Evaluation of the nutritional value of processed plant-based foods

E S Bychkova¹, I O Lomovsky², N F Beizel³,⁴ and D V Gosman¹

¹ Novosibirsk State Technical University, K. Marks Ave. 20, Novosibirsk, 630073, Russia
² Institute of Solid State Chemistry and Mechanochemistry SB RAS, Kutateladze Str. 18, Novosibirsk, 630128, Russia
³ Nikolaev Institute of Inorganic Chemistry SB RAS, Akademika Lavrentyeva Ave. 3, Novosibirsk, 630090, Russia
⁴ Novosibirsk State University, Pirogova Str. 1, Novosibirsk, 630090, Russia

Corresponding author e-mail: bychkova.nstu@gmail.com

Abstract. This paper presents the data on nutritional value of food products obtained from plant-based feedstock. Purées made from apples, cranberries, red beets, and horseradish roots were used as study objects. The pre-made purées were found to be a valuable source of dietary fiber as the contents of pectic substances and fibers in them are rather high. The hydropectin/protopectin ratio in the study objects was evaluated. The protopectin content was the highest in the purée made from horseradish roots, while the lowest protopectin content was observed in cranberry purée. The degree of pectin methylation was determined experimentally. The cranberry and apple purées contain high-methoxy pectin, while the beet purée and the purée made from horseradish roots contain low-methoxy pectin. Information about the degree of pectin methylation is needed to understand the processing features of the ingredients. The data on antioxidant capacity of the samples are reported. Cranberry purée has pronounced antioxidant properties. The mineral composition of the samples was determined. Beet purée is rich in Na, K and Fe; the purée made from horseradish roots is rich in K, Ca and Fe; apple purée contains a sufficiently high amount of Fe. The analyzed plant-based purées can be used to design functional food products characterized by good processing properties, longer shelf life, and high nutritional value.

1. Introduction

The development of functional foods using local plant-based feedstock [1, 2] and bioengineering products [3, 4] is quite relevant today. It is promising to produce these innovative foods from plant-based feedstock because these foods will contain a wide range of biologically active substances (vitamins, minerals, pectin, phenols, antioxidants, etc.), which positively affect the immune status of humans. High-value crops include red beets, cranberries, apples, and horseradish roots.

The interest in the effect of red beets on human health has been increasing over the past century. Beets are considered to be among the highest-value vegetable crops. They are widely used in nutritional treatment for patients with gastrointestinal diseases, hypertension, diabetes mellitus, and nephrolithiasis. Beets improve the overall health, stimulate the gallbladder and liver functions, and improve digestion. The presence of such elements as rubidium and cesium in this vegetable allows one...
to use it to treat weakness, fatigue, and anemia. Magnesium found in beets regulates the vascular tone and prevents blood clotting. Vitamin U promotes ulcer healing, exhibits antiscorbutic and antiallergic activities, and improves cholesterol metabolism. Beetroot juice is especially effective as an antianemic, anti-ischemic, anti-inflammatory, and anticarcinogenic product [5, 6, 7].

Biologically active substances within apples and cranberries normalize the biochemical and physiological processes occurring in the human body. Phenols within these crops exhibit an antiradiation activity; pectins facilitate the more rapid and complete removal of breakdown products and radioactive elements from the intestine, as well as reduce cholesterol level. In addition, cranberries improve heart function and intensify the blood flow; they are used to improve the gastrointestinal secretion, as well as to treat and prevent atherosclerosis [8, 9]. Apples normalize liver cholesterol level and are indispensable for avitaminosis prevention [10, 11].

Many publications have recently focused on studying horseradish roots and developing novel food products from them. The curative properties of this plant are mainly caused by essential oils within it. Allyl isothiocyanate stimulates the secretion by digestive glands, increases gastric acid production and its acidity, and improves intestinal motility. Furthermore, horseradish roots contain lysozyme, a protein having antimicrobial properties. Horseradish roots are rich in vitamin C, potassium, calcium, and iron. Flavonoids contained in this vegetable improve the function of the human immune system and reduce the risk of cardiovascular diseases. Horseradish roots exhibit fungicidal, bactericidal, nematocidal, allelopathic, and anticarcinogenic activities [12, 13].

The lack of antioxidants and excessive amount of free radicals in the human body are among the reasons for decline in immunity, premature aging, development of many diseases, and reduction of life expectancy. The excessive amount of free radicals weakens the immune system and leads to the development of many disorders, such as cancer, cardiovascular diseases, arthritis, cataract, Parkinson's disease, Alzheimer's disease, etc. Timely systemic administration of antioxidants is required.

The range of biological activities of antioxidants is rather wide. It is mainly caused by their protective functions (the ability to neutralize the negative effects of free radicals). Many antioxidants (e.g., vitamins C and E, β-carotene, glutathione, quercetin, lutein, etc.) inhibit the oxidation of low-density cholesterol (lipoproteins) and cholesterol plaque formation in arteries and prevent cardiovascular diseases. Antioxidants act as antimutagens and detoxicants for heavy metals. From the technology viewpoint, the use of natural antioxidants within feedstock allows one to extend the shelf life of food raw materials, pre-made foods, and finished products by protecting them against spoilage caused by oxidation with atmospheric oxygen.

2. Problem Statement
Because of the progressive dynamics of diseases caused by unfavorable environmental factors, as well as the factors related to systemic nutritional deficiency, there is a demand for developing nutrient-dense foods. Today, special focus is placed on plant-based feedstock and development of foods based on it [1, 2, 14].

3. Objects of research
The objects of research were as follows: purées made from apples, cranberries, red beets, and horseradish roots.

4. Materials and Methods

4.1 Quantitative determination of pectic substances
The pectin content in the samples was determined using the calcium pectate method, which is based on coprecipitation of pectic acids as calcium salts followed by gravimetric analysis of their weights. The contents of soluble pectin and protopectin can be determined individually depending on the study objective [15].
4.2 Determining the degree of pectin methylation
The degree of methyl esterification of the extracted pectin was determined by IR spectroscopy [16].

4.3 Determining antioxidant capacity of the samples
The antioxidant capacity of the samples was determined using the amperometric method by measuring electric current emerging when the test substance (or their mixture) was electromechanically oxidized on the surface of a working electrode at a certain electrode potential [17].

4.4 Determining the mineral composition
The mineral composition of the study objects was determined by atomic absorption spectrometry on a Z-8000 spectrophotometer (Hitachi, Japan) using the procedure described earlier in [18]. To make the test components pass into the solution, the accurately weighed portions of purée were treated with concentrated nitric acid while being heated under an infrared lamp; their volume was reduced twice until moist salts were obtained. The salts were then dissolved in an accurately measured volume of distilled water. During the analysis, the reference and sample solutions were sputtered into air–acetylene flame of the atomic absorption spectrometer, and the analytical signal of each analysis element was recorded at its resonance wavelength: Na, at 589.0 nm; K, at 766.5 nm; Ca, at 422.7 nm; Mg, at 285.2 nm; and Fe, at 248.3 nm. Hollow cathode lamps were used as sources of radiation when performing iron and calcium/magnesium assays; potassium and sodium contents were determined in the emission mode [19].

4.5 Determining the fiber content
The total crude fiber content was estimated using the Henneberg–Stohmann method [20]. This technique is based on consecutive treatment of an accurately weighed test sample with acid and alkali solutions followed by calcination and gravimetric determination of the weight of the organic residue.

5. Results and Discussion
The physicochemical quality parameters of the samples of apple, cranberry, and beet purées, as well as the purée made from horseradish roots, were studied. The results are summarized in Table 1.

Table 1. Physicochemical quality parameters of pre-made purées

| Parameter                                | Apple purée | Cranberry purée | Beet purée | Purée made from horseradish roots |
|------------------------------------------|-------------|-----------------|------------|----------------------------------|
| Solids, %                                | 11.99±0.11  | 9.60 ± 0.61     | 12.94±0.25 | 21.16±0.71                       |
| Titratable acidity, % (expressed as malic acid) | 0.75±0.06  | 3.58±0.16       | 0.13±0.01  | 0.25±0.01                       |
| Active acidity                           | 3.2±0.1     | 2.1±0.2         | 4.7±0.1    | 3.9±0.1                         |
| Pectic substances, including:            |             |                 |            |                                  |
| Pectin, %                                | 1.41±0.09   | 0.71±0.04       | 1.62±0.03  | 0.55±0.04                       |
| Protopectin, %                           | 0.53±0.07   | 0.11±0.02       | 0.40±0.07  | 12.60±0.50                      |
| Fiber, %                                 | 0.33±0.02   | 0.63±0.02       | 0.83±0.02  | 2.65±0.09                       |
| Ash, %                                   | 0.80±0.02   | 0.61±0.04       | 1.21±0.09  | 1.60±0.08                       |
| AOC, mg of quercetin/g of the product    | 0.41±0.02   | 1.5±0.02        | 1.08±0.09  | 0.52±0.01                       |

One can see from the reported data that beet purée and purée made from horseradish root are characterized by the highest contents of solids, fiber, and ash. Since the recommended daily intake of
pectin is 4 g, apple purée, cranberry purée, beet purée, and purée made from horseradish roots provide 35, 17, 40, and 14% of the daily value, respectively (per 100 g of the product under study).

Table 2 lists the data on the degree of pectin methylation in the samples under study.

| Purée type                  | Degree of pectin methylation, % |
|-----------------------------|----------------------------------|
| Apple purée                 | 66                               |
| Cranberry purée             | 70                               |
| Beet purée                  | 35                               |
| Purée made from horseradish roots | 34                           |

It was found that cranberry and apple purées contain high-methoxyl pectin, while beet purée and purée made from horseradish roots contain low-methoxyl pectin. High-methoxyl pectin has high water-binding capacity, while the low-methoxyl one exhibits radioprotective properties [21, 22].

In plants, pectic substances exist in water-soluble (pectin) and water-insoluble (protopectin) forms. The molecular weight distribution of pectic substances was studied. Each type of purées contains pectin and protopectin at a certain ratio. This ratio depends on the structure of the initial feedstock and the method used for purée production. According to the diagram shown in Figure 1, protopectin content is maximal in the purée made from horseradish roots, while being minimal in cranberry purée. The reason is that the protopectin-rich cranberry pulp is separated from the juice when cranberry purée is produced. Horseradish root mainly consists of cell walls, where protopectin resides. Pectin content in apple and beet purées is much higher than that of protopectin, since the crude material is cooked when producing these purées, so the conversion of some protopectin to pectin is facilitated.

![Figure 1](image)

**Figure 1.** The ratio of pectin to protopectin in the pre-made purées under study

Cranberry and beet purées have pronounced antioxidant properties as they contain anthocyanins, flavonoids, minerals, vitamins, and other antioxidants. Figure 2 shows the diagram of antioxidant capacity (AOC) of the pre-made purées under study.
Taking into account the recommended daily intake of antioxidants (1100–1400 mg), our studies demonstrated that apple, cranberry, and beet purées provide 10, 22, and 27% of it, respectively.

Table 3 summarizes the data on daily value for minerals in 100 g of purées. The beet purée is rich in Na, K, and Fe; the purée made from horseradish roots is rich in potassium, calcium, and iron; the apple purée contains a sufficiently large amount of iron.

Table 3. Percent daily value for minerals, %

| Chemical element | Pre-formed purée | Apple purée | Cranberry purée | Beet purée | Purée made from horseradish roots |
|------------------|------------------|-------------|-----------------|-----------|----------------------------------|
| Na               | 0.19             | 0.2         | 10.01           | 6.04      |
| K                | 4.76             | 3.5         | 13.5            | 21.36     |
| Ca               | 1.99             | 1.7         | 7               | 14.4      |
| Mg               | 1                | 1.5         | 6.3             | 6.32      |
| Fe               | 15.9             | 6.1         | 11.9            | 12.1      |

6. Conclusions
The studies have demonstrated that the analyzed types of purée contain sufficient amounts of dietary fiber. The antioxidant capacity of cranberry and beet purées is more pronounced. The purée made from horseradish roots is a source of potassium, calcium, and iron; apple and beet purées are a good source of iron. The degree of pectin methylation gives grounds for predicting the processing and physiological features of pre-made purées. Apple and beet purées contain high-ester pectins, which can make the product more stable. The purées made from horseradish root and beets contain low-ester pectins, which will have a greater effect on their nutritional value. The analyzed purées made from plant-based feedstock can be used to produce functional foods characterized by good processing features and high nutritional value.

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