediment minus the mass of protein and ash.

In addition, the percentage of carbohydrates has been calculated, as the difference between 100 g of fresh product and the sum of water (g), total fat (g), protein (g), and mineral compounds—ash (g).

2.3. Statistical Analysis

All analyses were conducted in three parallel replications and mean ± standard deviations (SD) were calculated for the values obtained. Significance of differences between mean values of raw, blanched, cooked and frozen stored material was checked by one-way analysis of variance (ANOVA). The significance of differences was estimated with the Duncan test at the critical significance level of $p \leq 0.05$. The Statistica 10.1 (Statistica, Tulsa, OK, USA) program was applied.

3. Results

3.1. Basic Composition and Dietary Fiber

Dry matter content in the vegetable varies depending on the process applied, therefore, to show only an effect of the applied process, all the results presented below have been calculated per the dry matter unit. Fresh vegetable contained 19.8 g dry matter, 2.36 g proteins, 0.14 g fat, 0.53 g ash, 16.3 g total carbohydrates, and 2.36 g dietary fiber per 100 g of fresh vegetable (Table 1).

Table 1. Selected antioxidative and bioactive compounds, antioxidant activity, basic composition, and nitrates and nitrites of raw purple cauliflower.

Component	Unit	Mean
Dry Mass	g/100 g	9.18 ± 0.04
Vitamin C	mg/100 g d.m.	689.54 ± 1.54
Total Polyphenols	mg CGA/100 g d.m.	1376.36 ± 3.85
Antioxidant Activity	µmol Trolox/g d.m.	79.85 ± 0.46
Thiocyanates	(SCN) mg/100 g d.m.	26.25 ± 1.69
Anthocyanins	µmol/g d.m.	78.21 ± 5.85
Total Protein	g/100 g d.m.	25.70 ± 1.56
Fat	g/100 g d.m.	1.55 ± 0.21
Ash	g/100 g d.m.	5.73 ± 0.29
Total Carbohydrates	g/100 g d.m.	66.72 ± 1.16
Dietary Fiber	g/100 g d.m.	25.67 ± 1.63
Nitrates	mg $NaNO_3$/kg d.m.	605.23 ± 23.72
Nitrites	mg $NaNO_2$/kg d.m.	17.97 ± 0.31

Technological treatments, both traditional cooking and cooking in the convection steam oven, resulted in a significant ($p \leq 0.05$) increase in dry matter content by 17.1 and 12.7% respectively, compared to fresh cauliflower. Frozen storage of the analyzed material for 2 and 4 months led to a substantial ($p \leq 0.05$) increase in the dry matter content respectively by 31.1 and 32.2% (conventional, in a PE-LD bag) and 30 and 32.2% (in vacuum) compared to the blanched product (Table 2).

Table 2. Content of selected compounds and antioxidant activity of purple cauliflower depending on the technological processing.

The Kind of Processing	Dry Mass g/100 g	Vitamin C mg/100 g d.m.	Total Polyphenols mg CGA/100 g d.m.	Antioxidant Activity µmol Trolox/g d.m.	Thiocyanates (SCN) mg/100 g d.m.	Anthocyanins µmol/g d.m.	Nitrates mg $NaNO_3$/kg d.m.	Nitrites mg $NaNO_2$/kg d.m.
fresh	$9.18^{a} \pm 0.04$	$689.54^{f} \pm 1.54$	$1376.36^{f} \pm 3.85$	$79.85^{d} \pm 0.46$	$26.25^{d} \pm 1.69$	$78.21^{c} \pm 5.85$	$605.23^{e} \pm 23.72$	$17.97^{c} \pm 0.31$
blanched	$8.85^{a} \pm 0.07$	$683.62^{f} \pm 7.99$	$1358.76^{f} \pm 13.58$	$80.79^{d} \pm 0.80$	$26.89^{d} \pm 0.31$	$80.34^{c} \pm 8.15$	$580.79^{e} \pm 33.56$	$17.29^{bc} \pm 0.48$
cooked	$10.75^{b} \pm 0.35$	$305.30^{d} \pm 0.26$	$493.40^{a} \pm 1.84$	$47.53^{a} \pm 2.76$	$12.27^{a} \pm 1.18$	$28.47^{a} \pm 5.92$	$219.16^{b} \pm 7.10$	$11.26^{a} \pm 1.18$
steamed	$10.35^{b} \pm 0.21$	$362.42^{e} \pm 4.24$	$1143.77^{e} \pm 15.30$	$61.55^{c} \pm 1.78$	$19.13^{bc} \pm 0.96$	$67.73^{bc} \pm 8.20$	$470.53^{d} \pm 4.10$	$14.11^{ab} \pm 1.50$
after 2 months of frozen storage (zipper bags)	$11.60^{c} \pm 0.14$	$245.69^{b} \pm 19.51$	$968.97^{c} \pm 6.10$	$52.76^{b} \pm 0.98$	$19.39^{bc} \pm 1.10$	$52.76^{b} \pm 11.83$	$211.81^{b} \pm 2.80$	$13.62^{a} \pm 1.10$
after 2 months of frozen storage (vacuum)	$11.50^{c} \pm 0.14$	$280.87^{c} \pm 2.46$	$1013.04^{d} \pm 7.38$	$59.39^{c} \pm 0.37$	$20.09^{c} \pm 1.23$	$60.43^{bc} \pm 17.09$	$291.39^{c} \pm 7.26$	$14.61^{abc} \pm 0.86$
after 4 months of frozen storage (zipper bags)	$11.70^{c} \pm 0.14$	$197.43^{a} \pm 1.21$	$899.23^{b} \pm 15.59$	$44.87^{a} \pm 1.21$	$13.08^{a} \pm 1.33$	$43.68^{ab} \pm 8.70$	$148.03^{a} \pm 6.41$	$22.99^{d} \pm 1.45$
after 4 months of frozen storage (vacuum)	$11.70^{c} \pm 0.28$	$232.48^{b} \pm 8.46$	$976.32^{c} \pm 11.72$	$53.08^{b} \pm 2.05$	$16.50^{b} \pm 2.05$	$53.85^{b} \pm 8.46$	$234.02^{b} \pm 8.70$	$33.16^{e} \pm 2.78$

Values are presented as mean value ± standard deviation and expressed in dry matter. Means in columns with different superscript letters in common (a, b, c, d, e) differ significantly ($p \leq 0.05$).

3.2. Vitamin C

Studies revealed that fresh product contained 63.2 mg/100 g (689.54 mg per 100 g dry matter) vitamin C (Table 2). Traditional cooking and convection steaming led to significant ($p \leq 0.05$) losses of ascorbic acid of 55.7 and 47.4% respectively, compared to the fresh vegetable. In the frozen stored material, all changes were significant in comparison with the blanched cauliflower ($p \leq 0.05$). Losses of vitamin C in products stored for 2 months were 64.1% and 58.9%, respectively, for the conventionally packed and vacuum packed ones. In the material stored for 4 months, vitamin content decreased by 71.1% (traditional packaging) and by 66.0% (vacuum packaging). At every stage of the study, losses were significantly ($p \leq 0.05$) lower in the vegetables stored in vacuum pouches compared to those kept in conventional l zipper bags.

3.3. Total Polyphenols

It has been revealed that 100 g of purple cauliflower had 126.35 mg of total polyphenols, expressed as chlorogenic acid (1376.36 mg/100 g dry matter) (Table 2). In comparison with the fresh vegetable, the applied hydrothermal treatment caused statistically significant ($p \leq 0.05$) losses of these components: by 64.2% in traditional cooking and by 16.9% in convection steaming. Losses of total polyphenols after 2 and 4-months of frozen storage in a traditional way and in vacuum, were respectively 28.7 and 33.8% as well as 25.4 and 28.1% and were statistically significant ($p \leq 0.05$) compared to the blanched material. At every stage of this experiment, they were significantly ($p \leq 0.05$) lower for steam-cooked vegetables and those frozen stored in vacuum.

3.4. Anthocyanins

Purple cauliflower contained 7.18 mg anthocyanins per 100 g fresh material (78.21 mg/100 g dry matter). Traditional cooking in water significantly reduced their content (63.6%), compared to fresh vegetables. However, the remaining heat treatments (blanching and convection steaming) had no significant effect on anthocyanin content in this cauliflower. After 2 and 4 months of frozen storage, anthocyanin content compared to blanched vegetables decreased significantly ($p \leq 0.05$) by respectively 34.3 and 45.6% (traditional packaging) and 24.8 and 33% (vacuum packaging). At every stage of the research, these losses were significantly ($p \leq 0.05$) lower in the vacuum packed vegetables than in those stored in PE-LD bags.

3.5. Antioxidant Activity

The study revealed that antioxidant activity in purple cauliflower was 7.33 µmol Trolox per 1 g fresh of vegetable matter (79.85 µmol Trolox/g dry vegetable matter). The applied technological treatments (except for blanching) caused significant ($p \leq 0.05$) reductions in antioxidant activity compared to not processed vegetables, by 40.5% for traditional cooking and by 22.9% for convection steaming. Frozen storage of vegetables in PE-LD bags and vacuum pouches for 2 and 4 months resulted in a significant fall in antioxidant activity, compared to blanched vegetables, of 34.6 and 44.5%, and 26.5 and 34.3%, respectively. At all stages of the experiment the reduction of this parameter was significantly ($p \leq 0.05$) lower in steam-boiled vegetables and in those stored in vacuum.

3.6. Thiocyanates

The content of thiocyanates (SCN) in purple cauliflower was 2.41 mg/100 g fresh mass (26.25 mg/100 g dry mass). As in the case of the majority of the discussed components as well as antioxidant activity, blanching did not change significantly ($p \leq 0.05$) the content of thiocyanates compared to the fresh material. However, losses were recorded after traditional cooking (53.3%) and convection steaming (27.1%). In turn, 2- and 4-month frozen storage of cauliflower reduced significantly ($p \leq 0.05$) the content of these components compared to blanched material by 27.9 and 51.3% (traditional storage in PE-LD bags) and by 25.3 and 38.6% (vacuum storage), respectively.

3.7. Nitrates and Nitrites

This study showed that purple cauliflower had 55.56 mg of nitrates, expressed as potassium nitrate (KNO_3), per 1000 g fresh mass (605.23 mg/1000 g dry mass). Traditional cooking and convectional steaming led to a significant ($p \leq 0.05$) decrease in these compounds compared to fresh vegetables, by 63.8 and 22.2% respectively. In addition, 2- and 4-month frozen storage in two package types—conventional PE-LD and vacuum packaging—caused a significant reduction in nitrates: by 63.5 and 74.5%, and 49.8 and 59.7%, respectively, compared to blanched vegetables. At every stage of this work, the reduction of this parameter was significantly ($p \leq 0.05$) lower in steam-cooked vegetables and in those frozen stored in vacuum.

The content of nitrites in 1000 g of fresh material was 1.65 mg (17.97 mg/1000 g dry matter). The applied hydrothermal treatment reduced significantly ($p \leq 0.05$) nitrites compared to the fresh material, by 37.3% (traditional cooking) and 21.5% (convection steaming). Two months' frozen storage of blanched cauliflower led to decreases in the content of nitrites in the examined material; however, only the difference recorded for conventional packaging (21.2%) was statistically significant ($p \leq 0.05$). In the case of 4-month stored cauliflower, significant ($p \leq 0.05$) increases in the content of nitrites were recorded in the products packed conventionally (by 33%) and in vacuum (by 91.8%).

4. Discussion

4.1. Basic Composition and Dietary Fiber

This study revealed that protein content (g per fresh and dry mass) in purple cauliflower was close to that found by Rumpel [25] and Kunachowicz et al. [26] and Kahlon et al. [27], according to whom, its values were 2.5 g and 2.4 g/100 g fresh weight of white cauliflower and 27.8 g/100 g dry matter, respectively. Fat content in white cauliflower, determined by the latter author, was 1.7 g/100 g dry matter, which is a higher value compared to that obtained in this work. Rumpel [25] reports that the content of assimilable carbohydrates in white cauliflower is 2.6 g/100 g of fresh vegetable, while Schonhof et al. [28] gives two values—2.27 and 2.56—depending on the cultivar, which differs from our findings. On the other hand, the content of dietary fiber found by Kahlon et al. [27] was similar (62.1 g/100 g dry mass) to our results. Both Rumpel [25] and Kunachowicz et al. [26] determined dietary fiber in white rose cauliflowers at the levels of 2.9 and 2.4 g/100 g fresh weight respectively, which is close to our findings. According to Puupponen-Pimiä et al. [29], the content of this constituent was 30.2 g/100 g dry matter unit. The values reported by Kahlon et al. [27] for ash content (10.1 g/100 g dry matter), considerably exceeding that obtained in this work (5.73 g/100 g dry matter). However, Ali [30] noted a similar content of micro- and macroelements, but in white cauliflower florets.

4.2. Dry Matter

According to the literature [31,32], dry matter content in the fresh white rose of Romanesco cauliflowers ranges from 6.96 to 13.95 g/100 g, which agrees with our results. Cooking in water as well as convection steaming increased its content compared to the fresh material, by 17.1% and 12.7% respectively. Similar increases, of 18.0% (white rose cauliflower) and 12.5% (green rose cauliflower), were also reported by Gębczyński and Kmiecik [33]. The reduced water content in the examined material was probably caused by the release of water from the tissues damaged during high-temperature processes [34].

This work showed that after 2-month frozen storage at −22 °C, the content of dry matter increased, which is congruent with the findings of Gębczyński and Kmiecik [33] and Cebula et al. [35], who noted mean increases of 22.3 and of 10.5% (white rose cultivar) and 14.5% (*Romanesco* cv.), respectively. An increase in dry matter in the frozen and then stored material may probably be explained by the phenomenon of denaturing cell walls at low temperature and resulting release of water [36].

4.3. Vitamin C

In 100 g of fresh cauliflower there was 63.20 mg of vitamin C, which is consistent with the findings of Kaulman et al. [37] and Volden et al. [38], who noted values of 63 mg and 64.2 mg (*Graffiti* cv.), respectively. The obtained results were in agreement also with those of Bhandari and Kwak [39] and Picchi et al. [40], who reported that vitamin C in cauliflower ranged from 396.7–649.7 and 346–638 mg of 100 g dry weight, respectively.

This study showed minimal losses of this component due to blanching, which was carried out using a convection steam oven. Cooking in water reduced vitamin C content by 55.7%, while convection steaming by 47.4%. Lower losses of vitamin C in this process were observed by Filipiak-Florkiewicz [31], Davey et al. [41], and Pellegrini et al. [42], and were 38.2% (white cauliflower) and 36.9% (*Romanesco* variety), 14.1–29.5%, and 50.9%, respectively.

Technological treatments for example, pre-processing or blanching may lead to considerable losses particularly in vitamin C. Their extent depends on the applied temperature, length of the exposure to this temperature, and a degree of the product comminuting [43]. Conventional frozen storage of cauliflower did result in a vitamin C decrease of 64.1 (after two months) and 71.1% (after 4 months). Volden et al. [38] noted losses in this constituent content after 3-month frozen storage, of 22.7% for the cultivar Graffiti and 24.1% for the green cauliflower cultivar *Celio*.

Incedayi and Suna [44] treated one group of cauliflower florets with 1,5% citric acid solution and the another group with 0.5% Ca-ascorbate plus citric acid 1% solution. Afterwards, florets were packed in two MAP gas mixtures and into biaxially oriented polypropylene film (BOPP). After 15 days of storage at 4 °C, vitamin C content decreased by 11.5%. Vacuum packaging led to a significantly lower ($p \leq 0.05$) reduction in the vitamin C content of 62.4%, on average, compared to conventional packing in zipper bags.

The losses in vegetable constituents are caused by both internal factors like, for example, respiration, production and the effect of ethylene, or changes in chemical composition, and external (environmental) ones such as relative humidity of the air, temperature, and gas composition of the surrounding atmosphere. Vacuum packaging reduces the access of oxygen to the material, which protects it against losses, for example, oxidation of vitamin C [45]. Quality of plant raw material is affected by factors connected with cultivars and by the broadly understood agricultural engineering factors [46].

4.4. Total Polyphenols

In most of the literature polyphenols are determined in various cauliflower varieties with white florets and calculated as total polyphenol content per 100 g fresh material. Volden et al. [38] and Pellegrini et al. [42] reported per 100 g of fresh vegetable 59.9 and 146 mg of total polyphenols, respectively. The results stated by Kaulman et al. [37], Bahorun et al. [47], and Kaur and Kapoor [48] are much lower: 63.8 mg, 27.8 mg, and 96 mg/100 g, respectively. Significant differences are most probably the result of the variety of the analyzed cultivars, growing conditions and the results' calculation methods.

Compared to fresh cauliflower, losses in total polyphenol content due to cooking in water were substantially larger than from blanching; slightly lower values were noted by Pellegrini et al. [42] and Filipiak-Florinkiewicz [31] for white varieties: 45.4 and 43.6%, respectively. Our results showed that losses resulting from traditional cooking were substantially larger than those found by Mazzeo et al. [49] and Picchi et al. [40] for varieties with white florets, being 30.8% and 18.9% respectively. As for cooking in a convection steam oven, the obtained results are almost identical with that reported by Pellegrini et al. [42] for white cauliflower (17.7%). Frozen storage of purple cauliflower led to a decline in the level of these compounds. Losses in the material stored for 4 months, noted by Gębczyński and Kmiecik [33], were much lower and were 11.6% (white cauliflower) and 20.4% (green cauliflower). This is consistent with the findings of Puupponen-Pimiä et al. [29], who observed a reduction in the content of these compounds by only 14.3% after 6 months of frozen storage.

Chassagne-Berces et al. [50] also noted that long-lasting storage of raw materials enhances the processes of enzymatic or chemical oxidation of polyphenolic compounds, the extent of which depends on the raw material or medium parameters such as temperature, pH, water activity, time, and oxygen content.

4.5. Anthocyanins

As for anthocyanin content, the results reported by Lo Scalzo et al. [51] and Li et al. [52] were lower (4.21 mg/100 g fresh weight) and higher (201.11. mg/100 g dry matter), respectively, compared to our findings. The same authors [51] noted that blanching reduced the content of these components by 64.6%, which markedly exceeds our results. Anthocyanins are known to be thermolabile compounds. However, due to the high temperature and short time of blanching, losses may be insignificant that explains such results [53]. Lo Scalzo et al. [51] and Palermo et al. [10] found larger losses of these compounds of 80.2 and 80%, respectively, after traditional cooking in water. According to these authors, there were no significant changes in the convection-steamed material, which is in line with our results. As opposed to Volden et al. [38], who did not observe significant changes in the material frozen stored for 3, 6, and 12 months, frozen storage of the blanched material caused significant losses in the content of these constituents.

4.6. Antioxidant Activity

Volden et al. [38] found that the cultivar Graffiti is characterized by strong antioxidant activity (25.7 µmol Trolox equivalent per 1 g of fresh vegetable). Antioxidant activity determined by Beecher et al. [53], Filipiak-Florkiewicz [31], Murcia et al. [54], and Mazzeo et al. [49] in other cauliflower varieties was similar or higher: 6.5, 6.15, 9.9, and 17.3 µmol Trolox equivalent per 1 g of fresh vegetable, respectively. Such differences may result from various processing conditions including, for example, methods applied for the measurement of antioxidant activity, different extractants, or various extraction times. Culinary treatments may contribute to the reduction of antioxidant activity due to the penetration of antioxidants into the solution or their degradation under elevated temperature [55]. In this case, however, there were no changes in antioxidant activity due to blanching. Losses observed by Volden et al. [38] and Filipiak-Florkiewicz [31] were larger, by 28.0% in the cultivars Graffiti and Celio, as well as by 10.4% and 25.4% in white and green cultivars, respectively. Cooking lowered antioxidant activity of purple cauliflower. Mazzeo et al. [49] and Filipiak-Florkiewicz [31] found reductions of 35.3 and 22.5%, respectively, compared to the fresh material (white cultivar) and of 34.7 (white cultivar) and 37.3% (green cultivar).

Similar decreases in antioxidant activity resulting from 3-month frozen storage, of 30.4% and 26.6%, were observed by Volden et al. [38] for the cultivars *Graffiti* and *Celio*. According to Murcia et al. [54], 24-h freezing caused a fall in antioxidant activity of 0.6%; whereas, Drużyńska et al. [56] noted an increase in this parameter after 48 h.

4.7. Thiocynates

Glucosinolates alone are not biologically active; only their enzymatic derivatives are. When the plant tissue is damaged, hydrolysis of glucosinolates takes place by the endogenous enzyme 'myrosinase' (thioglucoside glucohydrolase EC 3:2:3:1) with a release of a range of breakdown products, including isothiocyanates, indoles, nitriles, oxazolidines, and thiocyanates [7]. This study showed that purple cauliflower contained 2.41 mg/100 of thiocyanates (SCN) per g fresh weight. To the best of our knowledge, there are few studies concerning not only the amount of glucosinolates and their profile, but also their breakdown products. According to Kapusta-Duch et al. [7], cooking decreased significantly the concentration of isothiocynates in green and purple cauliflowers, by 11.0 and 42.4%, respectively, in comparison with raw vegetables. Similar results were found in this work.

4.8. Nitrates and Nitrites

Nitrites and indirectly nitrates, when consumed with food in too large quantities, can be harmful to health [57]. Among vegetables, Brassicas are characterized by medium or low degree of accumulation of these compounds. However, due to the consumed mass they may constitute significant proportion in the daily food ration [58]. In comparison with our results, most authors report several times higher or similar contents of nitrates in various cauliflower cultivars. For example, the values reported were 143–354 mg [59], 210.6 mg [60], 171.2 mg [61], or 61 mg/kg fresh mass [62]. As far as the content of nitrites is concerned, the results obtained by researchers, depending on the examined cultivar, were lower or markedly higher compared to our findings. For example, Leszczyńska et al. [62] found 3.49 mg and 47 mg nitrites in white and green cauliflower respectively, while Gajewska et al. [60] stated 0.8 mg of these constituents per kg of fresh vegetable. According to Leszczyńska et al. [62], the reductions in these compounds due to blanching were much greater than that in this work, amounting to 72.2% for white rose cauliflower and 37.9% for the cultivar Romanesco. Cooking was also responsible for the reduction of nitrates, which agrees with the findings of Shimada and Ko [63], who determined losses of these compounds within the range of 14 to 79%. Filipiak-Florkiewicz et al. [61] observed higher losses of nitrates, compared to those obtained in this work, of up to 72.2% in white rose cauliflower. In comparison with blanching, frozen storage lowered the content of nitrates, on average by 61.9%. Leszczyńska et al. [62] noted a decline in these constituents by 78.7% in white rose cauliflower.

Compared to fresh vegetables, no significant change in the content of nitrites was found due to blanching. However, losses reported by Leszczyńska et al. [62] due to this process were significant and amounted to 8.9% on average. Cooking purple cauliflower led to an average 29.4% decrease in nitrite content compared to fresh vegetables. Similar decreases, of 22.9 (white rose cauliflower) and 17% (*Romanesco* cv.) obtained Filipiak-Florkiewicz et al. [61] and Leszczyńska et al. [62].

Storage of the material contributes to an increase of nitrite content in cauliflower as a result of the reduction of nitrates which takes place in tissues due to enzyme or bacteria activity [64]. After 2-months frozen storage, the content of nitrites decreased, on average by 18.3%, while after a 4 months increased significantly, by 62.4% on average, compared to blanched vegetables. A similar upward trend (151%) for the level of nitrites noted Leszczyńska et al. [62] for green rose cauliflower, frozen and stored for 4 months. Filipiak-Florkiewicz et al. [61], who cooked a vegetable previously frozen stored for the identical period of time, also observed a 105.7% increase in the amount of these compounds.

The results obtained indicate that further studies are needed to explain changes in nutritive and non-nutritive components during selected treatments like cooking or freezing not only purple cauliflower, but other colored Brassica vegetables. The results presented by other authors and those obtained in this work are not clear-cut, so the research problem seems to be interesting. Therefore, the research goal should be to optimize hydrothermal processes and to select the best type of packaging in order to make the best possible use of pro-health substances occurring in Brassica vegetables in human nutrition in accordance with the idea of sustainable development.

5. Conclusions

Brassica are among the top 10 economic vegetables in the world and a source of valuable nutrients, but their content is strongly affected by the method of their preparation. This study clearly showed that technological treatments had a significant effect on nutrient and health-promoting compounds in purple cauliflower. The nutritional content in Brassica vegetables have been reported to vary during the growth period due to climatic and agronomical factors, but also the postharvest treatments are valid factors influenced on quality of these vegetables.

All technological processes, i.e., blanching, cooking, and frozen storage, led to significant changes in the content of the examined nutritive and non-nutritive compounds as well as antioxidant activity or the level of selected chemical pollutions. A trend was also observed towards lower losses of constituents due to convection steaming, compared to traditional cooking in water. Moreover, the reduction of

examined compounds was smaller in vacuum-packed and frozen-stored vegetables then in those stored in zipper PE-LD bags.

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