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Методом гальваностатичної кулонометрії визначено загальну антиоксидантну ємність мармеладу желейно-фруктового та маршмелоу з рослинними добавками з яблук, айви, винограду, гарбуза, моркви, шипшини, обліпихи, суданської троянди, чорноплідної горобини, отриманих за кріогенними технологіями. На підставі розрахунків, які базуються на адитивній схемі, показано, що функціональні властивості виробів обумовлені антиоксидантними властивостями введених добавок

Ключові слова: антиоксидант, кулонометрія, рослинна добавка, кріогенна технологія, кріопаста, кріопорошок, мармелад, маршмелоу

Методом гальваностатической кулонометрии определена общая антиоксидантная емкость мармелада желейно-фруктового и маршмелоу с растительными добавками из яблок, айвы, винограда, тыквы, моркови, шиповника, облепихи, суданской розы, черноплодной рябины, полученных по криогенным технологиям. На основании расчетов по аддитивной схеме показано, что функциональные свойства изделий определяются антиоксидантными свойствами введенных добавок

Ключевые слова: антиоксидант, кулонометрия, растительная добавка, криогенная технология, криопаста, криопорошок, мармелад, маршмеллоу

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DETERMINATION OF TOTAL ANTIOXIDANT CAPACITY IN MARMALADE AND MARSHMALLOW

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1. Introduction

According to the results of recent research in the field of medicine, one of the main reasons for the change of pathological conditions in a human body that cause many diseases and lead to premature aging is an excessive level of free oxygen radicals [1–3]. Their constant high content in intercellular and intracellular biological fluids creates conditions for the development of oxidative stress, which from the biochemical point of view is expressed in oxidation of vessel walls, proteins, DNA, lipids [4].

Harmful effects of free radicals can be reduced by regular consumption of natural foods such as fruits, vegetables, herbs and the like. Another source of antioxidants is functional foods, made with the addition of natural additives. Natural additives beneficial effects on human health are due to the presence of natural phenols and polyphenols, which are able to break off the chain free radical oxidation reactions [5, 6]. Phenolic compounds combine several classes of chemical compounds, among which a special place belongs to flavonoids – the most important natural antioxidants. Synthesis of these structures in living organisms is impossible. In this regard, the creation of functional foods with various plant additives as a preventive means in population antioxidant protection programs is an urgent task.

2. Literature review and problem statement

Confectionery, including fruit jelly and marshmallow, are in high demand among the population, especially children, due to a pleasant taste and bright color. However, they

do not always meet modern quality requirements as they do not contain or contain small amounts of such important components of a diet as phenolic compounds, vitamins, minerals, dietary fiber. One way to increase consumer properties of marmalade (fruit jelly) and marshmallow is to create technologies with the use of plant additives in the form of purees, pastes, juices, extracts, etc. [7, 8]. Introduction of plant additives provides products with attractive appearance, bright color, high antioxidant potential, high biological and nutritional value.

Among plant additives, we should highlight those that are prepared by cryogenic grinding of raw materials – cryopastes and cryopowders [9–12]. Plant cryoadditives are a concentrate of bioactive substances, contain a significant amount of low molecular weight and macromolecular phenolic compounds, dietary fiber, vitamins, glycosides, organic acids, macro- and micronutrients and possess antioxidant, immunomodulating properties, as well as high coloring ability, good taste and aromatic characteristics. Previous research had established the possibility of using cryoadditives in technologies of pastries [13], semi-finished products [14], marmalade and pastila products [15–17], ice cream [18] and so on.

Understanding the role of antioxidants of different nature and their contribution to the overall effect is a challenging task because of the complexity of plant additives. This is due to the presence of several hundred chemical compounds of different nature and the need to distinguish the effect of each antioxidant, study their synergies. Therefore, the use of cumulative quantitative parameter – total antioxidant capacity (TAC), which determines the total ability of substances to be inhibitors of oxidation of food components to assess antioxidant properties is justified [19]. The TAC of foods is one of the parameters that determine the overall nutritional value and quality.

In the literature there is some uncertainty as to the use of the terms "antioxidant capacity" or "antioxidant activity" [19, 20], comparison of experimental results [2, 21] and the diversity of determination methods [22–25]. The point is that different authors use different indicator systems, different-type and non-standardized methods, which are often poorly reproducible, time-consuming and laborious for the quantitative assessment of the antioxidant capacity under *in vitro* conditions. Mechanisms of interaction of indicator systems with antioxidants are also different: with hydrogen atom transfer or electron transfer [26, 27]. The analytical signals, generated at the same time are characterized by different nature, and the results have different dimensions, which complicates their comparison. In addition, the contribution of different groups of reducing agents to the total antioxidant capacity is unclear. These factors are a driving force in the search for a standardized method of the TAC evaluation [27].

The free radical scavenging ability of polyphenols and other antioxidants can be measured by the level of oxidation of these compounds by model oxidants, i. e. electrochemical oxidation can be used in measuring the free radical absorption rate. This approach explains the considerable attention of researchers to electrochemical methods. Literature review suggests the possible use of potentiometry [28], various techniques of voltammetry [29, 30], coulometry [31–33] and so on for the TAC determination.

Among the electrochemical methods, we should note the galvanostatic coulometry. According to the literature review, a promising way to determine the total antioxidant capacity of food systems is a method that is based on the use of electrogenerated titrants, especially bromine [31, 32]. This is largely due to the mechanism of electron transfer in an aqueous medium in the interaction of active oxygen-containing compounds as the main process that determines the antioxidant capacity. Thus, the use of bromine obtained by electrolysis for quantitative determination is quite a feasible approach. A quantitative indicator, which is obtained in the determination is referred to as "bromine TAC" – the value that characterizes the total amount of antioxidants in food systems.

Numerous studies have shown that quince, apples, carrots, pumpkins, grapes, rosehips, sea buckthorn, black chokeberry, Sudanese rose and their extracts have antioxidant, immunomodulating properties, as well as high coloring ability, good taste and aromatic characteristics [17]. The research of the antioxidant capacity of marmalade and marshmallow with fine additives of these materials had not been carried out. Therefore, determination of this indicator by means of coulometry with electrogenerated bromine will provide a comparative description of products in terms of antioxidant properties and allow determining the contribution of additives to the TAC.

3. Research aims and objectives

The aim of the research was to determine the antioxidant capacity of fruit jelly

and marshmallow with fine plant additives that is caused by water-soluble antioxidants, such as ascorbic acid, polyphenols, etc., and prove the possibility of creating a functional product with the given antioxidant capacity based on the additive calculation scheme of TAC.

To achieve this aim it was necessary to solve the following problems:

– to determine the antioxidant capacity of cryopowders of apples, quince, grapes, pumpkins, carrots and cryopowders of grapes, rose hips, sea buckthorn, Sudanese rose, black chokeberry;

– to determine the antioxidant capacity of extracts of cryopowders of Sudanese rose, black chokeberry;

– to determine the antioxidant capacity of fruit jelly and marshmallow with fine plant additives;

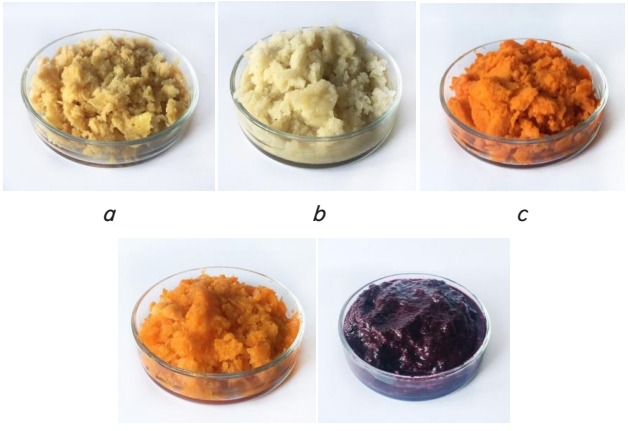
– to determine the contribution of TAC of cryopowders to the TAC of products based on the additive scheme.

4. Materials and methods of research of antioxidant activity of plant additives and finished products with them

4. 1. Investigated materials and equipment used in the experiment

The paper investigated the TAC of the following samples:

1. Cryopastes of quince "Muscatna", apples "Ukrayinski", carrots "Vitaminna 6", pumpkins "Novynka", grapes "Isabella" (Fig. 1). Ripe fruits and vegetables that have been grown in Ukraine in the natural environment and purchased at retail were used to produce cryopastes. The samples have been made in vitro according to the technology, which provides cryogenic (by means of liquid nitrogen) freezing of materials at temperatures (–35...–70 °C) without the use of chemical stabilizers and further low-temperature homogenization [9, 18].

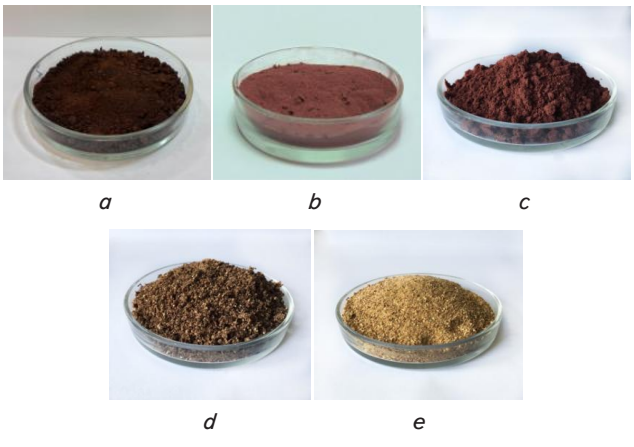


a *b* *c*

d *e*

Fig. 1. Cryopastes of: *a* — quince; *b* — apples; *c* — carrots; *d* — pumpkins; *e* — grapes

2. Cryopowders (lyophilizate) of sea buckthorn (*Hippophaë rhamnoides*), sweetbriar rose (*Rosa rubiginosa*), dark grape varieties (including seeds) (samples produced by JSC "Kriokon", Ukraine) and Sudanese rose (*Hibiscus Sabdariffa*), black chokeberry (*Aronia melanocarpa*) (samples produced by LLC "NPP Krias Plyus", Ukraine), obtained by the technology of low-temperature freeze drying followed by low-temperature grinding (Fig. 2).



a *b* *c*

d *e*

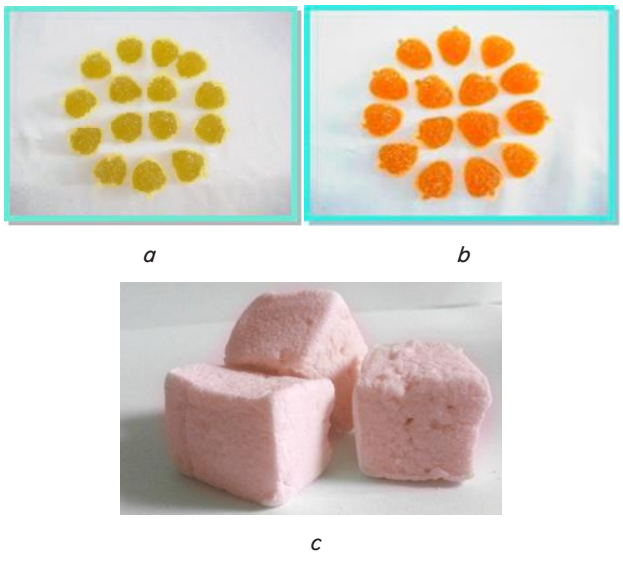
Fig. 2. Cryopowders of: *a* — black chokeberry; *b* — Sudanese rose; *c* — grapes; *d* — sea buckthorn; *e* — rose hips

3. Fruit jelly with plant cryoadditives (Fig. 3, *a, b*), produced by the following technology: pectin-sugar mixture (1:3) was dissolved in water when heating, sugar and syrup were introduced, the syrup was boiled down to the solids content of 78...80 %, then the cryopaste was introduced, boiled down to the solids content of 77...79 % and cooled, sodium lactate, cryopowder (if necessary) were added, citric acid solution was introduced and poured in forms [34, 37].

4. Marshmallow with plant cryoadditives (Fig. 3, *c*). The marshmallow was made by the technology, which involves the cooking of fondant syrup, boiling, mixing, first cooling, whipping, second cooling, mixing with the Sudanese rose or black chokeberry cryopowder extract, shaping, cutting, setting [34].

The following chemical reactants were used in the experiment: potassium bromide "c. p." (Reachim, Russia), sulfuric acid "c. p." (Sumykhimprom, Ukraine), hydrochloric acid "c. p." (Sumykhimprom, Ukraine), nitric acid "c. p." (Reachim, Russia), distilled water.

Distilled water with a conductivity of 0.55 mS/m, the value of which has been measured with a KEL-1M2 conductometer (Analitpribor, Georgia) was used to prepare the solutions.



a *b*

c

Fig. 3. Samples: a — fruit jelly with combined apple-carrot cryopastes; b — fruit jelly with combined quince-pumpkin cryopastes; c — marshmallow with Sudanese rose cryopowder extract

The study of the antioxidant capacity of plant additives, their extracts and marmalade-pastila products was carried out by means of galvanostatic coulometric titration at the facility, which consisted of the following parts:

1) coulometric cell – a 50 ml glass with a glass membrane that separated the cathode and anode compartments;

2) generating systems of electrodes consisting of a platinum redox electrode with a total area about 3 cm^2 (anode) SM29-PT9 (Yokogawa Europa, Netherlands) and a platinum needle electrode (cathode);

3) potentiostat – T-201M1 titrator unit (PA Analitpribor, Georgia). Current control was performed with the combined device V7-21a (Lorta, Ukraine) in the ammeter mode with an accuracy, better than 0.1 %;

4) the indicator system consisting of a platinum redox electrode EPV-1 (indicator electrode) and the silver-chlorine electrode EVL-1M3.1 (half-cell) (JSC ZIP, Belarus). The measurement of the electromotive force of the electrochemical system was performed using the 692 pH/Ionmeter (Metroohm, Switzerland) with an accuracy of 0.1 mV connected to a computer.

The solution was stirred using a magnetic stirrer MM-01 (JSC ZIP, Belarus).

4. 2. Method of determining the antioxidant capacity of samples

4. 2. 1. Preparation of samples

Determination of the antioxidant capacity was performed in extracts of cryopastes and cryopowders (apples, quince, grapes, pumpkins, carrots, rosehips, sea buckthorn, Sudanese rose, black chokeberry), marmalade and marshmallow solutions.

To prepare the extracts, a portion of the corresponding ground sample weighing 5.0–8.0 g was pounded with a pestle with 10–20 ml of an extractant and quantitatively transferred to pre-weighed 100 ml flask, the solution volume was brought to about 100 ml and weighed. 2 % aqueous solution of hydrochloric acid was used as an extractant due to the need for better extraction, compared to water, of one of the antioxidants – ascorbic acid. According to previous experiments, this raw material: extractant ratio provides the fullest removal of antioxidants from the samples. The contents of the flask were kept for 10 minutes at room temperature (20±2 °C), stirred and filtered under vacuum using a glass filter.

The samples were weighed on laboratory scales balance CBA-300-0.005 (T-Scale, China) with an accuracy of 5 mg.

4. 2. 2. Determination of TAC

Determination of TAC of the studied objects was based on coulometric titration of samples with electrogenerated bromine. The latter was generated from an aqueous solution of 0.2 M potassium bromide in 0.1 M sulfuric acid. The pH of the resulting solution was controlled at the level of 1.25 by the Combined LL pH glass electrode with Pt 1000 temperature sensor, № 6.0238.000 (Metroohm, Switzerland). The efficiency of coulometric bromine titration has been experimentally tested earlier [35].

Before measurements, the surface of platinum electrodes was cleaned according to the method [36], namely, soaked in the following solutions at an operating current of 5 mA:

1) for 5 minutes in 0.2 M KBr solution;

2) in nitric acid solution (the ratio of concentrated acid to water 1:1) for 5 minutes;

3) for 15 minutes in 0.2 M sulfuric acid solution. The electrodes were stored in potassium bromide solution between measurements.

In the experiment, 40 ml of background solution (0.2 M potassium bromide solution in 0.1 M sulfuric acid solution), 0.2–5.0 g of obtained extracts were introduced in a coulometric cell and titrated with electrogenerated bromine at an amperage of 1...10 mA. The ratio of the sample weight and amperage was set based on the concentration of the examined solution so that the titration time was 300...500 s, on the one hand, and on the other, that the current density at the generating electrode did not exceed 5 mA/cm^2. The following conditions are needed to ensure rapidity of the method and accuracy of measurement associated with 100 % current efficiency.

The end point of titration was recorded using the indicator system by the potentiometric method. To do this, several consecutive procedures were performed: a preliminary electrolysis to a certain value of electromotive force in the range of 780–800 mV; introduction of the sample portion of the above weight and noting the titration time; titration of analyte to the level of electromotive force equal to the value at the time of the sample introduction and recording the titration time. Monitoring and recording of titration data (electromotive force – time) were conducted electronically by means of the data logger ADC-10 (PicoScope Ltd., UK) using the PicoLog Recorder v.5.24 software (PicoScope Ltd., UK), allowing to automate the primary processing of experimental data to determine the end point of titration.

From experimental data of coulometric titration, the TAC values (C/100 g) of the investigated objects were calculated according to the formula:

$$TAC = \frac{100 \cdot I \cdot t \cdot m_e}{m_a \cdot m}, \quad (1)$$

where I – current strength, A; t – time of achieving the end point of titration, s; m – the mass of the sample taken for the analysis, g; m_e – the mass of the extract, g; m_a – the mass of the aliquot used for the analysis, g.

4. 3. Statistical processing of the results

Determination of the antioxidant capacity (TAC) of cryopastes, cryopowders and their extracts, fruit jelly and marshmallow with fine plant additives was conducted in a number of parallel measurements (n=4) with the analysis of failures using Q-test. Then the average value of the antioxidant capacity of a certain sample, random deviations, variance and standard deviation, the value of which was used to verify the results for the presence of failures when using more precise criteria were calculated.

To assess the reproducibility, sample variance of the average value and standard deviation of the average result (S_r) were calculated. The value of the confidence interval was determined by Student's t test. A $p<0.05$ was considered as statistically significant. The resulting values of the antioxidant capacity of samples are presented in Tables 1–3 in the form of TAC±ΔTAC, where TAC – average value of the antioxidant capacity of the sample and ΔTAC – confidence interval of the antioxidant capacity.

Statistical data processing was carried out using the Microsoft Office Excel 2010 and IBM SPSS Statistic v.20.

5. Discussion of results of research of antioxidant capacity of plant additives, obtained by cryogenic technologies, marmalade and marshmallow

5. 1. Antioxidant capacity of cryoadditives, marmalade and marshmallow

The results of determining the antioxidant capacity of cryopastes and cryopowders of plant material are shown in Fig. 4, 5.

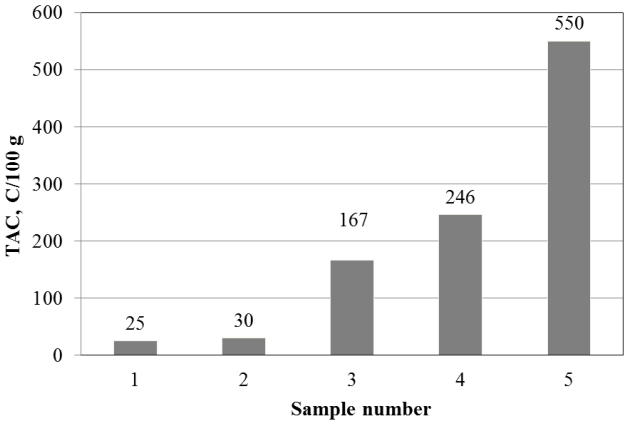


Fig. 4. Antioxidant capacity of cryopastes of: 1 – pumpkins, 2 – carrots, 3 – quince, 4 – apples, 5 – grapes

As shown in Fig. 4, the antioxidant capacity of cryopastes of pumpkins and carrots is the lowest. This is because the method allows determining the antioxidant capacity caused by the presence of water-soluble antioxidants only. In cryopastes of quince and apples, this value is 167 and 246 C/100 g,

respectively. The values of TAC of cryopastes of quince and apples are comparable because of the approximate content of the main antioxidants, especially ascorbic acid and polyphenols [16]. The TAC value of cryopastes of grapes is about 550 C/100 g. This is due to a high content of anthocyanin compounds – 5 g/100 g. At the same time, the ascorbic acid content in all samples is in the range of 15–30 mg/100 g and brings nearly the same contribution to the overall TAC.

The TAC of cryopowders increases in the row: grapes<black chockeberries<Sudanese rose<sea buckthorn<rosehips from 663 to 4.400 C/100 g. Anthocyanins make the main contribution to the TAC of the first three, vitamin C – sea buckthorn and rosehips.

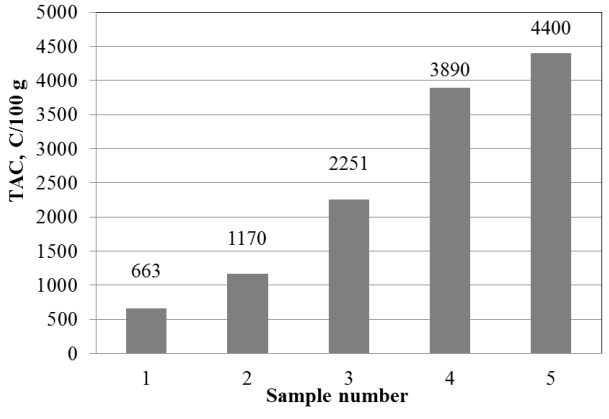


Fig. 5. Antioxidant capacity of cryopowders of: 1 – grapes, 2 – black chokeberry, 3 – Sudanese rose, 4 – sea buckthorn, 5 – rosehips

The TAC determined for 13 samples of fruit jelly with different amount of introduced cryopastes (10 %, 20 %), cryopowders (1.5 %) and combinations thereof are presented in Table 1. As shown in Table 1, marmalade with cryopastes of carrots and pumpkins has the lowest bromine TAC. Additional introduction of the sea buckthorn cryopowder provides products with fairly pronounced antioxidant properties. The TAC of products increased by 10 times.

A similar situation occurs when introducing quince or apple cryopastes combined with the rosehip cryopowder to products. The TAC of products increased by 3.8 and 2.6 times.

Marmalade with grape cryopaste is characterized by the TAC of 50.9 C/100 g. Additional introduction of the grape cryopowder to the products allows increasing the TAC of products up to 68.8 C/100 g, i. e. by 35.1 %.

As a result of previous research [34], it was found that the optimum form of introduction of Sudanese rose (SR) and black chokeberry (BC) cryopowders in the marshmallow production are water and water-alcohol extracts with the addition of citric acid (CA). So the next step was to determine the antioxidant capacity of these extracts. The results are shown in Table 2.

It was found that the TAC of the Sudanese rose cryopowder extract is almost twice as much compared to the black chokeberry cryopowder extract due to a higher anthocyanin content. The use of water-alcohol solution as an extractant provides an extract with more pronounced antioxidant properties. The TAC of the extracts increased by 3.3 and 1.5 times, respectively.

The research [34] found that optimum concentrations of water-alcohol extracts of Sudanese rose and black chokeberry cryopowders to obtain high-quality marshmallow are 3...4 % and 8...10 % of the total mass of the system. The TAC values of marshmallow samples with the addition of 3 % SR cryopowder extract and 9 % BC cryopowder extract of the total mass of the system are given in Table 3.

Table 1

The results of determining the antioxidant capacity of fruit jelly with plant additives (n=4, p<0.05)

№	Samples	TAC, C/100 g	S_r
1	Marmalade without additives (base)	2.2±0.4	0.17
2	Marmalade with carrot cryopaste	6.2±0.7	0.07
3	Marmalade with pumpkin cryopaste	6.3±3.1	0.27
4	Marmalade with quince cryopaste	18.2±2.0	0.25
5	Marmalade with apple cryopaste	27.2±0.2	0.01
6	Marmalade with grape cryopaste	50.9±0.3	0.01
7	Marmalade with quince and pumpkin cryopastes	48.4±1.0	0.14
8	Marmalade with apple and carrot cryopastes	50.2±3.3	0.25
9	Marmalade with carrot cryopaste and sea buckthorn cryopowder	63.6±3.9	0.08
10	Marmalade with pumpkin cryopaste and sea buckthorn cryopowder	64.0±3.8	0.04
11	Marmalade with grape cryopaste and cryopowder	68.8±3.3	0.03
12	Marmalade with quince cryopaste and rosehip cryopowder	70.6±4.4	0.01
13	Marmalade with apple cryopaste and rosehip cryopowder	71.1±4.5	0.01

Table 2

The results of determining the antioxidant capacity of Sudanese rose and black chokeberry cryopowder extracts (n=4, p<0.05)

№	Samples	TAC, C/100 g	S_r
1	BC cryopowder extract in 2 % CA solution	84.5±8.8	0.15
2	SR cryopowder extract in 1.5 % CA solution	164±12	0.18
3	BC cryopowder extract in 40 % water-alcohol solution with addition of 1 % CA	281±15	0.19
4	SR cryopowder extract in 40 % water-alcohol solution with addition of 1 % CA	252±12	0.10

Table 3

The results of determining the bromine antioxidant capacity of marshmallow with plant additives (n=4, p<0.05)

№	Samples	TAC, C/100 g	S_r
1	Marshmallow without additives (base)	15.8±3.0	0.10
2	Marshmallow with SR cryopowder extract	36.3±4.1	0.19
3	Marshmallow with BC cryopowder extract	69.3±5.0	0.19

The TAC value of marshmallow samples with the addition of the water-alcohol black chokeberry cryopowder extract is above that of the samples with the Sudanese rose black chokeberry cryopowder extract. This is due to three times higher BC cryopowder extract content in marshmallow.

5. 2. Calculation of TAC based on additive scheme

A retrospective look at the values of TAC of fruit jelly and marshmallow allows predicting the following fact. The changes in the TAC are similar to the changes in the above cryopastes and cryopowders in the context of the plant components used. This may indicate a dominance of the TAC of plant additives in the TAC of the final product. To confirm this hypothesis, additive calculation scheme of TAC of fruit jelly and marshmallow was considered, according to which the specified value can be represented as a sum of two contributions: the antioxidant capacity of the product without additives (so-called base) and plant additives. This corresponds to the expression:

$$TAC(m)=\frac{m_d}{m_m}TAC(d)+\frac{m_o}{m_m}TAC(o), \quad (2)$$

where TAC(m), TAC(d), TAC(o) – the antioxidant capacity of fruit jelly or marshmallow, plant additives and base, respectively; m_d, m_o, m_m – masses of plant additives, base and fruit jelly or marshmallow, respectively.

Based on the formulation of the studied confectionery and above TAC values of plant additives and the base, the values of TAC(m) were calculated. Fig. 6, 7 present the estimated values of TAC(m) compared with the experimental values.

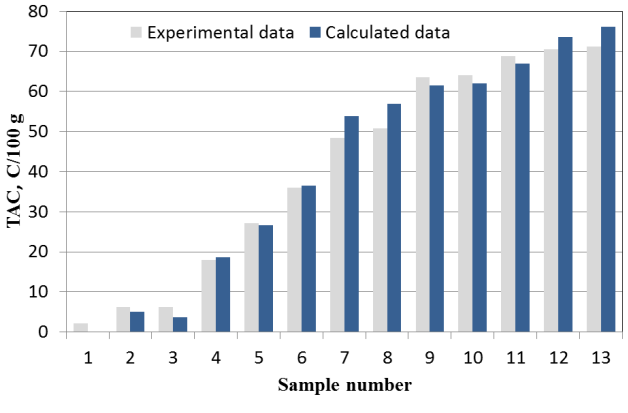


Fig. 6. Comparison of the calculated and experimental values of TAC: marmalade with cryopaste: 1 — without additives, 2 — carrots, 3 — pumpkins, 4 — quince, 5 — apples, 6 — grapes, 7 — quince and pumpkins, 8 — apples and carrots, marmalade with cryopaste and cryopowder, 9 — carrots and sea buckthorn, 10 — pumpkins and sea buckthorn, 11 — grapes, 12 — quince and rose hips, 13 — apples and rose hips

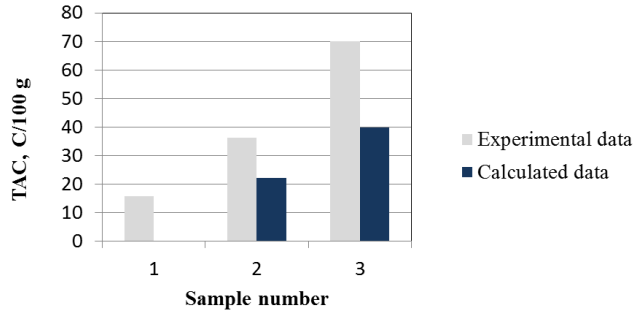


Fig. 7. Comparison of the calculated and experimental values of TAC of marshmallow: 1 — without additives, 2 — Sudanese rose cryopowder extract, 3 — black chokeberry cryopowder extract

According to Fig. 6, the resulting estimated values within 25 % coincide with experimental values, precisely conveying the trend of changes in the antioxidant capacity in several samples when changing additives. This shows, firstly, the validity of the above hypothesis that the contribution of the antioxidant capacity of the cryoadditive to the total value of the antioxidant capacity of marmalade is predominant, ranging from 75 to 98 %. The experimental TAC values of marshmallow exceed the estimated values by 57 and 75 %, respectively (Fig. 7). This suggests that the additive scheme may not take into account the synergy of marshmallow components.

Secondly, significant stability and reproducibility of antioxidant properties of cryoadditives in the finished product, despite the rather "tough" temperature conditions in the production technologies of the above confectionery, which can result in the loss of some antioxidants of plant additives. It should be noted that the results are to some extent a consequence of the innovations that were introduced in the fruit jelly production [37]. In order to preserve the maximum amount of antioxidants in the marmalade production, it was proposed to introduce cryopastes at a concentration of 10...20 % at the stage of the marmalade mass preparation after boiling of the pectin-fondant syrup and cryopowders at a concentration of 1.5 % at the stage of the marmalade mass processing. The marshmallow production technology provides for the introduction of cryopowder extracts at the stage of whipping.

And, thirdly, development of the database of TAC of cryopowders of different plant materials allows predicting the creation of fruit jelly and marshmallow as functional foods with the given values of TAC through optimization of the amount of plant additives.

Thus, the analysis and synthesis of the experimental data show the feasibility of using fine plant additives in the marmalade and marshmallow technology to improve their antioxidant properties.

6. Conclusions

1. It was found that the TAC of cryopastes increases in the row: pumpkins <carrots<quince<apples<grapes from 25 to 550 C/100 g. The TAC of cryopowders increases in the row: grapes<black chokeberry<Sudanese rose<sea buckthorn<rose hips from 663 to 4400 C/100 g. The values correlate with the content of the main classes of antioxidants of these cryoadditives.

2. It was revealed that use of water-alcohol solution as an extractant with the addition of 1 % citric acid provides the cryopowder extract with more pronounced antioxidant properties.

3. It was determined that marmalade with the addition of carrot and pumpkin cryopastes has the lowest bromine TAC. Additional introduction of cryopowders in marmalade samples with cryopastes in an amount 1.5 % increases the TAC of marmalade by 3.5–10 times. Marmalade with apple cryopaste and rose hip cryopowder (71.1 C/100 g) and marshmallow with black chokeberry cryopowder extract (69.3 C/100 g) had the highest TAC.

4. Based on the additive scheme, the values of TAC as the sum of the contributions of the base and plant additives within 25 % are consistent with experimental data. It is

shown that the contribution of the antioxidant capacity of cryoadditives to the overall value of TAC is predominant, ranging from 75 to 98 % for marmalade and 56–77 % for marshmallow. This fact proved that the antioxidant properties of marmalade and marshmallow are improved by the introduction of plant cryoadditives.

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