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The Effect of *Sous-Vide* Processing Time on Chemical and Sensory Properties of Broccoli, Green Beans and Beetroots

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Abstract: Vegetables are a natural source of bioactive compounds, however, their content is strongly affected by the preparation methods. The study aimed to find the balance between high health-promoting properties, resulting from well-retained minerals content, and sensory properties by testing different times of *sous-vide* cooking of vegetables at 85 °C. For each vegetable, broccoli, green beans and beetroots, three times options of *sous-vide* treatment were individually applied. No effect of *sous-vide* cooking on dry matter content was found for tested vegetables, with the exception of dry mass loss of beetroots cooked for 180 min. The results of potassium, magnesium, calcium and phosphorus determination, confirmed that the *sous-vide* technique often allows for the retention of these minerals at a level not lower than in raw vegetables. For both broccoli and beetroots, it was observed that the longer the *sous-vide* processing time, the lower the color intensity, and in the case of each tested vegetable, the worse the consistency. Therefore, the study proves that this method of heat treatment reduces the loss of minerals and preserves the desired color of studied vegetables.

Keywords: *sous-vide*; green vegetables; beetroots; minerals; dry matter; sensory evaluation; color analysis

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Citation: Czarnowska-Kujawska, M.; Draszanowska, A.; Chróst, M.; Starowicz, M. The Effect of *Sous-Vide* Processing Time on Chemical and Sensory Properties of Broccoli, Green Beans and Beetroots. *Appl. Sci.* **2023**, *13*, 4086. https://doi.org/10.3390/app13074086

Academic Editor: António José Madeira Nogueira

Received: 22 February 2023
Revised: 16 March 2023
Accepted: 21 March 2023
Published: 23 March 2023

1. Introduction

Vegetables are an essential element of a healthy diet. It is recommended to eat at least five portions of vegetables and fruits each day (half of the plate according to the concept Healthy Eating Plate presented by researchers at Harvard). For adults and adolescents over 15 years of age, 600 g of fruits and vegetables per day is suggested to eat, whereas for children from 5 to 14 years—480 g/day, and children from 0 to 4 years—330 g/day [1]. Due to the fact that vegetables are a significant source of bioactive compounds, including minerals and vitamins, vegetables are valuable for our health.

Minerals, are a group of compounds that are not synthesized in the human body and must be supplied to it in appropriate amounts and proportions with food. The content of minerals in the body of an adult person is about 4% of the total body weight, and their source is water, food products and dietary supplements. Epidemiological studies have shown that the consumption of cruciferous vegetables reduces the risk of cancer, including skin, lung, pancreatic, stomach and thyroid cancer, which is associated with a high content of secondary metabolites, especially glucosinolates [2].

Sous-vide technique of cooking requires much lower temperatures comparing to traditional cooking in water, roasting or baking [3]. This allows to retain more bioactive compounds of health-promoting properties, and promote antioxidant properties of some vegetables [4]. The *sous-vide* method is successfully used for preparation of products such as: meat, vegetables, seafood and some raw or semi-cooked fruits. The vegetables, e.g., broccoli, beetroot and kale [4], artichokes, green beans, broccoli and carrots [5], asparagus [6] or potatoes, ref. [7] have been already applied to the *sous-vide* treatment. An undoubted advantage of the *sous-vide* method is the ability to reduce the weight loss of the boiled product. Zavadlav et al. [8] noted that that the asparagus after *sous-vide* treatment lost only 2.1% of its weight, and after cooking in the microwave the losses amounted to the 11.9%. The same authors presented that *sous-vide*-cooked vegetables have a higher vitamin C content than those traditionally cooked in water [8]. It might be linked with low or no oxygen presence in the bag and the mitigation of the oxidation process of ascorbic acid. Moreover, the use of vacuumed packages in the *sous-vide* reduces the release of components e.g., amino acids or organic acids, thanks to which the taste is better preserved, also the retention of proteolytic and lipolytic enzymes affects the taste and undesirable color change reactions [9,10].

This study aimed to assess the influence of *sous-vide* processing at 85 °C on selected characteristics of vegetables quality (broccoli, green beans and beetroots), including evaluation of organoleptic features, determination of dry matter and minerals content. The experiment consisted of the following stages: (1) thermal treatment of vegetables using the *sous-vide* method at 85 °C and time parameters selected appropriately for each vegetable; (2) evaluation of selected organoleptic features of vegetables after *sous-vide* treatment using a 10-point scale; (3) evaluation of the dry matter content; (4) mineralization of samples; and (5) determination of the minerals' content. Calcium and magnesium were determined using flame atomic absorption spectrometry (FAAS), whereas potassium and sodium were determined by flame emission spectroscopy (air-acetylene flame). Phosphorus was determined by colorimetric method with ammonium molybdate (VI), sodium sulfate (IV) and hydroquinone.

2. Materials and Methods

2.1. Samples Preparation

The vegetables used in our study were fresh broccoli (*Brassica oleracea*), green beans (*Phaseolus vulgaris*) and beetroots (*Beta vulgaris*) purchased in a local supermarket. The vegetables were cleaned and washed. In the case of broccoli, only florets were used, beetroots were cut into slices (long beet with a cylindrical shape), beans pods were used as a whole with the ends cut off. Vegetables were divided into portions of 200 g and 300 g for beetroots. The test material was packed into vacuum bags and subjected to *sous-vide* heat treatment under the following conditions (Table 1).

Table 1. *Sous-vide* parameters of vegetables samples preparation.

Sample	Time/Temperature	Description
Broccoli	15 min/85 °C 30 min/85 °C 45 min/85 °C	Portions of vegetables were packed separately in plastic bags using the Busch Edesa vacuum sealer (Montcada, Barcelona, Spain). The polyamide/polyethylene (PA/PE) bags designed specifically for *sous-vide* were used with a thickness of 52 µm (Hendi, Lamprechtshausen, Austria). The samples cooking was conducted in the fusionchef Diamond Z immersion circulator *sous-vide* cooker by Julabo (Seelbach, Germany).
Green beans	30 min/85 °C 60 min/85 °C 90 min/85 °C	
Beetroots	45 min/85 °C 90 min/85 °C 180 min/85 °C	

2.2. Determination of Dry Matter Content

The content of dry matter was determined directly after drying. Slices of tested vegetables were put into a weighing glass of known weight, with an accuracy of 0.0001 g, and were dried overnight at 105 °C in the lab dryer UFE 500 by Memmert (Schwabach, Germany). After that, the vessels were placed into a desiccator to cool (about 30 min) and weighed again. Then the samples were dried for another one hour, weighed, and the procedure was repeated until a constant weight was obtained.

2.3. Minerals Content Determination

2.3.1. Reagents and Standards

Water was purified in the Mili-Q system (Millipore; Vienna, Austria), the used chemicals were of analytical grade. Hydrated lanthanum chloride ($Cl_3La \bullet 7H_2O$) used in determination of minerals content was purchased from Merck (Darmstadt, Germany). Other reagents, ammonium molybdate VI, sodium sulfate IV and hydroquinone were purchased from "POCH" S. A. (Gliwice, Poland). Minerals standards (magnesium, potassium, calcium and phosphorus) were diluted with 0.1 M nitric acid at the concentration of 1 mg/cm^3.

2.3.2. Samples Mineralization

Vegetables samples were weighed (approximately 6.0 g) in the tubes from borosilicate glass and mineralized in a mixture 3:1 (*v:v*) of nitric and perchloric acids. The mineralization was conducted in an electric aluminum heating block (VELP DK 20, Scientifica, East Sussex, UK) with the gradual temperature increase from 100 to 180 °C within few hours. The colorless mineralizate was then transferred to 50 cm^3 volumetric flask and filled to the mark with water. Test samples were prepared in parallel with reagent samples.

2.3.3. Minerals Determination

Determination of Magnesium (Mg) and Calcium (Ca) was carried out by the flame atomic absorption spectrometry (acetylene—air flame) technique using a Thermo iCE 3000 Series (Madison, WI, USA) atomic absorption spectrometer equipped with the Glite data station, background correction (deuterium lamp) and appropriate cathode lamps [11]. The 10% aqueous solution of lanthanum chloride was added to all measured solutions in a quantity, ensuring a final La^{+3} concentration of 1%. The elements determination was performed at the following wavelengths: 285.2 nm (Mg), and 422.7 nm (Ca).

Sodium (Na) and Potassium (K) determination was carried with the emission technique (acetylene-air flame) with the use of the atomic absorption spectrometer Thermo iCE 3000 Series (Waltham, MA, USA), equipped with a Glite data station, operating in an emission system. Minerals were determined at the following wave-lengths: 589.0 nm (Na) and 766.5 nm (K).

Phosphorus (P) was determined using the colorimetric method with ammonium molybdate (VI), sodium sulfate (IV) and hydroquinone. This method is based on the phosphates conversion in the environment of a sulfuric acid Then the samples were analyzed by measuring the absorbance using the Spectrophotometer VIS 6000—KRÜSS—OPTRONIC (Waltham, MA, USA).

The individual minerals content was calculated in 100 g of fresh vegetables samples.

2.4. Sensory Analysis

The sensory attributes of the vegetables samples was evaluated just after *sous-vide* treatment by a six-person evaluation team with sensory sensitivity and considerable experience confirmed during plant products sensory testing. The beetroot samples were tested cut into slices, green beans as individual whole pieces and broccoli in the form of florets. All samples were evaluated while warm. Each sample was coded with the code of three digits and randomly served on white plates. The samples were assessed on a 10-point scale according to the Polish Standard PN-ISO 4121:1998 [12]. All samples were rated for overall appearance and overall quality (1-bad, 10-very good); color intensity (1-low, 10-high); aroma intensity (1-undetectable, 10-very intense); aroma and taste desirability (1-not desirable, 10-highly desirable) and consistency (1-very soft, 10-hard). The sensory evaluation of the tested vegetables was conducted in a laboratory, specially designed and equipped with a room temperature and fluorescent lighting according to the requirements of Polish Standard PN-ISO 8589:2010 [13].

2.5. Color Analysis

Instrumental color measurements was performed on raw, cooked and cooled samples, using Chroma Meter CR-400 (Konica Minolta, Osaka, Japan) with a port (Ø 8 mm) and the D65 illuminant, and standard observer 2°. The equipment was calibrated before measurement using a white standard plate with Y = 89.3, x = 0.3159, and y = 0.3225. Measurements were made in eight replicates on the surface of broccoli florets, bean pods and beet slices. The color parameters were expressed as L^* (100 lightness/darkness 0), a^* (+a redness/greenness -a), and b^* (+b yellowness/blueness -b) in the CIE Lab system (The International Commission on Illumination). To better highlight differences in color, the indexes of color saturation (parameter C^*, Equation (1)) and hue ($h°$—hue angle, Equation (2), when $a^* < 0$ and $b^* > 0$) were calculated according to the formula [14]:

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (1)$$

$$h^\circ = arctan\left(\frac{b^*}{a^*}\right) + 180^\circ \quad (2)$$

Total color difference ΔE (Equation (3)) was calculated, using raw vegetable as a reference, according to the equation [15]:

$$\Delta E^* = \sqrt{\left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]} \quad (3)$$

2.6. Statistical Analysis

Statistical analysis of the results were carried out using Statistica version 13.1 (2016) by StatSoft (Cracow, Poland). Data were compared using one-way ANOVA at a significance level of $p < 0.05$. Tukey's HSD test was used to determine statistical significance at $p < 0.05$. All the measurements were repeated three times.

3. Results

3.1. Dry Matter Content

Table 2 presents the obtained results for dry matter determination for raw and *sous-vide* treated vegetables' samples. It was shown that dry matter contents for raw green beans, beetroots and broccoli were 8.03 g/100 g, 11.84 g/100 g and 9.43 g/100 g, respectively. Dry mass content for broccoli was well in line with the level reported by Cieślik et al., (9.6 g/100 g) [16] but lower than the result obtained by Florkiewicz et al. [17] (12.81 g/100 g). Similar levels for raw broccoli (9.5 g/100 g) and higher for raw green beans (10.9 g/100 g) and slightly higher for beetroots (12.4 g/100 g) were presented in food composition and nutritional value tables [18]. Differences for dry matter levels reported for the same vegetable can result from different species or variety of plant, as well as different conditions of cultivation, harvesting or storage [17].

The content of dry matter in vegetables varies depending on the processing method applied. Traditional cooking techniques can cause losses in dry mass, which is the result of washing out of soluble nutrients and also water absorption by fiber constituents [19,20]. In the study of Florkiewicz & Berski [19] traditional cooking of cauliflower, broccoli, Romanesco-type cauliflower and Brussels sprouts caused significant decrease of dry matter. The authors observed the highest values of dry mass in vegetables conducted to steaming and only minimal changes in dry matter content in *sous-vide* treated samples. In their study cauliflower processed with the *sous-vide* method showed 2.38% loss of dry weight, while traditionally cooked—7.36% compared with the raw sample. Gonella et al. [6] also reported only slight dry weight loss of 2.1% in asparagus spears after *sous-vide* cooking for 15 min at 85 °C, whereas the highest loss was observed in microwaved samples. Similarly in our study dry matter of green beans after *sous-vide* treatment ranged from 8.02 g/100 g to 8.19 g/100 g and the processing in any tested time had no significant ($p < 0.05$) influence on its content. This is probably because of the lower process temperature compared with traditional cooking method, and prevention, provided by vacuum packaging, of direct contact with water [17]. In *sous-vide* treated beetroot samples dry matter levels were in the range of 10.55 g/100 g—12.35 g/100 g. Only cooking for the longest time of 180 min resulted in significant ($p < 0.05$) losses in dry matter of 10.9% compared with the raw sample. Such a long processing probably caused damage to the cells and leakage of liquid from the vegetable [19,20]. Otherwise, in broccoli samples, a significant growth ($p < 0.05$) of 1.3% in dry matter amount was observed in the sample cooked for the shortest time of 15 min. Other cooking times of 30 min and 45 min had no significant effect of dry matter content compared with raw samples. Also Kmiecik et al. [21] reported an increase of dry matter in broccoli and both white and green cauliflowers conducted to cooking, differently to examined Brussels sprouts samples where a slight decrease was observed. Florkiewicz & Berski [19] observed significant increase of 0.43% in dry mass after *sous-vide* cooking of Romanesco type cauliflower.

Table 2. Dry matter content in the tested samples of raw and conducted to *sous-vide* treatment vegetables.

Samples	Dry Matter [g/100 g]
Raw broccoli	9.43 ± 0.01^{b}
Broccoli 15 min/85 °C	9.55 ± 0.01^{a}
Broccoli 30 min/85 °C	9.47 ± 0.02^{b}
Broccoli 45 min/85 °C	9.44 ± 0.04^{b}
Raw green beans	8.03 ± 0.05^{a}
Green beans 30 min/85 °C	8.12 ± 0.03^{a}
Green beans 60 min/85 °C	8.19 ± 0.16^{a}
Green beans 90 min/85 °C	8.02 ± 0.15^{a}
Raw beetroot	11.84 ± 0.14^{a}
Beetroot 45 min/85 °C	12.35 ± 0.15^{a}
Beetroot 90 min/85 °C	12.22 ± 0.1^{a}
Beetroot 180 min/85 °C	10.55 ± 0.33^{b}

Mean values with different letters (a, b) in the column are statistically different ($p < 0.05$).

3.2. Minerals

Vegetables are an important source of many bioactive substances, including minerals. These are inorganic substances present in all body tissues and fluids. They are a building material for skeletal system, have different regulating effects and fundamental importance for metabolic processes in the organism [20,22]. Different minerals perform various functions in the body. Magnesium (next to potassium) is crucial intracellular cation, which activates over 300 enzymes. It takes part in the biosynthesis of protein, DNA and RNA. It performs an important function in neuromuscular conduction, regulation of blood pressure, heart function and insulin metabolism. Hence, magnesium deficiencies are the cause of neuromuscular and cardiovascular disorders [23,24]. Calcium, besides its building role in bones and teeth, is involved in the conduction of nerve stimuli, muscle contractility, activation of certain enzymes, hormonal regulation and blood coagulation. This is necessary for correct functioning of the heart and cardiovascular system [22,23,25–28]. Phosphorus is also involved in the mineralization of skeletal system. It is necessary for the construction of soft tissues, cell membranes and is a component of nucleic acids. It participates in the conduction of nerve stimuli, metabolic processes, energy transformations and helps in maintaining the acid-base balance in the body [22,29,30]. Sodium and potassium take part in water and electrolyte management, acid-base balance and in the regulation of the osmotic pressure of cells. An important role of potassium is the activation of many body enzymes and participation in the metabolism of nutrients: carbohydrates and proteins [22,29,30].

Determined amounts of magnesium, potassium, sodium, calcium and phosphorus in tested raw samples of vegetables are presented in Table 3. The obtained minerals content in raw green beans was lower than reported in food composition and nutritional value tables (Mg—22 mg/100 g, K—264 mg/100 g, Na—6 mg/100 g, Ca 65 mg/100 g, P—44 mg/100 g) [18]. Similarly, for another two examined raw vegetables, the minerals levels given in food composition tables exceed the amounts determined in our study (for raw beetroot: Mg—17 mg/100 g, K—348 mg/100 g, Na—52 mg/100 g, Ca 41 mg/100 g, P—17 mg/100 g; for broccoli: Mg—23 mg/100 g, K—385 mg/100 g, Na—7 mg/100 g, Ca 48 mg/100 g, P—66 mg/100 g). Such differences in the minerals content in the same non-processed vegetable may result from a different plant variety, soil and climate conditions, agronomic practices such as plants maturity state, fertilizers application, as well as weather conditions during harvesting [20,31,32].

Table 3. The content of selected minerals in the tested samples of raw and conducted to *sous-vide* treatment vegetables.

Samples	Minerals Content [mg/100 g]				
	Mg	**K**	**Na**	**Ca**	**P**
Raw broccoli	17.7 ± 0.12 [a]	236.5 ± 5.41 [a]	4.3 ± 0.32 [a]	28.0 ± 0.23 [b]	38.3 ± 0.42 [a]
Broccoli 15 min/85 °C	17.1 ± 0.36 [a]	222.1 ± 5.22 [ab]	4.2 ± 0.19 [a]	29.0 ± 0.04 [a]	37.2 ± 0.55 [b]
Broccoli 30 min/85 °C	16.9 ± 0.11 [a]	214.1 ± 11.07 [b]	4.0 ± 0.11 [a]	26.8 ± 0.34 [c]	36.6 ± 0.03 [b]
Broccoli 45 min/85 °C	16.3 ± 1.12 [a]	238.7 ± 0.62 [a]	3.6 ± 0.26 [a]	27.9 ± 0.19 [b]	36.7 ± 0.23 [b]
Raw green beans	16.8 ± 1.33 [b]	211.1 ± 11.40 [a]	0.4 ± 0.02 [b]	41.9 ± 1.26 [c]	17.2 ± 0.23 [a]
Green beans 30 min/85 °C	18.4 ± 0.04 [ab]	215.1 ± 1.35 [a]	0.5 ± 0.05 [a]	44.7 ± 1.65 [bc]	18.1 ± 0.38 [a]
Green beans 60 min/85 °C	19.1 ± 0.10 [a]	211.3 ± 3.04 [a]	0.5 ± 0.01 [a]	48.5 ± 0.85 [a]	17.6 ± 0.64 [a]
Green beans 90 min/85 °C	18.7 ± 0.03 [ab]	206.7 ± 5.51 [a]	0.5 ± 0.00 [a]	45.4 ± 0.58 [ab]	17.9 ± 0.09 [a]
Raw beetroot	16.2 ± 0.33 [c]	256.8 ± 23.32 [ab]	50.3 ± 0.44 [d]	17.5 ± 0.35 [a]	12.5 ± 0.03 [ab]
Beetroot 45 min/85 °C	14.0 ± 0.17 [d]	239.8 ± 14.56 [b]	71.2 ± 1.76 [b]	17.1 ± 1.56 [a]	11.1 ± 0.52 [b]
Beetroot 90 min/85 °C	20.1 ± 0.24 [a]	296.1 ± 12.33 [a]	105.5 ± 0.59 [a]	19.3 ± 0.14 [a]	13.8 ± 0.9 [a]
Beetroot 180 min/85 °C	19.1 ± 0.09 [b]	247.0 ± 9.71 [b]	56.3 ± 0.28 [c]	17.9 ± 0.07 [a]	11.2 ± 0.01 [b]

Mean values with different letters (a–d) in the column are statistically different ($p < 0.05$).

The content of minerals in processed vegetables is strongly affected by preparation method. Although minerals show a higher stability to food processing than, for example, vitamins, possible loss can be due to moisture, light, oxygen or heat availability changes during processing and storage of food materials. In addition, processing may also improve the accessibility of minerals by reducing levels of anti-nutrients [20,33]. The degree of mineral salt retention in vegetables depends on the cooking method used, the amount of water, raw material fragmentation and the form of minerals affecting their solubility. During food processing, complexes with organic compounds may release minerals that may change their biological activity. Changes in the minerals content in the product may be caused by both leaching (dissolving) or transfer to the broth [19,20]. Therefore, more attention is paid to alternative food preparation methods, such as *sous-vide*, which allow for higher retention of health-promoting nutrients. Recent literature data report on the positive effect of *sous-vide* treatment of different vegetables on their nutritional value [8]. In our previous study, *sous-vide* technique allowed for the best folates, vitamins B, retention in spinach and broccoli compared with steaming, boiling, cooking in a combi oven and microwaving. Also the DPPH value of tested vegetables was the most stable after *sous-vide* cooking [34]. Kosewski et al. [4] in comparison with the traditional cooking techniques, observed the improvement of antioxidative potential in *sous-vide* treated several vegetables (cauliflower, broccoli, red onion, parsley root, tomato). Florkiewicz et al. [35] found *sous-vide* cooking as the optimal thermal processing for *Brassica* vegetables' in terms of the phenolic compounds retention in comparison with traditional cooking in water and steaming. Amoroso at al. [7] in the study on potato slices with the addition of rosemary essential oil reported slight reduction in total phenols ascorbic acid, and antioxidant activity after *sous-vide* cooking.

In our study *sous-vide* cooking of green beans regardless of processing time, did not result in significant ($p < 0.05$) decrease in any determined mineral (Table 3). Additionally, no significant ($p < 0.05$) effect on potassium and phosphorus contents was observed during *sous-vide* cooking from 30 min to 90 min. The applied treatment in all examined times resulted in a significant ($p < 0.05$) increase in sodium content compared with raw beans, as well as in magnesium when cooked for 60 min, and calcium for 60 min and 90 min. In beetroots samples *sous-vide* processing from 45 min to 180 min did not significantly ($p < 0.05$) affect the content of potassium, calcium and phosphorus when compared with non-processed sample (Table 3). Similar to green beans, a significant increase ($p < 0.05$) in the content of some minerals was observed under *sous-vide* cooking. 90 min and 180 min treatment resulted in a significant ($p < 0.05$) increase in magnesium content, while cooking for 45 min caused a significant decrease in its content. As in the case of beans, the *sous-vide* treatment of beetroots caused a significant ($p < 0.05$) increase in the sodium content at all examined processing times. Differently to beetroot, *sous-vide* treatment of broccoli caused no effect on magnesium and sodium contents. Unlike in green beans and beetroots, phosphorus content in processed broccoli decreased significantly ($p < 0.05$) after all tested sous-vide time options. Potassium content significant ($p < 0.05$) loss was noticed only after cooking for 30 min. For calcium, cooking for 15 min resulted in significant ($p < 0.05$) increase in this element content, processing for 30 min caused significant decrease and 45 min treatment showed no effect on this element amount.

The conducted research shows that *sous-vide* processing allowed for preservation of the analyzed minerals in vegetables regardless of the cooking time. With the single exceptions for broccoli and beetroot, such a tendency was even reported for potassium. Although potassium is the most numerous mineral found in vegetables, because of high solubility in water and extreme mobility, it can be easily leached during cooking with water contact [20,36]. The presented results are well in line with the study of Florkiewicz & Berski [19] in which *sous-vide* method was proved to be the most favorable for minerals retention in *Brassicas* vegetables comparing with traditional methods of cooking in water and steaming. It was also noticed that in most of the analyzed materials, the level of the tested elements did not significantly change after the storage time. Also the study conducted by Kapusta-Duch et al. [20] showed that traditional cooking methods in water affect minerals content in vegetables such as kale, rutabaga, green and purple cauliflower. In comparison to traditional cooking techniques such as cooking in water, steaming, microwaving, the reduced oxygen level inside vacuum packaging helps to preserve bioactive ingredients in *sous-vide* cooked vegetables. Unlike conventional methods, *sous-vide* treated vegetables tend less to lose nutrients because cellular walls are not damage by heat that could otherwise cause leak of water and nutrients [8]. In turn, the observed increase in the content of some minerals during *sous-vide* processing can be explained by different minerals solubility and bonding them with the plant tissue. Different authors reported that, for instance, magnesium and calcium, which are bound with plant tissue, and thus, are not so easily lost by leaching, but sometimes they amounts can be taken up during blanching, steaming or traditional cooking by vegetables [19,20,36,37]. The increase of temperature may cause disintegration of the cell walls, and therefore there is a greater access to the minerals bound with plant tissue [38]. In addition, there is the possibility of minerals migration through the protective film of *sous-vide* packaging, however, research on this is still missing.

3.3. Sensory Evaluation

The method of preparing vegetables affects not only their chemical composition, but also their sensory properties. Despite this, there is a lack of research on the impact of vegetables' processing on their organoleptic characteristics. Meanwhile, sensory properties determine the acceptability of food by consumers. If the vegetable, despite the applied heat treatment, retains its fresh smell, taste, natural and intense color, it is still perceived by the consumer as a fresh and healthy product. Thus, the effect of food research should be a balance between sensory quality and nutritional composition of processed food materials [35,39]. There is lack of literature data on the effect of *sous-vide* cooking on sensory quality attributes of different vegetables. However, the available studies emphasized that sous-vide cooking offers improved sensory properties compared with conventional cooking methods, for instance, in retaining more aroma and taste than conventional methods [8,40–42]. Florkiewicz et al. [35], based on the results of sensory evaluation using the 9-point hedonic scale, reported that steamed and *sous-vide* cooked cauliflower, broccoli and Brussels sprouts showed a higher sensory quality than samples traditionally cooked in water. In addition, the evaluation with the method of sensory profiling using a structured scale, confirmed that the texture of both sous-vide and steamed vegetables was higher rated than traditionally cooked [35]. Meanwhile, Gonella et al. [6] in the study on the effect on boiling, steaming, conventional microwaving, *sous-vide* boiling and *sous-vide* microwaving on sensory properties of asparagus spears, found the best sensory preferences for *sous-vide* microwaved samples.

The Figures 1–3 present the results of the sensory evaluation of broccoli, green beans, and beetroots immediately after *sous-vide* processing at 85 °C in different time parameters individually applied for each tested vegetable. This allowed the comparison of how the processing time affects the selected properties of the sensory quality of the examined vegetables. The shortest time of *sous-vide* cooking (45 min) allowed to maintain the intense red color (10 points) typical for fresh beetroot, and the most appropriate consistency (7 points). With the increase of the cooking time, the lower ratings were obtained for color intensity as well as consistency, which becomes more tender due to dissolving of pectins—the cementing material, which holds the cells together [43]. In the temperature around 85 °C pectins begins to dissolve and its depolymerization causes texture degradation that might not be a desired change by consumers [44]. However, for vegetables, the *sous-vide* process temperature cannot be lowered, like in other products, for instance meat, for which the proper temperature is in the range of 65–70 °C, and must be conducted at temperatures close to 100 °C to inactivate main foodborne pathogens, *Escherichia coli* and *Salmonella* [5,8,43–45]. The overall quality of beetroots cooked for 45 min and 90 min was rated the highest, with 8 and 9 points, respectively. The longest cooking for 180 min allowed for the extraction of the most intensive and at the same time the most desirable aroma as well as best overall appearance (10 points). However, the taste of beetroots processed for 180 min was the least desired (6 points). The results of research by other authors confirm that vegetables after *sous-vide* processing have a more intense taste and aroma. In contrast, vegetables cooked in water, as a result of leaching out soluble flavor compounds, are characterized by a lower intensity of these characteristics [35,45].

In the case of broccoli, similarly to beetroots, the highest scores were given to the intensity of consistency (8 points) and color (10 points) of the vegetables cooked for the shortest time of 15 min. The green color intensity decreased during the treatment. Florkiewicz et al. [35] reported that the high temperature used during thermal processing causes damage to chlorophyll pigments, and thus, vegetables that contain chlorophyll darken which depends on time and temperature parameters of the process. Danowska-Oziewicz et al. [39] indicated that color changes of a green vegetable may be affected by the activity of enzymes, as well as the change of chlorophyll into olive-green pheophytin during thermal processing. The shortest cooked broccoli showed the best general appearance (10 points) but the lower overall quality (7 points). Broccoli cooked the longest, 45 min, showed the most intense (7 points) but at the same time less desired aroma (4 points). On the contrary, the desirability of taste increased with the time of *sous-vide* cooking. This can be the effect of the high retention of nutrients during *sous-vide* processing comparing with other heat treatments, which may intensify the aroma, which in the case of some vegetables will not be desired by consumers [35,45].

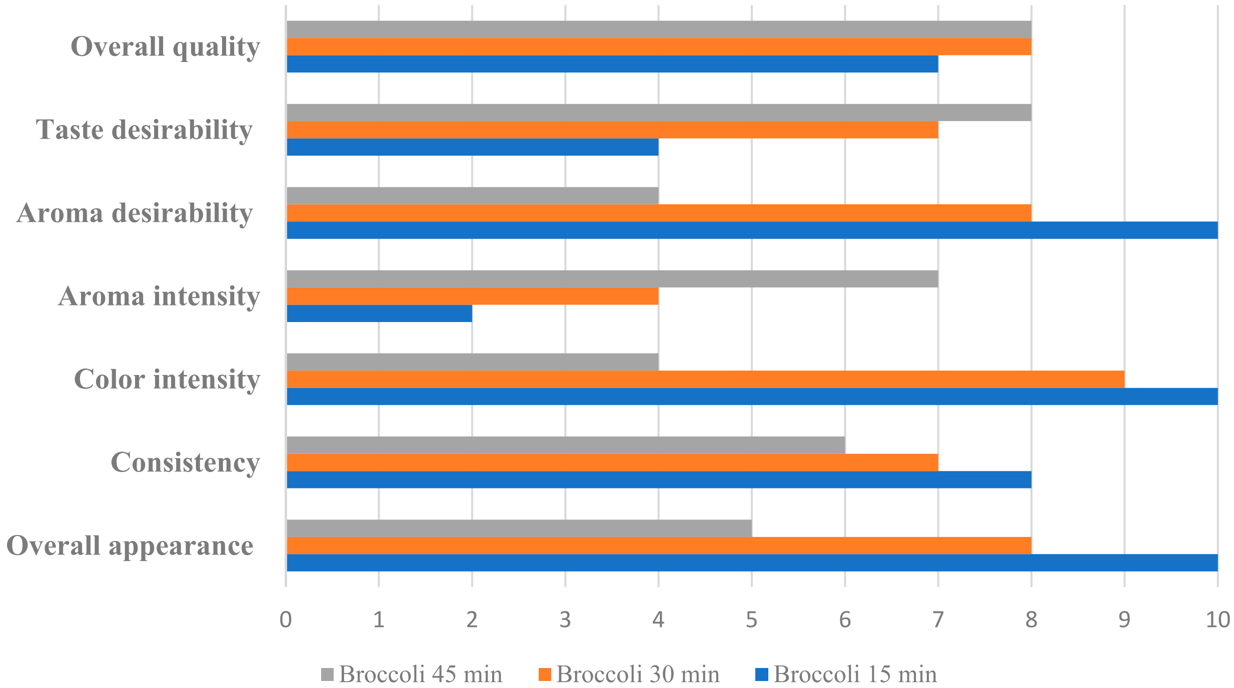

Figure 1. Results of sensory evaluation of *sous-vide* processed broccoli.

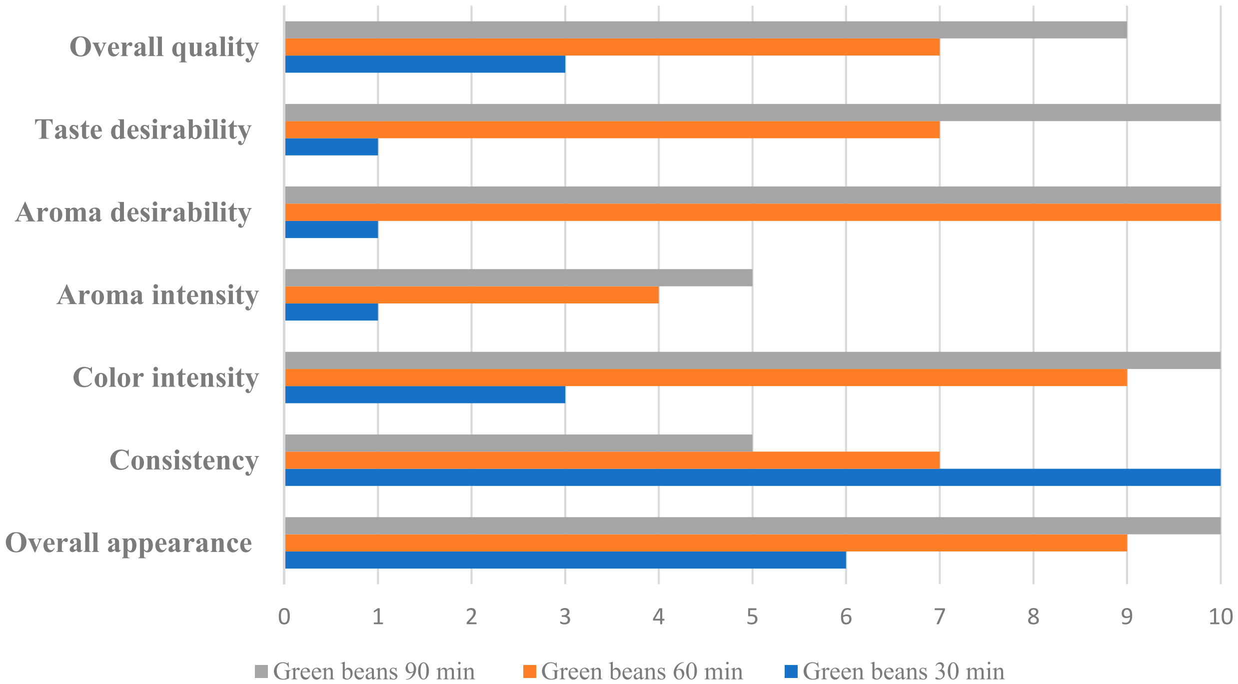

Figure 2. Results of sensory evaluation of *sous-vide* processed green beans.

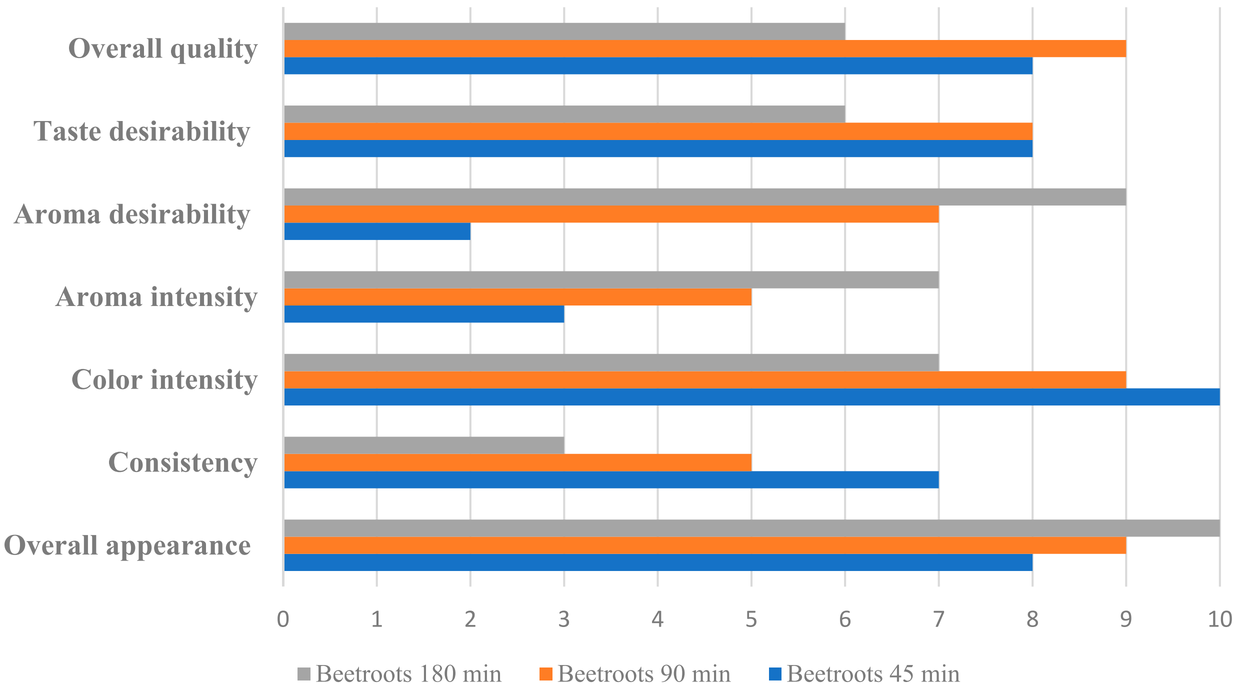

Figure 3. Results of sensory evaluation of *sous-vide* processed beetroots.

Unlike in beetroots and broccoli, the longer the time of *sous-vide* treatment, the more intense color of green beans. Like in broccoli, this is probably due to the increased amount of pheophytin which causes greener or yellower color of heat treated green vegetables [39]. The consistency, similarly to broccoli and beetroots, was rated the best (10 points) after a short cooking time of 30 min. Beans cooked for the longest time, 90 min, were characterized by the best appearance and overall quality, 10 points and 9 points, respectively. The desirability for taste, as in the case of broccoli, increased with the duration of the *sous-vide* treatment. As in the case of beetroots, the intensity and desirability of the aroma of green beans cooked longer for 60 min and 90 min were rated the highest. Other authors studies on *sous-vide* cooking on broccoli, green beans and carrots, confirmed higher retention of aromatic volatile components compared with boiled samples [8,40–42]. These observations are well in line with the results presented in our study which confirmed for all tested vegetables that the aroma intensity did not decrease with *sous-vide* cooking time.

3.4. Color

Color is a very important feature of a product, which affects its positive or negative perception by the consumer. Currently, two methods of color measurement are used, instrumental and sensory. The instrumental method is considered to be objective, but the measurement is performed on a limited sample area, which is a disadvantage [46].

The *sous-vide* heat treatment method had an effect on reducing the lightness (L^*) of broccoli, green beans and beetroot comparing to the raw sample (Table 1). However, for cooked broccoli and beetroot, the differences obtained were not significant ($p > 0.05$). The results correlate with those of Dos Reis et al. [47], Danowska-Oziewicz et al. [39], and Czarnowska-Kujawska et al. [34] who also noticed a lower L* value for broccoli after cooking. For green beans, however, the L^* value (30 and 60 min) remained at a similar level compared with the raw sample, and significant ($p < 0.05$) changes in lightness were recorded only in the longest-cooked sample (90 min).

As the cooking time increased, green color intensity ($-a^*$) of broccoli and green beans decreased, but in most cases these changes were not significant ($p > 0.05$). Broccoli cooked for the shortest time (15 min) showed very similar green color intensity to the raw sample. The intensity (a^*) of red color of beetroot decreased during cooking, but the values of this parameter remained similar regardless of cooking time (45, 90, 180 min). Green vegetables color mainly relates to chlorophyll, whose degradation to isomers leads to color changes. As the effect of heat treatment, the transitions of chlorophyll into pheophytins and then degrades to pyrophenophytes. The color changes can also be a result of the activity of enzyme, which alters the light reflecting properties of the surface which is due to the air removal from plant tissue and its replacement with water and cell juice because of cell membrane disruption [34,39,48,49].

Yellowness (b^*) of broccoli increased along with cooking time and significant differences ($p < 0.05$) were reported after 30 and 45 min of cooking. Chlorophyll degradation reduces the green color intensity and leads to yellowing. The yellowness of broccoli has been associated with enzyme peroxidase and lipoxygenase [50]. Heat treatment of green beans and beetroot caused a significant decrease ($p < 0.05$) yellowness in comparison with raw vegetable. The yellowness (b^*) of green beans significantly ($p < 0.05$) decreased during the longest (90 min) heat treatment, and in beet it was reported at a comparable level regardless of the length of cooking time (45–180 min).

With the use of the measured values of the $L^*a^*b^*$ parameters, color saturation (C^*), hue angle (h°) and the total color difference (ΔE^*) were calculated (Table 1). The color saturation (C^*) of all samples after *sous-vide* cooking differed significantly ($p < 0.05$) from the raw sample. While the color saturation of broccoli significantly ($p < 0.05$) increased, it significantly ($p < 0.05$) decreased in green beans and beetroot. The values of color saturation for individual vegetables, regardless of cooking time, remained at similar levels and no significant differences were found between them ($p > 0.05$).

The values of color tone (h°) in all heat-treated samples (broccoli, green beans, beetroot) significantly ($p < 0.05$) decreased in comparison to raw material, and their values remained at a similar level regardless of cooking time ($p > 0.05$). A decrease in the value of the h° parameter resulted in a less intense hue of green and red. Similar results presented Turkmen et al. [51] and Czarnowska-Kujawska et al. [34], who observed that the hue angle (h°) values of broccoli decreased after steaming. The susceptibility of pigment content in vegetables to heating is varied, with chlorophylls and betalains being the most sensitive, and carotenoids the least [52,53].

The total color difference (ΔE^*) in cooked green beans ranged between 11 and 15, while for beetroot between 21 and 24. This indicates that an increase in cooking time resulted in a significant ($p < 0.05$) color change compared to raw vegetables. In the case of broccoli, increasing cooking time at the same temperature of 85 °C did not significantly ($p > 0.05$) affect the total color difference (ΔE^*) between raw and cooked vegetables. Different findings were presented by Zhong et al. [49], Danowska-Oziewicz et al. [39], and Czarnowska-Kujawska et al. [34], who recorded a higher value in the total color difference (ΔE^*) for broccoli subjected to different cooking methods (32–36; 16–24; 9–16, respectively).

4. Conclusions

The *sous-vide* processing time should be selected individually for each vegetable to ensure the most desirable sensory properties of the product. The thermal treatment time affects the deterioration of the consistency of the vegetable, and in the case of beetroots and broccoli, the color intensity decreases. Although the aroma intensity of the vegetable increases with the processing time, it should be considered that such a change might not always be desired by consumers, as in the case of broccoli.

In most cases, *sous-vide* method did not cause magnesium, sodium, potassium, phosphorus or calcium decrease even after prolonged cooking time. Therefore, *sous-vide* cooked vegetables can constitute for no less valuable than raw vegetables source of minerals in the daily diet, with improved sensory properties of processed food.

Sous-vide heat treatment, despite the increase of cooking time, allowed the tested color parameters to be maintained at similar levels. The smallest color changes were observed in broccoli. The shortest cooking time in all tested vegetables caused the smallest color changes, which was also confirmed by the panelists in the organoleptic color evaluation. The study proves that the sous vide method reduces color loss.

Author Contributions: M.C.-K. and A.D. conceptualization, performed the experiment, methodology and validation, data analysis, review and writing—original draft preparation. M.C. performed the experiment, data analysis. M.S. review and writing—original draft preparation. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data are available from the first author.

Acknowledgments: We would like to express our special thanks to Elżbieta Tońska from the Department of Commodity Science and Food Analysis for the technical support in the determination of the mineral composition of the samples.

Conflicts of Interest: The authors declare no conflict of interest.

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