Influence of low temperature blanching and calcium chloride soaking on colour and consumer attractiveness of broccoli

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SUMMARY

The aim of the presented research was to evaluate the influence of low-temperature blanching and calcium chloride soaking on colour and consumer attractiveness of broccoli. The object of the study was broccoli soaked in 1% calcium chloride solution before blanching at a low temperature (50–80 °C). After the thermal treatment, measurement of components of colour was conducted in *L*a*b** system and attractiveness of colour as well as global attractiveness of samples were evaluated by sensory analysis. Application of the technology of low-temperature blanching at the temperature of 50–60 °C for 10 min, with or without exposure to calcium ions, allows broccoli to achieve the most attractive colour. Soaking in 1% calcium chloride solution prior to low-temperature blanching resulted in obtaining a colour more attractive for consumers, compared to the use of conventional technology.

Keywords

low-temperature blanching; colour; sensory analysis; calcium chloride

Blanching is a pre-treatment thermal process, which is applied in case of raw vegetables and fruits prior to processes such as sterilization/pasteurization, freezing or drying. Blanching determines the quality of the final product. The main aim of this process is to deactivate enzymes (e.g. polyphenol oxidase, ascorbic acid oxidase, peroxidase, chlorophyllase, lipoxygenase) that may catalyse reactions responsible for deteriorating the quality of the final product, including colour degradation or undesirable flavour and texture changes [1–3]. Blanching deactivates enzymes, so during the further stages of processing, degradation of chlorophyll and carotenoids is limited and, as a consequence, negative impact on colour of vegetables is also reduced [4]. During blanching and the further stages of processing, tissue damage may occur, which is another factor contributing to negative changes of colour of processed vegetables, because of chlorophyll degradation [5].

Consumer acceptance of processed vegetables is determined by their appearance, colour, texture, flavour and nutritional value. It has to be taken into account that colour and appearance, as the only visible factors, are the first and most important criteria for consumers, apart from the price, when choosing food products [6]. Research on low-temperature blanching (LTB) of vegetables, which takes place at the temperature of 60–70 °C for 5 min, indicates that such thermal treatment results in obtaining a product characterized by stronger texture, being more crunchy [7], and more attractive colour of green vegetables [8]. Furthermore, addition of calcium salts during the LTB treatment improves the texture of plant products, as calcium ions enter into cross-bindings between polymers of pectin and stabilize them [9]. The mentioned addition allows to obtain the vegetables that are characterized by the texture desired by the consumers and are quite stable during further thermal treatment. However, conducting the process with calcium chloride may in-

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fluence the colour, in particular in case of green vegetables, as brighter colour and no browning is observed at lower temperatures of the process [10, 11].

The colour of vegetables may be changed due to certain biochemical reactions occurring during technological processing, in particular during thermal treatment [12]. At applying high temperatures, central magnesium atom is removed from the chlorophyll molecule, which is responsible for green colour, and the molecule is transformed to pheophytin of olivaceous/russet colour [13–16]. Therefore chlorophyll degradation model is described mainly as a function of temperature [17, 18] and time [17].

The aim of this study was to evaluate the influence of low-temperature blanching on the colour and consumer attractiveness of broccoli. Low-temperature blanching was applied with and without preliminary calcium chloride soaking, which is an innovative texture-improving approach.

MATERIALS AND METHODS

Sample preparation and blanching treatment

The object of the study was broccoli (*Brassica oleracea* var *italic*) from local markets in Poland. pH of crushed raw broccoli was 7.0, while L^* component of colour was 39.4, a^* component of colour was –10.4 and b^* component of colour was 20.1. It was washed in cold water and divided into florets of regular shape and size, weighing 40 g ± 5 g. Half of the analysed samples of vegetables was soaked in 1% calcium chloride solution (pH 9.5) for 120 s prior to blanching. The low-temperature blanching (LTB) was applied at following temperatures: 50 °C (code: s50), 60 °C (code: s60), 70 °C (code: s70) or 80 °C (code: s80), for following periods: 5 min (code: s1), 10 min (code: s2) or 15 min (code: s3). Afterwards, all samples were subjected to conventional blanching at 97 °C for 3 min, followed by immediate cooling by immersion in iced water for 2 min. The control sample (s0 sample) was blanched at 97 °C for 3 min and cooled by immersion in iced water for 2 min.

The samples of broccoli were packaged into commercial polymeric bags and cooled in blast freezer Küppersbusch KCT 110 (Küppersbusch Großküchentechnik, Gelsenkirchen, Germany) to the temperature of –18 °C ± 0.5 °C with an average freezing rate of 0.5 °C per min. The samples were stored under constant freezing conditions (–24 °C ± 0.5 °C) for two weeks and afterwards heated in convection oven Küppersbusch CPE 110 (Küppersbusch Großküchentechnik) under full steam conditions. The period of thermal treatment was determined on the basis of preliminary sensory analysis and was individualized to obtain optimum texture for each broccoli sample. It varied from 4 min (for s3_80 sample) to 15 min (for s0 sample), as a result of different time and temperature of LTB process.

Measurement of components of colour of broccoli florets, with no previous grinding or cutting, was conducted in $L^*a^*b^*$ system using chromameter Minolta CR 310 (Minolta Camera, Osaka, Japan). The measurement was performed under standard conditions, in the middle section of each broccoli floret, with the measuring head positioned 50 mm from the measuring area, wide-area illumination and 0° viewing angle. Sensory analysis was conducted at Faculty of Human Nutrition and Consumer Sciences, Warsaw, Poland.

Colour measurements

The colour of broccoli after thermal treatment (LTB followed by conventional blanching and cooling) was measured using a Hunter Lab chromometer Minolta CR 310 (Minolta Camera) at a controlled constant temperature of 23 °C inside the sample. For each sample, average of 10 measurements was calculated. The chromometer was previously calibrated against a standard white reference tile (L^* = 7.75, a^* = –0.08, b^* = 1.77). The L^* (lightness), a^* (bluish-green/red-purple hue component) and b^* (yellow/blue hue component) values were collected for all of the samples. It is known that the combination of colour components may be more effective to evaluate the overall colour change of processed vegetables than the individual L^*, a^*, b^* components [19], so the colour change (ΔE), metric chroma (C^*) and hue angle ($h°$) were calculated on the basis of a widely accepted methodology [20, 21]:

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

(calculated against s0 sample)

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

$$h° = \tan^{-1}\frac{b^*}{a^*} \quad (3)$$

and when $a^* < 0$,

$$h° = 180 + \tan^{-1}\frac{b^*}{a^*} \quad (4)$$

Sensory analysis

Attractiveness of colour and global attractiveness of analysed samples of broccoli after LTB followed by conventional blanching and cooling, were evaluated by sensory analysis, a randomized test with 2 repetitions. The panel consisted of 30 members (15 female, 15 male, aged 20–55). Sensory analysis was conducted at Faculty of Human Nutrition and Consumer Sciences, Warsaw, Poland. Sensory properties were assessed using 10-point descriptive scale, converted afterwards for statistical analysis to a 1–10 numerical scale, with 1 = not attractive and 10 = most attractive, according to the widely accepted methodology [22–26].

Statistical analysis

In order to characterize the relationship between the analysed factors, two way ANOVA and post-hoc tests (HSD-Tukey test) were conducted with soaking in 1% calcium chloride solution and temperature or time as conditions. Levels of significance $p \leq 0.05$ and $p \leq 0.1$ were used. Statistical analysis was conducted using Statistica software version 8.0 (StatSoft, Tulsa, Oklahoma, USA).

RESULTS AND DISCUSSION

Heating has different effects on colour of all vegetables, depending on the type of vegetable and the cooking method involved [27]. Presented analysis of thermal treatment is associated with temperature and time of treatment as well as influence of soaking in 1% calcium chloride solution prior to the LTB process.

Analysis of influence of soaking in 1% calcium chloride solution and temperature of the LTB process

The analysis of influence of soaking in 1% calcium chloride solution and temperature of LTB process on the components of colour and sensory features of broccoli revealed that soaking in 1% calcium chloride solution was the most important factor. Soaking in calcium chloride solution had significant influence on the a^*, b^*, C^* and $h°$ values, as well as on global attractiveness and attractiveness of colour ($p < 0.05$) in the sensory analysis. Simultaneously, temperature had significant influence on the a^* component, global attractiveness and attractiveness of colour ($p < 0.05$) as well as, close to significance ($p = 0.05$), on the L^* component of colour. The effect of the interaction between soaking in 1% calcium chloride solution and temperature was observed in case of the L^*, a^* and b^* components of colour ($p < 0.05$) of broccoli. Tab. 1 presents the results of colour components and sensory features in post-hoc statistical analysis for broccoli samples, with soaking in 1% calcium chloride solution and temperature as conditions.

The influence of the analysed factors, soaking in 1% calcium chloride solution and temperature, on the L^* component of broccoli colour was not substantial and the significant difference was observed only between s0 and s50_b. Similar situation was observed by other researchers in case of the L^* component of colour, when analysing the influence of the LTB process (50 °C) on qualitative features of lettuce [28]. The results of the conducted analysis are also confirmed by results of other studies, indicating incipient brightening of the green colour during pre-heating conducted at a low temperature. However, without pre-heating, in case of s0, the mentioned pattern does not develop [29].

The conditions of the applied process strongly influenced the a^* component of colour. Calcium chloride was associated with lower values of the a^* component of colour. The a^* component of colour of s80 sample after calcium chloride soaking was similar as in case of raw broccoli. It is known from kinetic studies that 2% sodium chloride stabilizes the green colour from degradation resulting from heat treatment, but the exact mechanism of stabilization is unknown [15].

Temperature of the applied technological process influenced significantly the b^* component of colour only in case of samples subjected to the LTB process with no calcium chloride soaking. The b^* component of colour of s0 sample was the most similar as in case of raw broccoli. Simultaneously, calcium chloride soaking had no influence on the b^* component of colour in case of samples subjected to the LTB process at a temperature of 60 °C. Similar observations were reported by Quintero-Ramos et al. [8] at optimization of low-temperature blanching of green Jalapeño. The authors concluded that the temperature of blanching had an effect, while all other factors had no effect on the b^* values. However, it may be generally concluded that the influence of temperature on the b^* component of colour is minor, in comparison with the influence on other components [30]. Although a general influence of soaking in calcium chloride on the $h°$ and C^* values was observed, no differences between individual samples were observed not only in case of the ΔE, but also $h°$ and C^* values.

The results of sensory analysis revealed significant differences between the samples after the process. In case of the attractiveness of colour of

Tab. 1. Components of colour and sensory features for broccoli samples – two way ANOVA with soaking in 1% calcium chloride solution and temperature of LTB process as conditions.

Sample code	Soaking in 1% calcium chloride solution	Temperature [°C]	$L^*a^*b^*$ colour measurement						Sensory analysis – attractiveness	
			L^*	a^*	b^*	ΔE	$h°$	C^*	Global	Colour
s0	–	97	37.4 ± 0.34^{a}	–8.2 ± 0.38^{bcd}	22.4 ± 0.50^{a}	–	180.4 ± 2.75^{a}	23.8 ± 0.51^{a}	5.0^{ab}	6.0^{abc}
s50	+	50	38.3 ± 1.34^{a}	–12.2 ± 1.33^{e}	23.4 ± 1.01^{a}	4.5^{a}	180.5 ± 2.68^{a}	24.3 ± 1.08^{a}	6.5^{bc}	7.1^{c}
s60	+	60	38.5 ± 2.31^{a}	–9.7 ± 1.25^{abc}	23.4 ± 1.71^{a}	3.2^{a}	182.2 ± 1.37^{a}	26.3 ± 1.27^{a}	7.2^{c}	6.7^{bc}
s70	+	70	37.9 ± 1.66^{a}	–8.2 ± 2.36^{bcd}	22.4 ± 1.40^{a}	4.0^{a}	182.9 ± 2.14^{a}	25.4 ± 1.98^{a}	4.9^{ab}	5.4^{abc}
s80	+	80	40.0 ± 2.45^{ab}	–10.4 ± 1.24^{ae}	23.4 ± 1.57^{a}	3.0^{a}	181.1 ± 1.18^{a}	25.4 ± 1.63^{a}	5.0^{ab}	4.8^{a}
s50_b	–	50	41.3 ± 2.18^{b}	–10.1 ± 1.97^{abe}	26.3 ± 1.49^{c}	5.2^{a}	180.0 ± 1.49^{a}	27.0 ± 1.49^{a}	5.4^{abc}	6.0^{abc}
s60_b	–	60	39.0 ± 2.55^{ab}	–7.1 ± 1.00^{d}	24.3 ± 1.11^{ab}	4.1^{a}	180.2 ± 0.95^{a}	27.5 ± 1.14^{a}	5.3^{abc}	5.1^{ab}
s70_b	–	70	38.3 ± 0.93^{a}	–8.7 ± 0.84^{abcd}	26.4 ± 1.34^{c}	3.9^{a}	180.0 ± 0.40^{a}	27.0 ± 1.48^{a}	3.9^{a}	4.5^{a}
s80_b	–	80	38.6 ± 0.96^{ab}	–7.8 ± 0.51^{cd}	25.6 ± 0.95^{bc}	3.8^{a}	180.1 ± 0.51^{a}	27.0 ± 0.90^{a}	4.0^{a}	4.4^{a}
p (two way ANOVA)			0.0105	0.0037	0.0116	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1

Mean values marked with different letters in columns differ significantly on the basis of post-hoc Tukey test criteria for $p \leq 0.05$.

Tab. 2. Components of colour and sensory features for broccoli samples – two way ANOVA with soaking in 1% calcium chloride solution and time of LTB process as conditions.

Sample code	Soaking in 1% calcium chloride solution	Time [min]	$L^*a^*b^*$ colour measurement						Sensory analysis – attractiveness	
			L^*	a^*	b^*	ΔE	$h°$	C^*	Global	Colour
s0	–	3	37.4 ± 0.34^{a}	–8.2 ± 0.38^{a}	22.4 ± 0.50^{a}	–	180.4 ± 2.75^{a}	23.8 ± 0.51^{a}	5.0^{a}	6.0^{a}
s1	+	5	37.7 ± 1.77^{a}	–10.9 ± 0.66^{b}	22.6 ± 1.18^{a}	4.2^{a}	183.4 ± 0.71^{ab}	25.8 ± 1.20^{a}	5.4^{a}	6.0^{a}
s2	+	10	39.1 ± 0.95^{ab}	–10.3 ± 1.86^{ab}	23.4 ± 0.88^{a}	3.2^{a}	180.8 ± 2.01^{ab}	25.6 ± 1.36^{a}	6.5^{a}	6.4^{a}
s3	+	15	39.2 ± 2.80^{ab}	–9.3 ± 3.02^{ab}	23.5 ± 2.01^{a}	3.7^{a}	180.8 ± 3.92^{ab}	24.6 ± 2.45^{a}	5.7^{a}	5.6^{a}
s1_b	–	5	39.0 ± 1.17^{ab}	–8.1 ± 0.50^{a}	25.2 ± 1.02^{b}	5.6^{a}	180.6 ± 0.56^{a}	28.0 ± 0.93^{a}	4.4^{a}	5.2^{a}
s2_b	–	10	40.6 ± 2.05^{b}	–9.1 ± 2.40^{ab}	26.2 ± 1.44^{b}	3.7^{a}	179.8 ± 1.42^{a}	26.1 ± 2.12^{a}	5.1^{a}	5.1^{a}
s3_b	–	15	38.3 ± 2.36^{ab}	–8.2 ± 1.36^{a}	25.5 ± 1.75^{b}	3.4^{a}	179.9 ± 0.92^{a}	27.3 ± 1.97^{a}	4.5^{a}	4.7^{a}
p (two way ANOVA)			0.0736	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1

Mean values marked with different letters in columns differ significantly on the basis of post-hoc Tukey test criteria for $p \leq 0.05$

samples not soaked in calcium chloride, no temperature-dependent differences were observed. On the other hand, for samples soaked in calcium chloride, higher temperature was associated with lower attractiveness of colour. It may be concluded that calcium chloride soaking is a factor, which protects colour from changes during thermal process. Other authors also proved that soaking in calcium lactate had a significant effect on all components of colour, making samples greener and more attractive [28].

As colour is a very important factor for consumers, mentioned relations are observed also for global attractiveness of broccoli samples. The most attractive were samples after the LTB process at temperatures of 50 °C and 60 °C, in particular if soaked previously in calcium chloride solution. The fact that the colour of the samples influenced significantly the global attractiveness of broccoli may be associated with influence of thermal treatment on the a^* component of colour. The samples after the LTB process at temperatures of 50–60 °C, after calcium chloride soaking, were characterized by lower values of the a^* than the s0 sample (greener colour), in particular in case of s50 sample. This difference was so substantial that sensory analysis was able to indicate significant differences between samples (in particular s0 and s60). As a consequence, the colour of samples after thermal treatment at temperatures of 50–60 °C, after calcium chloride soaking, was perceived as better than in case of other samples. On the other hand, loss of the green colour is mainly attributed to chlorophyll to pheophytin transformation at a temperature of 80 °C [14].

Majority of researchers conclude that during thermal treatment of green vegetables, a decline in green colour intensity is observed, which is attributed to the mentioned chlorophyll-to-pheophytin transformation [8]. It is caused by the application of high temperature and removal of the central atom of magnesium from porphyrin. Prolonging the thermal treatment causes further degradation of chlorophyll and generation of pyropheophytin. Described changes are associated with colour transformation from green to olivaceous [13–16].

Simultaneously, increase in green colour intensity was reported to be observed during pre-treatment LTB heating (50–60 °C) [18, 29]. However, during pre-treatment LTB heating at higher temperatures in the beginning of the process, an increase in the intensity of green colour was also observed in case of watercress [31] and leaves of oregano [32].

It may be concluded that the technological process applied in case of s60 sample improved the quality, in particular the colour. At sensory analysis, samples blanched at higher temperatures were characterized by lower grades of colour and, as a consequence, by lower grades of global attractiveness. The influence of colour on the global attractiveness of broccoli in sensory analysis was confirmed also by analysis of other sensory features (not presented in the article).

Analysis of influence of soaking in 1% calcium chloride solution and time of LTB process

The analysis of influence of soaking in 1% calcium chloride solution and time of LTB process on the components of colour and sensory features of broccoli revealed that soaking in 1% calcium chloride solution was a major factor, similarly to results of the above mentioned analysis of soaking and temperature of process. Soaking in calcium chloride solution had a significant influence on the a^*, b^*, C^* and $h°$ values, as well as on global attractiveness and attractiveness of colour ($p < 0.05$) in sensory analysis, i.e. on the same parameters as in previous analyses. Simultaneously, time had a significant influence ($p < 0.05$) on the L^* component of colour and the $h°$ value of broccoli samples. The effect of interaction between soaking in 1% calcium chloride solution and time was close to significance in case of the L^* component of colour ($p = 0.07$). Results of post-hoc statistical analysis of components of colour and sensory features of broccoli samples, with soaking in 1% calcium chloride solution and time as conditions, are presented in Tab. 2.

The influence of soaking in 1% calcium chloride solution and time on the L^* component of broccoli colour was not substantial and a significant difference was observed only between s0 and s2_b. Simultaneously, the L^* component of colour of s3 sample after calcium chloride soaking was most similar to raw broccoli. Also other authors proved, in studies on optimization of low-temperature blanching of green Jalapeño, that time of blanching had no significant effect on the L^* component of colour [8].

Analysis of the influence of time of the LTB process and soaking in calcium chloride on the a^* component of colour did not reveal any statistically significant differences between the majority of samples. Individual differences were observed only between s1 and s0, s1_b as well as s3_b samples. It may be concluded that the influence of soaking in calcium chloride was observed only in case of samples after 5 min of thermal treatment, which had lower values of the a^* component of colour indicating a greener colour of vegetables. The lower values of the a^* component of colour were also observed by other authors in case of green beans [14] and watercress [31] blanched during shorter periods of time or at lower temperatures.

The analysis confirmed also a substantial influence of exposure to calcium chloride on the b^* component of colour. The value of the mentioned component of colour was always higher in case of samples after soaking in calcium chloride. SAFTNER et al. also demonstrated that thermal treatment combined with exposition to calcium inhibited colour changes in honeydew chunks [33].

The post-hoc statistical analysis of components of colour and sensory features of broccoli samples, with soaking in 1% calcium chloride solution and time as conditions, revealed no statistically significant differences between individual samples of the ΔE, $h°$ and C^* values, as well as between attractiveness of colour and global attractiveness. It may be associated with a minor influence of time of thermal treatment, in comparison with temperature and soaking in 1% calcium chloride solution.

To summarize, blanching applied in case of green vegetables is responsible for deactivation of chlorophyllase and other enzymes, which prevents texture and colour from deterioration [5, 17]. LTB is applied before conventional blanching mainly to improve the texture of vegetables [34] but, in case of green vegetables, choice of thermal treatment parameters must also guarantee maintenance of the characteristic green colour, which is attractive for consumers. Changes in colour of green vegetables into olivaceous or even yellow, is perceived by consumers as the indicator of lower quality of such vegetables [5, 35]. Consumers treat the mentioned colours as non-specific and do not accept it, so the possibility of maintaining an attractive, green colour of broccoli by means of LTB process conditions has a measurable value for the food industry. As it was concluded from the conducted research, and as other authors suggest [18, 29], LTB process applied at temperatures of 50–60 °C, may cause an increase in green colour intensity. Prolonged heating of green vegetables causes also degradation of chlorophyll pigments, which leads to a colour change from green to olivaceous, as it was shown in the conducted research and in the research of other authors [8, 29]. The influence of pH on colour changes is also important. Chlorophyll, being more stable at higher than at lower pH [36], is changing into pheophytin in particular at a lower pH. Preliminary soaking in a calcium chloride solution, applied to stabilize the structure of the cell wall [37], may simultaneously contribute to attainment of a more attractive colour based on pH changes.

CONCLUSIONS

Results of the presented research allow us to conclude that temperature and time of the low-temperature blanching process, applied before further stages of technological processing, may exert positive influence on colour of broccoli (measured instrumentally and evaluated by sensory analysis) and as a consequence, on the global attractiveness. Applied technology of low-temperature blanching at temperatures of 50–60 °C for 10 min, with or without exposure to calcium ions, facilitates achieving the most attractive colour of broccoli. Simultaneously, soaking in 1% calcium chloride solution before low-temperature blanching results in a colour that is more attractive to consumers than that obtained when using the conventional technology.

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