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STABILIZATION OF THE NATURAL COLOR OF SWEET PEPPER (CAPSICUM ANNUUM L.) DURING ITS PROCESSING

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Досліджено вплив різних параметрів технологічної обробки на ступінь руйнування хлорофілів і зміну зеленого кольору перцю солодкого (Capsicum annuum L.). Установлено, що температура та тривалість її дії на перець солодкий під час первинної теплової обробки перетворюють його природний зелений колір на жовтий з коричневим відтінком. Представлено експериментальні спектри інтенсивності світлопоглинання зразків перцю солодкого, які дозволяють встановити закономірності впливу часу та температури на колір і ступінь руйнування хлорофілів.

Під час бланшування руйнується від 25,2 до 59,2 % загальної кількості хлорофілів від вихідного значення залежно від температури води. Установлено, що тривалість процесу бланшування також негативно впливає на вміст хлорофілів: залежно від часу протікання процесу руйнується 20,2–61,7 % від вихідного вмісту. Наведені експериментальні спектри дифузного відбиття для непрозорих об'єктів дозволили визначити залежність кольору оброблених у відварі Xanthium strumarium зразків перцю від різних чинників технологічного процесу.

Показано, що використання відвару натуральної рослинної сировини Xanthium strumarium для обробки зразків призводить до стабілізації зеленого кольору перцю у порівнянні із бланшованих у воді. Досліджено вплив концентрації Xanthium strumarium, температури та часу витримки у відварі на колір зразків перцю. Використання розрахованих на основі отриманих спектральних коефіцієнтів відбиття за методом CIE XYZ кольоропараметричних характеристик – домінуюча довжина хвилі (λ, нм), чистота кольору (P, %), яскравість (T, %) – дозволили провести порівняльну оцінку кольору дослідних зразків перцю у порівнянні із свіжими зразками (контроль-1), а також із зразками, бланшованими у воді (контроль-2).

Проведений багатофакторний експеримент дозволив провести оптимізацію параметрів технологічної обробки зразків перцю у відварі Xanthium strumarium. Основними параметрами обробки перцю солодкого є 1 % відвар Xanthium strumarium, температура обробки – 75 °C, тривалість обробки – 15 хв.

Ключові слова: перець солодкий, технологічна обробка, стабілізація пігментів, кольоропараметрічні характеристики

1. Introduction

Among the vegetable plants that make up the diet of humans, pepper occupies one of the main places as its fruits possess not only the high taste, dietary and nutrient properties, but they are also distinguished by the elevated content of vitamins and other bioactive substances (BAS). The content of ascorbic acid in green pepper is 150...180 mg %, in mature fruits is 300...480 mg %. Sweet pepper is also a supplier of low-molecular phenolic compounds for the human body (flavanols, catechins, anthocyanins, etc.), which have a P-vitamin effect. Sweet pepper is also characterized by the high content of carotenoids – up to 12 mg %. In terms of the content of vitamins B, sweet pepper is ranked high among vegetables. It contains vitamin B_1 contains in the amount of 60 mg %, B_2 – 30 mg %, B_9 – 17 mg %. Pepper is very rich in potassium salts (about 50 % of the total amount of all ash), it also contains sodium salts (13...16 % of all ash), calcium, magnesium, iron (16 % of all ash), aluminum, phosphorus, sulphur, chlorine, silicon, manganese, copper, zinc, fluoride, and iodine. All specified components are important in human nutrition [1].

The color of sweet pepper depends on the content and ratio of natural coloring substances. Green color is predetermined by the dominant amount of chlorophylls *a* and *b*, while yellow and red – by the total amount and ratio of individual carotenoids.

The green color of pepper easily changes into unattractive gray-green with a brown tint under the influence of many factors.

Researchers are looking for possible ways to improve the color characteristics of tinned products made from plant raw materials. However, there is no any generally accepted technique because color is, first, formed by the composition of the pigment complex of starting raw materials. A change in the pigment complex is significantly affected by technological operations – various types of mechanical and thermal treatment. In addition, color is formed through the use of food additives which have a protective effect against color, or by adding natural or artificial colorants for color correction. However, the use of many substances is very dangerous for human health, so there is a need to control their content in food products. Certain techniques are difficult to implement and require the re-equipment of production with questionable efficiency of many techniques.

Therefore, it is a relevant task to search for new, effective and safe methods to stabilize green coloration of pepper that would make it possible to extend the range of high-quality and healthy food products, which will always have benefits for consumers.

2. Literature review and problem statement

Much research addresses determining the techniques for treating sweet pepper, predominantly red, since carotenoids are more resistant during treatment to the effects of light, temperature, pH of the medium [2–4]. Much less research tackles determining the content of chlorophylls in plant raw materials and their conversion in processed products. Thus, paper [5] reports results of research into different canned foods made of green vegetables. It was shown that they revealed pheophytins, pheophorbides and other derivatives of chlorophylls.

This is explained by the fact that under the action of mineral acids, even very weak, there is a cleavage of Mg^{2+} from the chlorophylls *a* and *b* with the formation of the corresponding derivatives – pheophytins *a* and *b*. That negatively influences the coloration, which changes from bright green into gray-green (olive).

It was established that the improvement of coloration of certain products involved food dyes, derived from chlorophyll, such as Cu-chlorophyllin, Cu-pheophytins, Cu-pheophorbides, and others.

In addition, high temperatures and the duration of exposure to them, oxygen of the air, lead to the transformation of chlorophylls with the formation of dark-stained compounds that irrevocably changes the original coloration of plant raw materials. Studies into the influence of microwave treatment (1,000 W over 340 s) and traditional pasteurization (97 °C over 30 s) of kiwi-based puree on both the total amount of carotenoids and chlorophylls and the individual compounds have shown that both heat treatment techniques resulted in a noticeable loss of chlorophylls (from 42 to 100 %) and carotenoids (from 62 to 91 %) [6]. Thus, there remains the unresolved issue of retaining chlorophylls and color of the puree.

Paper [7] reports results of the combined convection, microwave, and infrared drying of green pepper. The experiments have shown that convection drying using both microwave and infrared radiation significantly reduced the duration of drying, and made it possible to better save the content of vitamin C, to improve color of the product. However, this preparation technique can be applied only for powdered products.

The authors of [8] examined various types of heat treatment of crushed fruits of green pepper and their influence on the total content of chlorophyll and coloration based on the system L*, a*, b*. It was established that following the heat treatment the total amount of chlorophyll ranged from 4.44±0.04 to 2.61±0.04 mg per 100 g of pepper, and the color of the green pepper's surface did not depend on various preparation methods assessed in a given study.

Chlorophylls not only affect the basic properties of food stuffs with their color, but also improve the nutritional value, form a physiological value, treatment-and-prophylactic properties of the product. Interest in chlorophylls may be explained by the fact that they provide the necessary activity of anti-oxidant system – the universal regulating system of the human body that controls the level of free-radical reactions of oxidation and prevents the accumulation of toxic products. The confirmation of this is the studies that established, based on the results of conducted experiments, that an extract of chlorophyll from the microalgae Phormidium autumnale is a powerful absorber of peroxide radicals, which is almost 200 times more effective than α-tocopherol [9].

Also known are the antimutagenic, antimicrobial, antioxidant properties of chlorophylls. The Japanese scientists found that the linear derivatives of chlorophyll (phycobilin), presented mostly in fruits, have significant advantages over other anti-oxidants. The metabolites of chlorophyll in yellow Japanese plums exhibit antioxidant properties, which significantly improves the antioxidant potential of these fruits along with phenolic compounds, carotenoids, vitamins C, PP, etc. [10].

An analysis of the scientific literature has revealed that when processing raw materials there occurs the transformation of chlorophylls with the participation of various factors. It was established that there is no any universal method for preventing the destruction of chlorophylls and original color of raw materials. Therefore, it is necessary to search for the new techniques taking into consideration the characteristics of raw materials, the influence of external factors on the activity of the progress of different processes during treatment.

3. The aim and objectives of the study

The study that we conducted set the aim to determine the influence of parameters of technological treatment on the degree of destruction of chlorophylls and on a change in the coloration of sweet pepper.

To accomplish the aim, the following tasks have been set:

– to determine the effect of temperature and duration of blanching on the degree of destruction of chlorophylls in green pepper;

– to determine the impact of treatment of samples of pepper in the Xanthium strumarium decoction on the stabilization of their color;

– to define technological parameters for treating pepper using the color-parametric characteristics.

4. Materials and methods of research

The object of our study was sweet pepper (Capsicum annuum L.) of green color. The degree of chlorophyll destruction under the influence of temperature and blanching duration was determined by measuring the light absorption by extracts of the pigment complex, obtained from the samples of sweet pepper after blanching. To this end, a batch of the sample was ground in a mortar with 5 ml of organic solvent in the presence of quartz sand and $MgCO_3$ to prevent chlorophyll destruction. Next, the mixture was taken to a glass filter that was washed until the complete removal of the pigments. The measured extracts were taken to a measuring flask to 50 cm^3; the volume of the extract was led to the mark with a solvent.

The intensity of light absorption was filmed using SF-2000 at 662 nm. The total content of chlorophylls was calculated from a formula. The degree of chlorophyll destruction in the experimental samples was determined relative to a sample of fresh pepper.

In order to determine the stabilizing action of the natural Xanthium strumarium raw material on color of sweet pepper, we prepared a decoction at different ratio of Xanthium strumarium:water (0.5:99.5; 1:99; 2:98; 3:97; 4:96). It was exposed to heat treatment at a temperature of 96–98 °C over 20 minutes. The decoction was aged, cooled to a temperature of 18 °C; Xanthium strumarium was removed from the decoction. Pepper was crushed, aged in the decoction at different temperatures and duration. The diffuse reflection coefficients of the treated samples were measured using the spectrophotometer Techkon SP-810 in the range of 400...700 nm in a step of 10 nm and over 20 cycles of accumulation; upon finishing the measurement, by using the integrated software SFScan, we determined color characteristics of the examined samples in the system CIE XYZ. This model is the closest to the senses of an actual observer.

By using the software SFScan, we determined the integral color coordinates X, Y, Z. The coordinates of color are conditionally expressed in relative units of the system CIE XYZ; they are dimensionless. Based on the data acquired, we calculated coordinates of coloration (x, y), which make it possible to define the parameters of “a dominant wavelength” in nm, “brightness” in %, “color purity” in %.

All experiments were repeated five times. The research results were processed using the methods of mathematical statistics and a correlation analysis on a PC employing the software Microsoft Word, Microsoft Excel, and MathCad.

5. Results of studying the influence of parameters of technological treatment on the overall content of chlorophylls and color of sweet pepper

5. 1. Determining the influence of temperature and blanching duration on the degree of chlorophyll destruction in green pepper

Among the large number of possible techniques of thermal culinary treatment, in this study we have selected the blanching, since the losses of chlorophyll at such a technique of thermal culinary treatment are minimal.

One of the important factors in the technological processing of pepper is the temperature of blanching. We also examined the influence of duration of the specified process. The blanching was conducted in water at different temperatures over 10 minutes. Next, we acquired the spectra of light absorption by the extracts of pigment complex, obtained from samples, in the visible light range of 400–700 nm. We have selected fresh green sweet pepper as control (Fig. 1).

The resulting curve for fresh pepper (Fig. 1, curve 1) demonstrates the absorption in the red region of the spectrum (600...700 nm), intensive light absorption at the border between the UV and visible regions (400...500 nm), minimum light absorption in the range of 500...600 nm. Intensive light absorption in the range of 400...500 nm belongs to the chlorophyll-characteristic tetrapyrrole macrocycle and is identified as the Sauret strip at 430.2 nm of chlorophyll *a* and at 455.0 of chlorophyll *b*. The width of the strip of absorption (~100 nm) and a shoulder in the direction of growth in the wavelength indicates the presence of substances in the extract that also absorb in this range.

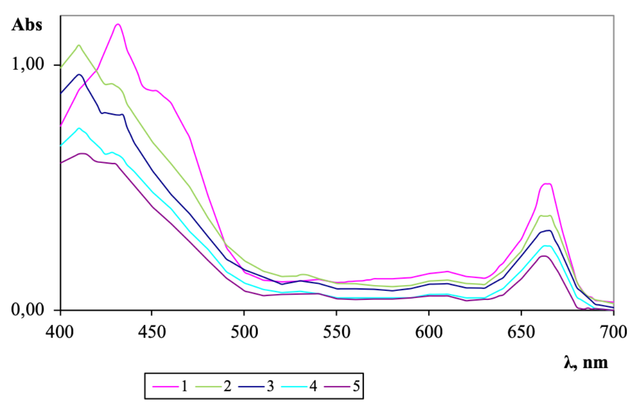

Fig. 1. Light absorption by extracts of pigment complex of sweet pepper sweet at a blanching temperature of: 1 – control: fresh pepper, 2 – 70 °C, 3 – 80 °C, 4 – 90 °C, 5 – 100 °C

The light absorption band in the range of 650...700 nm for all extracts are almost the same, the only difference being the intensity at λ_{max}. However, the character of the second, more intense, band of light absorption in the short-wave region of spectrum is different for the specified extracts.

The results obtained have shown that during blanching at a temperature of 70 °C there is the destruction of 25.2 %, at 80 °C – 37.3 %, at 90 °C – 48.9 %, at 100 °C – 59.2 %, of the total content of chlorophylls in the samples. We visually observed a change in the color of pepper samples depending on the degree of destruction of the total chlorophyll: from rich green to light yellow-green.

Studying the influence of blanching duration at a temperature of 70 °C on preserving the overall content of chlorophylls has revealed that during blanching over 5 minutes there is the destruction of 20.2 %, over 10 min. – 25.0 %, 15 min. – 38.8 %, 20 min. – 50.1 %, 25 min. – 61.7 %, of the starting content (Fig. 2).

Visually, there is a change in the color of pepper samples from rich green to light yellow-green with a brown tint depending on the time of heating.

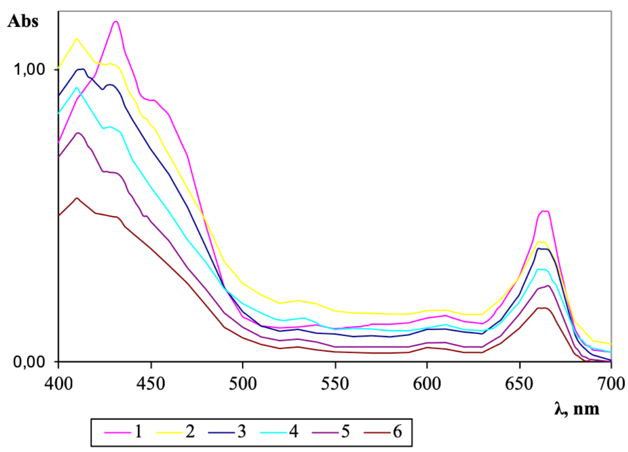

Fig. 2. Light absorption by extracts of pigment complex of sweet pepper at 70 °C over: 1 – control: fresh peppers, 2 – 5 min., 3 – 10 min., 4 – 15 min., 5 – 20 min., 6 – 25 min.

5. 2. Determining the influence of treating pepper samples with Xanthium strumarium on the stabilization of their color

To preserve the color of green pepper, we selected Xanthium strumarium, which was poured over with water, exposed to heat treatment at a temperature of 96–98 °C for 20 minutes. The decoction was cooled to a temperature of 18 °C; Xanthium strumarium was then removed. The decoction was used for blanching the green pepper.

To determine the optimal treatment conditions for preserving the color of green pepper, we performed a multi-factor experiment. The variables chosen were the concentration of Xanthium strumarium, temperature, and duration of treatment. The chosen criterion for treatment efficiency was the color characteristics of samples that were determined using the spectral coefficients of diffuse reflection. To this end, the samples of pepper were exposed to treatment, followed by the acquisition of reflection spectra.

At the first stage, we examined the effect of concentration (0.5–4 %) of Xanthium strumarium on the color of green pepper, which was aged at 90 °C over 20 minutes. Control-1 was fresh green sweet pepper; control-2 was green sweet pepper, treated in water under the same conditions.

The determined spectral characteristics demonstrated that curve 1 (fresh pepper of saturated green color) is different from others by low coefficients of reflection, whose maximum values are in the range of 430–500 nm (Fig. 3). This range characterizes the green component of the color of light. Other curves are almost of the same shape but different in the magnitude of reflection coefficients, whose maximum is in the range of 490–530 nm, which characterizes the green component of the color of light. Thus, during treatment there is an increase in the wavelength.

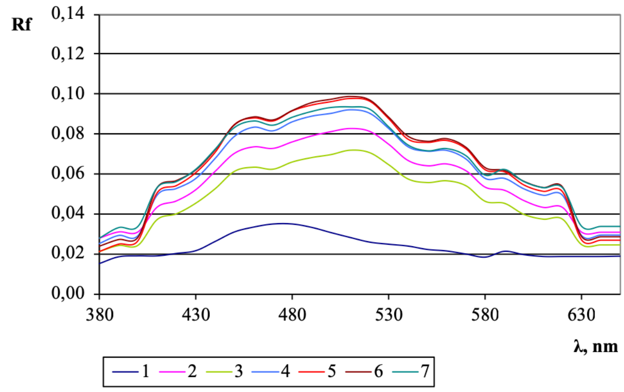

Fig. 3. Reflection spectra of pepper samples, aged in the Xanthium strumarium decoction of varying concentration, over 20 minutes at a temperature of 90 °C: 1 – control-1, 2 – 3 %, 3 – 1 %, 4 – 0.5 %, 5 – 2 %, 6 – control-2, 7 – 4 %

At the second stage, we examined the effect of temperature on the color of samples of pepper. In addition, we acquired the reflection spectra of pepper samples, treated at different temperatures (75–95 °C) with Xanthium strumarium over 20 minutes (Fig. 4).

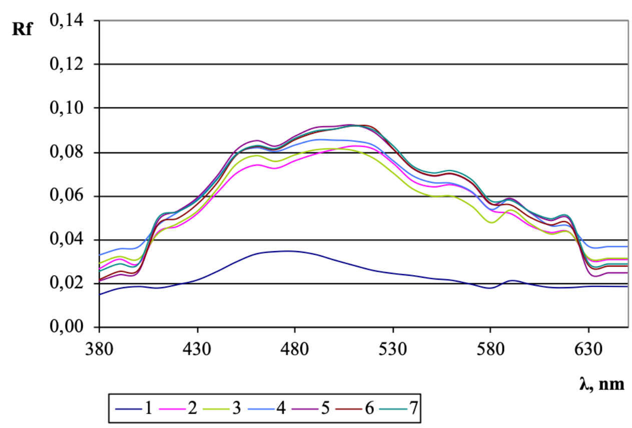

Fig. 4. Reflection spectra of samples of pepper, aged in a 1 % decoction of Xanthium strumarium over 20 minutes at a temperature of: 1 – control-1, 2 – 80 °C, 3 – 70 °C, 4 – 75 °C, 5 – control-2, 6 – 85 °C, 7 – 90 °C

The obtained spectral characteristics showed the same shape of curves for the treated samples as opposed to a sample of fresh pepper with saturated green color (Fig. 4, curve 1). Coefficients of reflection increased almost three times compared to control-1, a maximum of the reflection is also in the range of 480–530 nm.

At the next stage, we determined the effect of treatment duration on the color of pepper samples. The reflection spectra of samples, aged in the Xanthium strumarium decoction with a concentration of 1 % at a temperature of 70 °C over a period of certain time (from 5 to 25 minutes), are shown in Fig. 5.

The spectral characteristics also showed the same shape of curves for the treated samples as opposed to a sample of fresh pepper (Fig. 5, curve 1). However, the reflection coefficients are different in magnitude; a maximum of reflection is also in the range of 480–530 nm.

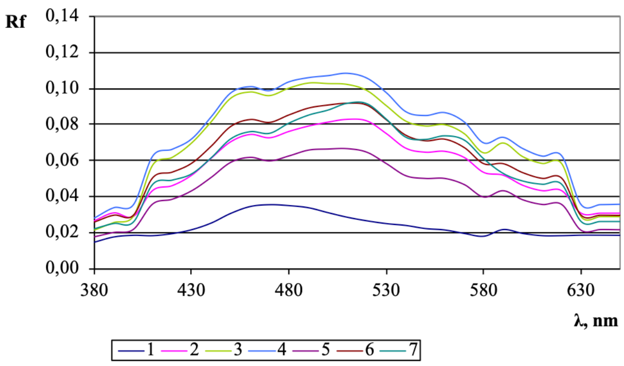

Fig. 5. Reflection spectra of samples of pepper, aged in a 1 % decoction of Xanthium strumarium at a temperature of 70 °C over: 1 — control-1, 2 —10 min., 3 — 15 min., 4 — control-2, 5 — 5 min., 6 — 20 min., 7 – 25 min.

5. 3. Determining the technological parameters for treating pepper using the color-parametric characteristics

Based on the acquired reflection spectra, we calculated color characteristics of the examined samples using the method CIE XYZ (Table 1).

Table 1

Effect of treatment parameters of sweet pepper on its color-parametric characteristics in the CIE XYZ system

Sample	Treatment parameters			Color-parametric characteristics		
	Concentration of Xanthium strumarium in decoction, %	Treatment duration, min.	Treatment temperature, °C	Dominant wavelength, nm	Color purity, %	Brightness, %
Control-1	–	–	–	515	39.41	25.71
Control-2	–	–	–	560	44.13	51.57
Treated pepper	0.5	20	90	553	41.27	36.73
	1.0	20	90	552	44.73	39.72
	2.0	20	90	553	40.24	37.08
	3.0	20	90	550	41.17	38.02
	4.0	20	90	551	45.00	35.04
	1.0	20	70	530	76.52	30.68
	1.0	20	75	535	73.63	31.89
	1.0	20	80	531	48.54	34.89
	1.0	20	85	537	48.69	35.81
	1.0	20	90	552	44.73	39.72
	1.0	5	70	529	73.16	31.75
	1.0	10	70	533	77.23	33.71
	1.0	15	70	537	61.42	33.01
	1.0	20	70	530	76.52	30.68

For the sample of fresh pepper, the dominant wavelength is 515 nm, it is in the blue-green region of visible light. The low value of the parameter "brightness", which is 25.71 %, indicates the color saturation of the sample.

As shown by results, aging the samples of pepper in the Xanthium strumarium decoctions of varying concentration at a temperature of 90 °C over 20 minutes did not essentially affect the stabilization of color. The dominant wavelength grows to 550–553 nm, which characterizes the yellow-green component of the color of light. Purity of the color ranges within 40.2–45.0 %, the brightness of samples, compared with fresh pepper (control-1), increases to 35.04–38.02 %, which indicates the clarification of the samples.

Reducing the temperature from 90 °C to 70 °C decreases the growth of the dominant wavelength to 530–535 nm, which characterizes the green component of the color of light. The "brightness" parameter also gradually decreases; in this case, the purity of color case increases from 44.73 % to 76.52 %.

The duration of sample treatment at a temperature of 70 °C also has a positive effect on the specified parameters: the value for a dominant wavelength indicates that the spectral color of samples remains in the green region of light. An increase in the duration of sample treatment leads to a decrease in the parameter "brightness", that is, the color becomes more intense. Visual evaluation of the color of all samples makes it possible to characterize it as green of different intensity.

6. Discussion of results of studying the influence of treatment on the preservation of color in sweet pepper

The presence of chlorophylls *a* and *b* predetermines the green coloration of the green varieties of sweet pepper. However, culinary treatment of fruits causes a change in their color. The reason for this is the destruction of natural pigments under the influence of various factors: temperature, its duration, pH of the environment, oxygen of the air. It is known that during thermal treatment organic acids partially vaporize and the green coloration of vegetables is retained better, which is why they are not treated in the sealed container.

To determine the extent of chlorophyll destruction in sweet pepper of green color, the blanching was conducted in water. The results showed that the temperature significantly affects the destruction of chlorophylls. This is due to the fact that in the fruits of pepper chlorophylls are found in a protoplasm in the form of chloroplasts and are bound to proteins and lipids. In fresh pepper, chloroplasts are protected from the action of organic acids with a layer of protoplasm. After grinding, and during heat treatment, the proteins of protoplasm collapse with the acids of cell juice destroying the chlorophylls. Under the action of acids, chlorophylls lose magnesium and pass into respective derivatives of green-brown color, pheophytin *a* and pheophytin *b*.

The higher the temperature, the more active this process; the rich green color of samples gradually changes to yellow-green. This is due to the fact that the rate of destruction of the blue-green chlorophyll *a* is higher than the rate of destruction of the yellow-green chlorophyll *b*. The total destruction of chlorophylls leads to the gradually manifested yellow color of carotenoids, which are also present in the pigment complex of pepper. They are invisible because of the green color of varying intensity of the fruits of pepper. The discoloration and accumulation of degradation products adversely affect the overall color of the treated samples.

The effect of temperature is enhanced by the length of its action. The results showed that an increase in the treatment time from 5 min to 25 min at the same temperature increases by three times the destruction of chlorophylls. Visually, there is a gradual change in the color of pepper samples from rich green to yellow-green color with a brown tint.

To stabilize the color, we selected the Xanthium strumarium natural raw material, with whose decoction we treated samples of the chopped green pepper. To determine the optimal treatment conditions, we examined the dependence of parameters of the color of raw materials on the concentration of Xanthium strumarium, temperature, and duration of treatment.

The results showed that the aging temperature of 90 °C did not produce a significant stabilizing effect of retaining the color of pepper samples. At this temperature there is the active destruction of chlorophylls, even at a concentration of 4 %. A greater concentration is impractical, as it leads to the manifestation of the significant effect of the Xanthium strumarium decoction on other organoleptic indicators of a finished product.

Research into the influence of different temperatures has made it possible to establish that the lower the temperature the better samples' color is retained. The value for the parameter "a dominant wavelength" indicates that the spectral color of samples is in the green component of the color of visible light, which is confirmed by an increase in the parameter "color purity". The color saturation of samples increases unlike the saturation of color at high temperatures, which is confirmed by a decrease in the values for the parameter "brightness".

The minimum duration of treatment (5 min) preserves well the color of pepper samples, but it is not sufficient for softening the tissues for the further homogenization in order to obtain a homogeneous product.

As evidenced by the results of experiment, an increase in the duration of samples treatment in the Xanthium strumarium decoction leads to that their color stabilizes and becomes more pronounced compared with the sample blanched in water (control-2). Visually, the color of all treated samples is characterized as being green of different intensity.

Thus, the optimal parameters that have been selected are the aging of chopped pepper in a 1 % Xanthium strumarium decoction at a temperature of 70 °C over 15 min.

7. Conclusions

1. Blanching at different temperatures from 70 °C to 100 °C, which make it possible to inactivate enzymes and to prevent the samples of pepper from turning brown, leads to the destruction of chlorophylls, from 25.2 % to 59.2 %. Visually, one observes a change in the color of pepper samples from rich green to light yellow-green.

2. The blanching duration over 5–25 min. at a minimum temperature of 70 °C causes the destruction of chlorophylls, from 20.2 % to 61.7 % of the starting content. Visually, one observes a change in the color of pepper samples from rich green to yellow-brown.

3. The color-parametric characteristics made it possible to optimize the parameters for technological treatment of pepper samples with a 1 % Xanthium strumarium decoction over 15 min. at a temperature of 75 °C.

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