Influence of sous-vide thermal treatment, boiling, and steaming on the colour, texture and content of bioactive compounds in root vegetables

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Abstract

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Introduction. The aim of the study was to compare the effect of sous-vide treatment, cooking in boiling water, and steaming on changes in the colour, texture, and retention of selected bioactive compounds in root vegetables.

Materials and methods. Carrots and parsley were subjected to sous-vide thermal treatment (SV) at 80 °C (SV 80) and 90 °C (SV 90), cooking in boiling water (B), and steaming (S) for 10, 20, and 30 minutes. Instrumental texture properties were assessed by texture profile analysis (TPA). The colour was measured with a colorimeter, and the content of total phenolic compounds and carotenoids was determined using the spectrophotometric method.

Results and discussion. The hardness, cohesiveness, and chewiness of the analysed vegetables differed significantly depending on the method and duration of culinary processing. The highest hardness, cohesiveness, and chewiness values were demonstrated for the SV 80 variants.

Most of the colour parameters of the vegetables differed statistically significantly depending on the method and duration of culinary processing. The lowest brightness (L^*) was demonstrated for parsley B (20-min treatment), and the highest value of the parameter was noted for parsley samples SV 80 (10-min treatment). The highest values of parameter a^* , which is the component of orange colour and determine the consumer attractiveness of carrots, were recorded in samples SV 80 and SV 90. Statistically significant differences were found in the b^* value between the types of thermal treatment applied. The highest value of yellowness was noted for samples R (raw), whereas samples B (20-min treatment) had the lowest values of this parameter. In the case of carrots, the highest values of parameter b^* were recorded in samples SV 90 (10-min treatment), and samples R exhibited the lowest yellowness value.

The highest retention of phenolic compounds was detected in parsley B (20-min treatment) and carrots SV 90 (20-min treatment). The highest value of carotenoid retention was reported for parsley SV 90 (10-min treatment) and carrot SV 80 (10-min treatment).

Conclusions. Compared to the boiled and steamed samples, sous-vide vegetables have higher hardness, cohesiveness, chewiness, and consumer-attractive colour. Carrots processed with this technique exhibit higher retention of carotenoids.

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Introduction

Vegetables are a rich source of nutrients and bioactive compounds. They are often subjected to heat treatment before consumption to increase their digestibility and improve their flavour. These treatments are accompanied by physical and chemical processes that result in changes in the texture and chemical composition (Saikai et al., 2013). The appearance and texture of vegetables determine the perception of their freshness by consumers (Saba et al., 2018) and influence the consumer willingness to eat this type of food (Torres de Castro et al., 2020). An adequate choice and a proper course of the culinary processing method yield products with high health-enhancing and sensory quality (Saikai et al., 2013).

The sous-vide technology is an increasingly popular method for thermal treatment. It is based on the use of low process temperature (below 100 °C) and vacuum packing of raw materials. Sealing raw foods in plastic bags prevents loss of nutrients, as is the case when cooking in boiling water (Michalak-Majewska et al., 2018). Vegetables cooked with the sous-vide technique are characterised by higher antioxidant potential than those subjected to other culinary processing methods (Kosewski et al., 2018). The sous-vide cooking method contributes to reduction of losses of chlorophyll, carotenoids, phenolic compounds (Guillén et al., 2017), anthocyanins (Iborra-Bernad et al., 2014), and volatile aroma substances during the thermal treatment of vegetables (Rinaldi et al., 2013). There are promising results of research on the retention of minerals in raw materials of plant origin (Rondanelli et al., 2017). Sous-vide products are perceived by consumers as the highest quality food with a number of advantages. Nevertheless, a dose of scepticism is raised by the need to pack the raw material in plastic bags and the fear of chemical compounds permeating from the packaging to the raw material or reactions of food ingredients with the packaging (Roascio-Albistur et al., 2018).

The aim of the study was to compare the effect of the sous-vide thermal treatment, cooking in boiling water, and steaming on the colour, texture, and content of some bioactive compounds in root vegetables.

Materials and methods

Vegetable materials and sample preparation

Fresh carrots (*Daucus carota* var. 'Aneta F1') and root parsley (*Petroselinum crispum* ssp. *Tuberosum* var. 'Sonata') were obtained from crops grown on the Felin Experimental Farm of the University of Life Sciences in Lublin (Poland; 51°22'N, 22°64'E). The vegetables were harvested a week before the experiments and stored at 4 °C until use.

All vegetables were washed, cleaned, peeled, and sliced into 10 mm±1 mm thick cylinders using a stainless steel knife. For the sous-vide treatment, the raw vegetables discs were vacuum sealed in plastic cooking vacuum bags (Stalgast, Poland). Air was removed from the bags, which were then sealed using a vacuum packaging machine (Lerica, model: Levac 3, Italy). For boiling and steaming, the vegetables were placed in water without vacuum packaging.

After cooking, all samples were immersed in an ice-water bath for rapid cooling. Boiled and steamed vegetables were sealed (no vacuum was applied) in plastic bags to prevent contact with water. The SV samples were cooled in the same bags.

The texture and colour measurements were performed after cooling the samples. Vegetables intended for chemical analysis were cooled, frozen, and lyophilised in a laboratory freeze drier (Alpha 1-2 LD plus; Martin Christ, Osterode am Harz, Germany). The freeze-dried material was fragmented in a mill and subjected to a further procedure.

Cooking conditions

Three cooking methods were applied: boiling, steaming, and sous-vide cooking.

Boiling (B) was carried out in a stainless steel pot and a cooking top (Stalgast IP 23, Poland) for 10 min, 20 min, or 30 min. The raw vegetable discs were placed in the pot when the water reached its boiling point (100 °C at atmospheric pressure) with a constant product weight:water volume ratio of 1:4.

For the steaming treatment (S), the samples were placed in a single layer on a steamer floor (Zelmer, model: 37Z010, Poland) with an appropriate distance, following the instruction manual. The raw material was steamed for 10 min, 20 min, or 30 min.

Cooking with the sous-vide method (SV) was performed using a sous-vide water bath (Hendi, model: 225448, Netherlands). The bags were immersed in hot water, and covered with a special limiter to prevent floating. The SV cooking conditions were 80 °C (SV 80) for 10 min, 20 min, or 30 min and 90 °C (SV 90) for 10 min, 20 min, or 30 min.

Colour measurement

Colour was measured using a Minolta CR-310 colorimeter (Osaka, Japan). The instrument was calibrated using standard white and black ceramic standards before use. The results were given in the CIELab colour system for illuminant D65. Six replicates were carried out for each vegetable and cooking condition. Parameters L^* (brightness), a^* (greenness-redness), and b^* (blueness-yellowness) were registered. These parameters were used to calculate the total colour difference using the following equation:

$$\Delta E = [(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2]^{1/2}$$

where L^* , a^* , and b^* are the colour values of SV (SV 80 and SV 90), B, and S samples. L_0^* , a_0^* , and b_0^* are the colour values of the raw vegetables (R).

Textural analysis

The Textural Profile Analysis (TPA) test was carried out using a TA-XTi texture analyser (Stable Micro Systems, Surrey, UK) with the Texture Expert program (version 1.22). To obtain a sample with the same tissue orientation and dimension, a 40-mm-diameter cylindrical sample was drilled out of the vegetable slices with a cork borer and compressed to 30% of the original height with a 75-mm cylindrical aluminium probe. The compression was carried out with 5 seconds waiting time between the first and the second compression. The test speed was kept at 1 mm/s. Each group was analysed in six replications. The raw vegetable discs (R) were not analysed due to their high hardness. The textural parameters, i.e. hardness [N], springiness, cohesiveness, and chewiness, were determined from the curves obtained from TPA. Six replicates were carried out for each vegetable and cooking condition.

Solvent extraction

For the preparation of ethanolic extracts, powdered samples of the vegetables (1 g) were extracted for 0.5 h with 30 ml of 80% (v/v) ethanol and centrifuged (4500× g for 15 min). The supernatants were used for further analysis. All extractions and chemical analyses were conducted in triplicate.

Total phenolic content

Total polyphenol content (TPC) was determined according to the method proposed by Singleton and Rossi (Singleton, 1965) with some changes (Radzki et al., 2014). The amount of TPC was expressed as gallic acid equivalents (GAE) in mg per 100 g of dry matter (d.m.).

Carotenoid determination

Carotenoids were determined according to the Polish standard (Przetworów Owocowych i Warzywnych, 1990) and expressed in mg per 100 g of d.m.

Statistical analysis

Statistical analysis was performed using Statistica 13.1 program (Statsoft, Cracow, Poland), applying Tukey's HSD test in the analysis of variance (ANOVA) to estimate the significance of the differences between the mean values at $p < 0.05$.

Results and discussion

Colour

The results of the colour of parsley are presented in Table 1.

Table 1

CIELab coordinates in root parsley under different conditions

Cooking conditions	Cooking time	CIELab coordinates			
		L*	a*	b*	ΔE
Raw (R)	N.A.	74.82 $\pm$ 0.94 ^g	-2.47 $\pm$ 0.08 ^b	6.95 $\pm$ 0.66 ^d	N.A.
Sous-vide 80 °C (SV 80)	10 min	61.04 $\pm$ 0.69 ^f	-3.75 $\pm$ 0.20 ^a	6.25 $\pm$ 0.26 ^d	13.86 $\pm$ 0.69 ^a
	20 min	55.24 $\pm$ 2.01 ^{cde}	-3.67 $\pm$ 0.38 ^a	4.03 $\pm$ 0.18 ^c	19.84 $\pm$ 1.94 ^{bcd}
	30 min	57.35 $\pm$ 1.11 ^{ef}	-3.61 $\pm$ 0.39 ^a	3.92 $\pm$ 0.24 ^c	17.78 $\pm$ 1.09 ^{ab}
Sous-vide 90 °C (SV 90)	10 min	55.88 $\pm$ 1.40 ^{def}	-3.55 $\pm$ 0.14 ^a	3.63 $\pm$ 0.25 ^c	19.26 $\pm$ 1.4 ^{abc}
	20 min	53.33 $\pm$ 1.31 ^{cde}	-3.64 $\pm$ 0.22 ^a	2.64 $\pm$ 0.22 ^b	21.95 $\pm$ 1.26 ^{bcd}
	30 min	52.87 $\pm$ 3.08 ^{cde}	-3.56 $\pm$ 0.38 ^a	2.33 $\pm$ 0.31 ^b	22.47 $\pm$ 2.97 ^{bcd}
Steaming (S)	10 min	50.99 $\pm$ 1.91 ^{bcd}	-3.54 $\pm$ 0.3 ^a	1.84 $\pm$ 0.17 ^b	24.40 $\pm$ 1.91 ^{cde}
	20 min	49.85 $\pm$ 0.34 ^{abc}	-3.56 $\pm$ 0.37 ^a	1.80 $\pm$ 0.17 ^b	25.52 $\pm$ 0.33 ^{def}
	30 min	50.91 $\pm$ 2.10 ^{abcd}	-3.53 $\pm$ 0.24 ^a	2.08 $\pm$ 0.32 ^b	24.42 $\pm$ 2.09 ^{cde}
Boiling (B)	10 min	50.76 $\pm$ 1.57 ^{abcd}	-3.37 $\pm$ 0.46 ^a	4.33 $\pm$ 0.33 ^c	24.23 $\pm$ 1.58 ^{cde}
	20 min	45.19 $\pm$ 4.02 ^a	-3.32 $\pm$ 0.25 ^{ab}	0.65 $\pm$ 0.22 ^a	30.32 $\pm$ 3.91 ^f
	30 min	45.59 $\pm$ 1.66 ^{ab}	-3.40 $\pm$ 0.13 ^a	4.07 $\pm$ 0.11 ^c	29.39 $\pm$ 1.66 ^{ef}

N.A.: not available. ^{a-f} Values in the same column are significantly different ($p \leq 0.05$).

Parameter L* expressing the brightness of the samples ranged from 45.19 to 74.82. The brightness of the thermally treated samples differed significantly from samples R. The lowest value of the parameter was demonstrated for parsley samples B (20-min treatment), whereas samples SV 80 (10-min treatment) were characterised by the highest brightness. Samples SV exhibited higher brightness than samples B and S; hence, they can be more attractive to consumers. The brightness of the colour of fresh-cut vegetables influences the perception of their freshness by consumers (Barret et al., 2010). In the case of the carrots, samples SV 80 (10-min treatment) had the highest brightness, while the lowest value of the parameter was shown for carrot samples B (10-min treatment). However, the value of brightness was not statistically significantly different from most of the samples (Table 2).

Table 2

CIELab coordinates in carrot under different conditions

Cooking conditions	Cooking time	CIELab coordinates			
		L*	a*	b*	ΔE
Raw (R)	N.A.	43.42 ± 1.03 ^{ab}	4.76 ± 0.37 ^a	14.68 ± 0.51 ^a	N.A.
Sous-vide 80°C (SV 80)	10 min	45.16 ± 2.02 ^b	12.51 ± 0.56 ^{cd}	32.54 ± 1.42 ^f	19.63 ± 1.33 ^e
	20 min	43.73 ± 3.51 ^{ab}	11.30 ± 0.23 ^{bcd}	27.62 ± 0.82 ^{de}	14.79 ± 0.74 ^d
	30 min	43.65 ± 1.44 ^{ab}	11.76 ± 0.27 ^{bcd}	27.40 ± 1.05 ^{de}	14.58 ± 0.79 ^{cd}
Sous-vide 90 °C (SV 90)	10 min	42.82 ± 1.48 ^{ab}	12.80 ± 1.10 ^d	27.48 ± 1.43 ^{de}	15.20 ± 1.56 ^d
	20 min	43.68 ± 1.42 ^{ab}	12.73 ± 0.40 ^d	27.32 ± 1.29 ^{cde}	15.02 ± 0.98 ^d
	30 min	42.46 ± 1.07 ^{ab}	11.75 ± 1.08 ^{bcd}	25.23 ± 1.05 ^{bcd}	12.73 ± 1.34 ^{bcd}
Steaming (S)	10 min	41.76 ± 2.20 ^{ab}	10.58 ± 0.6 ^{bcd}	24.42 ± 1.07 ^{bcd}	11.64 ± 0.69 ^{abc}
	20 min	41.64 ± 1.56 ^{ab}	10.36 ± 1.36 ^{bc}	24.12 ± 0.9 ^{bc}	11.25 ± 0.88 ^{ab}
	30 min	40.38 ± 1.11 ^{ab}	9.53 ± 0.59 ^b	23.55 ± 1.07 ^b	10.59 ± 0.78 ^{ab}
Boiling (B)	10 min	39.64 ± 2.04 ^a	5.83 ± 1.08 ^a	22.39 ± 1.29 ^b	8.78 ± 1.94 ^a
	20 min	41.40 ± 1.11 ^{ab}	9.75 ± 0.68 ^b	29.11 ± 1.00 ^e	15.44 ± 0.88 ^d
	30 min	41.67 ± 0.51 ^{ab}	6.91 ± 0.55 ^a	25.47 ± 0.82 ^{bcd}	11.16 ± 0.84 ^{ab}

N.A.: not available. ^{a-f} Values in the same column are significantly different ($p \leq 0.05$).

As demonstrated by Mazzeo et al. (Mazzeo et al., 2011), steaming (S) significantly reduced the brightness of carrots, whereas treatment B did not change this parameter significantly. The authors emphasise, however, that the stability of the colour in their experiment may have been influenced by the fact that the carrots were blanched prior to the

treatment. It has also been reported that sous-vide (SV) cooking does not significantly alter the brightness of thermally processed cruciferous vegetables, compared to thermally unprocessed vegetables (Lafarga et al., 2018). The present study showed that parsley that was in direct contact with water (B and S) was characterised by a greater total difference in the colour and lower brightness than samples SV. Similar observations were reported by Tomaszewska et al. (Tomaszewska et al., 2012), who showed that the direct contact of the heating agent with the raw material (steaming or boiling in water) had a significant impact on the differentiation of carrot brightness. In turn, Guillen et al. (Guillén et al., 2007) observed no significant differences in the brightness of vegetables subjected to the sous-vide treatment, cooked in boiling water, and cooked in water at $<100^{\circ}\text{C}$.

The values of parameter a^* differed significantly between parsley samples R and the thermally treated samples. There were no statistically significant differences in parameter a^* of the samples between the type of the thermal treatment. In the case of the carrot samples, significant differences were found in the values of parameter a^* depending on the thermal treatment type. The significant differences in the values of this parameter may result from the fact that carotenoids, responsible for the yellow and red colour, are present mainly in chromoplasts surrounded by the cell wall and membrane (Zielińska et al., 2011). Thermal treatment destroys the cell structure and promotes the penetration of crystalline chromoplasts into the intercellular space (Marx et al., 2003). This is probably the reason why the untreated carrots in the present study were significantly less yellow and red than the thermally treated carrots. These results indicate that the SV 90 carrot samples (10-min treatment) had the highest value of redness, while samples R were the least red. In the case of carrot samples that were in direct contact with the thermal agent (B and S), the red colour was less saturated than in samples R, SV 80, and SV 90. A decline in the intensity of the red colour of carrots during boiling and steaming was reported by other authors as well (Mazzeo et al., 2011). It can be observed that the intensity of the red colour decreased with the duration of the thermal treatment in the case of all the methods employed, with the exception of sample B. Similar observations were reported by Biller and Wierzbicka (Biller et al., 2015), where the mean values of parameter a^* declined successively after each heating stage.

The values of parameter b^* differed significantly between the untreated and thermally treated parsley samples. Similarly, statistically significant differences were found in the b^* value between the types of thermal treatment applied. The highest value of yellowness was noted for samples R, whereas samples B (20-min treatment) had the lowest values of this parameter. In the case of carrots, the highest values of parameter b^* were recorded in samples SV 90 (10-min treatment), and samples R exhibited the lowest yellowness value. It was evident that the intensity of the yellow colour declined with the duration of the thermal process in all processing methods except for samples B. Schifferstein et al. (Schifferstein et al., 2019) have demonstrated that consumers most often choose orange carrots for consumption. At low saturation of the orange colour, carrots are perceived as unattractive and less fresh. Therefore, high values of parameters a^* and b^* (components of the orange and yellow colour respectively) are particularly important in consumer assessment of the attractiveness of these vegetables. High values were noted for samples SV 80 and SV 90, which may suggest that sous-vide carrots will be particularly attractive to consumers.

Taking parsley R as the standard, the smallest total difference in the colour (ΔE) was demonstrated for SV 80 (10-min treatment), while the highest value of the parameter was recorded for parsley samples B (20-min treatment). As reported by Marić et al. (2020), the highest ΔE was noted in parsley subjected to convection drying at a temperature of 70°C , and the lowest value of the parameter was recorded in the same type of convection drying at a temperature of 50°C . In the present study, the high temperature of the thermal treatment

(B) was associated with highest ΔE value, and the heat treatment at low temperature (SV 80) induced the lowest values of the parameter. In the case of carrots, the lowest and the highest values of the total colour difference (ΔE) were demonstrated for samples SV 80 (10-min treatment) and samples B (20-min treatment), respectively. Torres de Castro et al. (Torres de Castro et al., 2020) showed greater changes in the colour of carrots induced by treatment S vs. B. The present study demonstrated larger colour differences between these two processing methods only in the 20-min treatment variant.

Texture

The hardness of parsley ranged from 24.11 to 218.53 N, with significant differences between the treatment methods and duration of processing (Table 3). The lowest hardness was exhibited by parsley samples S (30-min treatment). In turn, parsley SV 80 was the hardest (10-min treatment). A comparison of the samples revealed that the hardness parameter in each time variant decreased in the following order: SV 80 > SV 90 > B > S. The hardness of the carrots also differed significantly depending on the variant and duration of the thermal treatment (Table 4). A comparison of the samples showed the following order of the decline in the hardness parameter in each time variant (except the 10-min B and S treatments): SV80 > SV 90 > S > B. The lowest value of hardness was recorded for samples B and S (30-min treatment), whereas the highest values of this parameter were determined for samples SV 80. In their investigations of the hardness of sous-vide cooked carrots, (Koç et al., 2017) showed a decline in this parameter along the processing time and with a rise in the process temperature. The hardness of carrots cooked in boiling water for 30 min was comparable to that in samples subjected to sous-vide cooking at 75 °C for 120 min. Similar results were obtained in the present study, i.e. the SV vegetables were even 3 times harder than the B and S vegetables at the same duration of the treatments. The results reported by Xu et al. (Xu et al., 2015) show that the hardness parameter in carrots is more potently influenced by high temperature than by the duration of the thermal process. Similar observations were reported by other authors as well (Vu et al., 2004). High temperatures directly damage the cell walls, thereby changing the texture. The non-enzymatic degradation of cell walls in food of plant origin occurs most effectively at a temperature > 80 °C and contributes to depolymerisation of pectins (Sila et al., 2008). This is a probable explanation of the higher hardness value in samples SV 80 than SV 90 in each time variant. The analysis of the present results indicates that the significant differences in hardness may also be associated with the absence of direct contact with the heating medium (hot water) in the case of samples SV vs. samples B and S. This may contribute to inhibition of pectin dissolution. The absence of direct contact with hot water in the case of SV reduces heat transfer to the heated product, which may also influence texture changes. Similar observations of the impact of the absence of direct contact of the heated product with water on the texture of vegetables were reported by other authors as well (Xie, 2000; Iborra-Bernad et al., 2015)

No statistically significant differences were found in the case of springiness of the analysed vegetables (Tables 3 and 4).

Cohesiveness is described as a tendency of food to lose its structural form after the first compression test in texture analysis. Potato chips and mashed potatoes are products with low cohesiveness (Wee et al., 2018). The cohesiveness of the analysed vegetable samples differed statistically significantly (Tables 3 and 4). The highest value of this parameter was recorded for parsley samples B (20-min treatment) and carrots SV 80 (20-min treatment). The SV technique yielded vegetables with the highest cohesiveness, compared with the other methods. The lowest values of this parameter were found for parsley samples S (30-min treatment) and carrot samples S (30-min treatment).

Table 3

Results of the TPA measurement of root parsley

Cooking conditions	Cooking time	Texture diameter			
		Hardness (N)	Springiness	Cohesiveness	Chewiness
Sous-vide 80 °C (SV 80)	10 min	218.53 ± 35.18 ^f	0.78 ± 0.01 ^a	0.50 ± 0.02 ^{de}	8638.01 ± 1529.28 ^d
	20 min	178.44 ± 50.36 ^{ef}	0.75 ± 0.02 ^a	0.50 ± 0.02 ^{de}	6825.53 ± 1587.74 ^{cd}
	30 min	170.13 ± 3.25 ^{ef}	0.78 ± 0.02 ^a	0.47 ± 0.02 ^{cde}	6454.49 ± 522.45 ^{cd}
Sous-vide 90 °C (SV 90)	10 min	135.59 ± 20.77 ^{de}	0.77 ± 0.06 ^a	0.49 ± 0.04 ^{cde}	3960.82 ± 2336.18 ^{bc}
	20 min	104.81 ± 28.46 ^{cd}	0.78 ± 0.08 ^a	0.38 ± 0.02 ^{abc}	3801.18 ± 1565.85 ^{abc}
	30 min	46.61 ± 9.32 ^{abc}	0.78 ± 0.06 ^a	0.34 ± 0.06 ^{ab}	970.49 ± 966.34 ^{ab}
Steaming (S)	10 min	63.22 ± 10.54 ^{abc}	0.82 ± 0.05 ^a	0.36 ± 0.05 ^{ab}	1878.91 ± 404.92 ^{ab}
	20 min	38.95 ± 9.01 ^{ab}	0.82 ± 0.01 ^a	0.35 ± 0.05 ^{ab}	1122.08 ± 245.30 ^{ab}
	30 min	24.11 ± 4.20 ^a	0.74 ± 0.02 ^a	0.28 ± 0.02 ^a	509.08 ± 118.04 ^a
Boiling (B)	10 min	91.77 ± 12.35 ^{bcd}	0.87 ± 0.01 ^a	0.45 ± 0.03 ^{bcd}	4196.23 ± 611.44 ^{bc}
	20 min	46.86 ± 20.11 ^{abc}	0.88 ± 0.01 ^a	0.52 ± 0.06 ^e	2210.79 ± 1166.75 ^{ab}
	30 min	44.83 ± 3.52 ^{abc}	0.80 ± 0.11 ^a	0.40 ± 0.03 ^{bcd}	1470.73 ± 267.73 ^{ab}

^{a-f} Values in the same column are significantly different ($p \leq 0.05$).

The comparison of the processing methods demonstrated the following order of the decline in the chewiness parameter in each time variant: SV 80 > SV 90 > B > S. Significant differences were found between the treatment methods and time variants. The highest chewiness parameter was recorded for root parsley samples SV 80 (10-min treatment) and carrot SV 80 (20-min treatment). In turn, root parsley samples S (30-min treatment) and carrot B (30-min treatment) exhibited the lowest chewiness.

Table 4

The results of the TPA measurement of carrot

Cooking conditions	Cooking time	Texture diameter			
		Hardness (N)	Springiness	Cohesiveness	Chewiness
Sous-vide 80 °C (SV 80)	10 min	265.79 ± 15.99 ^d	0.71 ± 0.03 ^{ab}	0.49 ± 0.01 ^c	9344.98 ± 613.74 ^{bc}
	20 min	274.03 ± 32.69 ^d	0.75 ± 0.06 ^{ab}	0.55 ± 0.06 ^c	11579.84 ± 3243.77 ^c
	30 min	265.51 ± 2.67 ^d	0.74 ± 0.01 ^{ab}	0.48 ± 0.02 ^c	9517.82 ± 479.64 ^{bc}
Sous-vide 90 °C (SV 90)	10 min	244.03 ± 5.14 ^d	0.74 ± 0.02 ^{ab}	0.48 ± 0.01 ^c	8726.07 ± 329.30 ^{bc}
	20 min	255.84 ± 19.84 ^d	0.66 ± 0.07 ^a	0.47 ± 0.01 ^c	8127.94 ± 1078.16 ^b
	30 min	163.75 ± 6.89 ^c	0.71 ± 0.02 ^{ab}	0.32 ± 0.01 ^{ab}	3781.48 ± 159.52 ^a
Steaming (S)	10 min	118.64 ± 19.02 ^{bc}	0.78 ± 0.02 ^b	0.30 ± 0.03 ^{ab}	2998.06 ± 689.80 ^a
	20 min	145.60 ± 5.02 ^{bc}	0.73 ± 0.07 ^{ab}	0.31 ± 0.06 ^{ab}	3255.01 ± 270.22 ^a
	30 min	103.61 ± 0.29 ^{ab}	0.75 ± 0.02 ^{ab}	0.26 ± 0.03 ^a	2042.05 ± 306.50 ^a
Boiling (B)	10 min	136.05 ± 36.46 ^{bc}	0.79 ± 0.01 ^b	0.37 ± 0.03 ^b	4088.03 ± 1309.73 ^a
	20 min	112.35 ± 14.63 ^{bc}	0.68 ± 0.02 ^{ab}	0.37 ± 0.04 ^b	2871.98 ± 94.64 ^a
	30 min	60.41 ± 17.29 ^a	0.76 ± 0.05 ^{ab}	0.32 ± 0.02 ^{ab}	1483.86 ± 382.36 ^a

^{a-d} Values in the same column are significantly different ($p \leq 0.05$).

Bioactive compounds content

The content of total phenolic compounds in the vegetables differed depending on the method and duration of the thermal treatment (Tables 5 and 6). The lowest content of these compounds was detected in parsley samples SV 90 (30-min treatment) and carrot samples R. The highest phenolic compound levels were determined in samples parsley B (20-min treatment) and carrot samples SV 90 (20-min treatment). The R samples of parsley cv. Sonata analysed in the present study had lower content of phenolic compounds (181 mg/100 g d.m.) than other cultivars available on the Polish market (303 mg/100 g d.m.) (Cieřlik et al., 2006). The content of phenolic compounds was significantly higher in the vacuum non-packed samples (B and S) subjected to the higher temperature treatment than in samples SV 90. However, some authors indicate that vacuum packing increases the content of phenolic acids in vegetables (Ravichandran et al., 2012). The present study also demonstrated that the content of phenolic compounds in samples R was lower than that in the thermally treated samples. This may have been related to the more severe thermally induced damage to the cell walls and thus more efficient release of phenolic compounds. Similar observations were reported by other authors as well (Ismail et al., 2004; Chumyam et al., 2013; Juániz et al., 2016).

Table 5

Carotenoids (mg/100 g dry matter) and total phenolics content (mg GAE/100 g dry matter) in root parsley cooked under different conditions

Cooking conditions	Cooking time	Carotenoids	Total phenolics
Raw (R)	N.A.	0.135 ± 0.00 ^{gh}	180.79 ± 2.07 ^{cd}
Sous-vide 80 °C (SV 80)	10 min	0.110 ± 0.00 ^{ab}	176.39 ± 7.66 ^c
	20 min	0.127 ± 0.00 ^{ef}	190.43 ± 2.13 ^{cde}
	30 min	0.126 ± 0.00 ^{de}	141.94 ± 5.22 ^{ab}
Sous-vide 90 °C (SV 90)	10 min	0.142 ± 0.00 ^h	176.98 ± 2.51 ^c
	20 min	0.120 ± 0.00 ^{cd}	154.04 ± 3.15 ^b
	30 min	0.104 ± 0.00 ^a	136.39 ± 5.86 ^a
Steaming (S)	10 min	0.123 ± 0.00 ^{cde}	189.61 ± 6.88 ^{cde}
	20 min	0.127 ± 0.00 ^{de}	196.89 ± 9.41 ^{de}
	30 min	0.134 ± 0.00 ^{fg}	185.96 ± 4.54 ^{cde}
Boiling (B)	10 min	0.137 ± 0.00 ^{gh}	178.08 ± 7.44 ^c
	20 min	0.123 ± 0.00 ^{cde}	203.51 ± 9.19 ^e
	30 min	0.117 ± 0.00 ^{bc}	185.44 ± 3.68 ^{cd}

N.A.: not available. ^{a-f} Values in the same column are significantly different ($p \leq 0.05$).

Table 6

Carotenoids (mg/100 g dry matter) and total phenolics content (mg GAE/100 g dry matter) in carrot cooked under different conditions

Cooking conditions	Cooking time	Carotenoids	Total phenolics
Raw (R)	N.A.	26.76 ± 0.51 ^f	94.74 ± 2.37 ^a
Sous-vide 80 °C (SV 80)	10 min	32.70 ± 0.33 ^g	113.69 ± 3.44 ^{cdef}
	20 min	31.04 ± 0.36 ^g	119.44 ± 3.84 ^{ef}
	30 min	32.10 ± 0.09 ^g	113.92 ± 5.45 ^{cdef}
Sous-vide 90 °C (SV 90)	10 min	26.25 ± 0.84 ^f	121.92 ± 3.79 ^f
	20 min	27.32 ± 0.71 ^f	123.54 ± 2.32 ^f
	30 min	14.06 ± 0.29 ^c	104.16 ± 2.68 ^{abc}
Steaming (S)	10 min	22.92 ± 0.99 ^e	106.10 ± 5.11 ^{abcd}
	20 min	6.21 ± 0.10 ^a	110.26 ± 1.35 ^{bcd}
	30 min	22.73 ± 0.78 ^e	116.86 ± 4.19 ^{def}
Boiling (B)	10 min	25.73 ± 0.47 ^f	121.44 ± 7.26 ^{ef}
	20 min	19.68 ± 0.80 ^d	113.92 ± 2.94 ^{cdef}
	30 min	11.75 ± 0.32 ^b	101.21 ± 0.79 ^{ab}

N.A.: not available. ^{a-f} Values in the same column are significantly different ($p \leq 0.05$).

The content of carotenoids in the parsley was negligible (0.104-0.142 mg/100 g d.m.). The level of these compounds in the carrots ranged from 6.21 mg/100 g d.m. in samples S (20-min treatment) to 32.70 mg/100 g d.m. in samples SV 80 (10-min treatment). The content of carotenoids may increase with the duration of thermal treatment of some vegetables. After exceeding certain treatment duration, this value was found to decline again (Kao et al., 2014). As suggested by Cuéllar-Villarreal et al. (Cuéllar-Villarreal et al., 2016), the degradation of carotenoids in carrots is associated with the activity of oxidative enzymes, and their

inactivation promotes the retention of these compounds. The present results confirm these observations. The vacuum packing and simultaneous reduction of the oxygen content in the package inhibited the activity of oxidative enzymes. This resulted in the highest content of carotenoids in the analysed carrots in samples SV 80. Carrot samples SV 90 had a lower carotenoid level than samples SV 80; therefore, temperature may be an additional determinant of the retention of these compounds.

Conclusion

The present results indicate that the different heat treatment types have a variable impact on the colour, texture, and retention of some bioactive compounds in root vegetables. In comparison with boiled or steamed vegetables, sous-vide vegetables are characterised by higher hardness, cohesiveness, chewiness, and a desirable colour as well as higher retention of carotenoids (in the case of carrots). Thermally treated carrots have significantly higher content of phenolic compounds than untreated carrots. The content of phenolic compounds in boiled and steamed parsley is significantly higher than in samples of this vegetable subjected to sous-vide treatments at 90 °C.

References

- Barret D.M., Beaulieu J.C., Shewfelt R. (2010), Color, flavor, texture, and nutritional quality of fresh-cut fruits and vegetables: Desirable levels, instrumental and sensory measurement, and the effects of processing, *Critical Reviews in Food Science and Nutrition*, 50(5), pp. 369–389.
- Biller E., Wierzbicka A., Póltorak A. (2015), Influence of heat treatment on carrot colour parameters, *Inżynieria Rolnicza*, 9, pp. 7–12.
- Chumyam A., Whangchai K., Jungklang J., Faiyue B., Saengnil K., (2013), Effects of heat treatments on antioxidant capacity and total phenolic content of four cultivars of purple skin eggplants, *ScienceAsia*, 39, pp. 246–251.
- Cieślak E., Gręda A., Adamus W. (2006), Contents of polyphenols in fruit and vegetables, *Food Chemistry*, 94(1), pp. 135–142.
- Cuéllar-Villarreal M.R., Ortega-Hernández E., Becerra-Moreno A., Welte-Chanes J., Cisneros-Zevallos L., Jacobo-Velázquez D.A. (2016), Effects of ultrasound treatment and storage time on the extractability and biosynthesis of nutraceuticals in carrot (*Daucus carota*), *Postharvest Biology and Technology* 119, pp. 18–26.
- Guillén S., Mir-Bel J., Oria R., Salvador M.L. (2017), Influence of cooking conditions on organoleptic and health-related properties of artichokes, green beans, broccoli and carrots, *Food Chemistry*, 217(15), pp. 209–216.
- Iborra-Bernad C., García-Segovia P., Martínez-Monzó J. (2015), Physico-chemical and structural characteristics of vegetables cooked under sous-vide, cook-vide, and conventional boiling, *Journal of Food Science*, 80(8), E1725–E1734.
- Iborra-Bernad C., García-Segovia P., Martínez-Monzó J. (2014), Effect of vacuum cooking treatment on physicochemical and structural characteristics of purple-flesh potato, *International Journal of Food Science and Technology*, 49(4), pp. 943–951.
- Iborra-Bernad C., Tárrega A., García-Segovia P., Martínez-Monzó J. (2014), Advantages of sous-vide cooked red cabbage: Structural, nutritional and sensory aspects, *LWT- Food Science and Technology*, 56(2), pp. 451–460.

Ismail A., Marjan Z.M., Foong C.W. (2004), Total antioxidant activity and phenolic content in selected vegetables, *Food Chemistry*, 87(4), pp. 581–586.

Juániz I., Ludwig I.A., Huarte E., Pereira-Caro G., Moreno-Rojas J.M., Cid C., De Peña M.-P., (2016), Influence of heat treatment on antioxidant capacity and (poly)phenolic compounds of selected vegetables, *Food Chemistry*, 197, pp. 466–473.

Kao F.-J., Chiu Y.-S., Chiang W.-D. (2014), Effect of water cooking on antioxidant capacity of carotenoid-rich vegetables in Taiwan, *Journal of Food and Drug Analysis*, 22(2), pp. 202–209.

Koç M., Baysan U., Devseren E., Okut D., Atak Z., Karataş H., Kaymak-Ertekin F. (2017), Effects of different cooking methods on the chemical and physical properties of carrots and green peas, *Innovative Food Science and Emerging Technologies* 42, pp. 109–119.

Kosewski G., Górna I., Bolesławska I., Kowalówka M., Więckowska B., Główna A.K., Morawska A., Jakubowski K., Dobrzyńska M., Miszczuk P., Przysławski J. (2018), Comparison of antioxidative properties of raw vegetables and thermally processed ones using the conventional and sous-vide methods, *Food Chemistry*, 240, pp. 1092–1096.

Lafarga T., Bobo G., Viñas I., Zudaire L., Simó J., Aguiló-Aguayo I. (2018), Steaming and sous-vide: Effects on antioxidant activity, vitamin C, and total phenolic content of *Brassica* vegetables, *International Journal of Gastronomy and Food Science*, 13, pp. 134–139.

Lafarga T., Viñas I., Bobo G., Simó J., Aguiló-Aguayo I. (2018), Effect of steaming and sous vide processing on the total phenolic content, vitamin C and antioxidant potential of the genus *Brassica*, *Innovative Food Science & Emerging Technologies*, 47, pp. 412–420.

Marić L., Malešić E., Tušek A.J., Benković M., Valinger D., Jurina T., Gajdoš Kljusurić J. (2020), Effects of drying on physical and chemical properties of root vegetables: Artificial neural network modelling, *Food and Bioprocess Technology*, 119, pp. 148–160.

Marx M., Stuparic M., Schieber A., Carle R. (2003), Effects of thermal processing on trans-cis-isomerization of β -carotene in carrot juices and carotene-containing preparations, *Food Chemistry*, 83, pp. 609–617.

Mazzeo T., N'Dri D., Chiavaro E., Visconti A., Fogliano V., Pellegrini N. (2011), Effect of two cooking procedures on phytochemical compounds, total antioxidant capacity and colour of selected frozen vegetables, *Food Chemistry*, 128(3), pp. 627–633.

Michalak-Majewska M., Stanikowski P., Gustaw W., Sławińska A., Radzki W., Skrzypczak K., Jabłońska-Ryś E. (2018), Technologia sous-vide – innowacyjny sposób obróbki cieplnej żywności, *ŻYWNOSĆ. Nauka. Technologia. Jakość*, 116(3), pp. 34–44.

Przetworów Owocowych i Warzywnych (1990), PN-A-75101:12 Przetwory owocowe i warzywne. Przygotowanie próbek i metody badań fizykochemicznych. Oznaczenie zawartości sumy karotenoidów i β -karotenu.

Radzki W., Sławińska A., Jabłońska-Ryś E., Gustaw W. (2014), Antioxidant capacity and polyphenolic content of dried wild edible mushrooms from Poland, *International Journal of Medicinal Mushrooms*, 16(1), pp. 65–75.

Ravichandran K., Ahmed A.R., Knorr D., Smetanska I., (2012), The effect of different processing methods on phenolic acid content and antioxidant activity of red beet, *Food Research International*, 48, pp. 16–20.

Rinaldi M., Dall'Asta C., Meli F., Morini E., Pellegrini N., Gatti M., Chiavaro M. (2013), Physicochemical and microbiological quality of sous-vide-processed carrots and brussels sprouts, *Food and Bioprocess Technology*, 6, pp. 3076–3087.

Roascio-Albistur A., Gámbaro A. (2018), Consumer perception of a non-traditional market on sous-vide dishes, *International Journal of Gastronomy and Food Science*, 11, pp. 20–24.

Rondanelli M., Daglia M., Meneghini S., Di Lorenzo A., Peroni G., Faliva M.A., Perna S. (2017), Nutritional advantages of sous-vide cooking compared to boiling on cereals and legumes: Determination of ashes and metals content in ready-to-eat products, *Food Science & Nutrition*, 5(3), pp. 827–833.

Saba A., Moneta E., Peparaio M., Sinesio F., Vassallo M., Paoletti F. (2018), Towards a multi-dimensional concept of vegetable freshness from the consumer's perspective, *Food Quality and Preference*, 66, pp. 1–12.

Saikia S., Mahanta C.L. (2013), Effect of steaming, boiling and microwave cooking on the total phenolics, flavonoids and antioxidant properties of different vegetables of Assam, India, *International Journal of Food and Nutritional Sciences*, 3(2), pp. 47–53.

Schifferstein H.N.J., Wehrle T., Carbon C.-C. (2019), Consumer expectations for vegetables with typical and atypical colors: The case of carrots, *Food Quality and Preference*, 72, pp. 98–108.

Sila D.N., Duvetter T., De Roeck A., Verlent I., Smout C., Moates G.K., Hills B.P., Waldron K.K., Hendrickx M., Van Loey A. (2008), Texture changes of processed fruits and vegetables: potential use of high-pressure processing, *Trends in Food Science & Technology*, 19, pp. 309–319.

Singleton V.L., Rossi J.A. (1965), Colorimetry of total phenolics with phosphomolybdic acid-phosphotungstic acid reagents, *American Journal of Enology and Viticulture*, 16, pp. 144–158.

Tomaszewska M., Zalewska M., Gomulska I. (2012), Evaluation of physical properties of carrot prepared according to sous vide method and traditionally, *Postępy Techniki Przetwórstwa Spożywczego*, 1, pp. 33–38.

Torres de Castro N., de Lacerda L., de Alencar E.R., Assunção Botelho R.B. (2020), Is there a best technique to cook vegetables? – A study about physical and sensory aspects to stimulate their consumption, *International Journal of Gastronomy and Food Science*, 21, 100218.

Vu T.S., Smout C., Sila D.N., LyNguyen B., Van Loey A.M.L., Hendrickx M.E.G., (2004), Effect of preheating on thermal degradation kinetics of carrot texture, *Innovative Food Science and Emerging Technologies*, 5(1), pp. 37–44.

Wee M.S.M., Goh A.T., Stieger M., Forde C.G. (2018), Correlation of instrumental texture properties from textural profile analysis (TPA) with eating behaviours and macronutrient composition for a wide range of solid foods, *Food & Function*, 9, pp. 5301–5312.

Xie G. (2000), Comparison of textural changes of dry peas in sous vide cook-chill and traditional cook-chill systems, *Journal of Food Engineering*, 43, pp. 141–146.

Xu C., Yu C., Li Y. (2015), Effect of blanching pretreatment on carrot texture attribute, rheological behavior, and cell structure during cooking process, *LWT – Food Science and Technology*, 62(1), pp. 48–54.

Zielińska M., Markowski M. (2011), Colour characteristics of carrots: Effect of drying and rehydration, *International Journal of Food Properties* 15, pp. 450–466.