Innovative technology for complex processing of plants of different cucurbit species

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Abstract. Global environmental degradation in almost all regions of the world dictates the need for expansion of a range of specialized products with powerful detoxification properties. Another equally urgent problem is an increasing output of competitive products per one unit of processed agricultural products. Pectic substances are effective plant-based sorbents. Cucurbit crops, such as desert gourd and watermelon, present promising raw materials for pectin production. Due to high pectin content, pulp and juice of their fruits, in particular desert gourds, have high viscosity and special consistency. Here we show the results of analysis of the total content of pectin substances and their fractional composition (mass fraction of protopectin and hydrated pectin). The results obtained formed the basis for development of an innovative technology for desert gourd and watermelon processing with production of pectin products. To evaluate fields of their applications, basic analytical characteristics of pectin’s were studied: content of free and methoxylated carboxyl groups, degree of esterification, methoxyl and acetyl moieties, and complexing ability. A characteristic of isolated pectin’s allowed us to evaluate the feasibility of cucurbit crop processing for expansion of the range of pectin-containing foods and increase of their production volumes. We also show data on the global and Russian food markets of pectin-containing foods.

1. Introduction
Foods (FF) have been gaining popularity in the modern food market. These are termed food for specific health use, and sometimes are even called “superfoods”. The difference between these products and their traditional counterparts is that they not only possess certain nutritional properties, but also have targeted effects on functions of individual organs, systems and the whole body, stimulating their performance with specific preventive and therapeutic purposes.

In fact, functional foods should be referred to specialized food products. This is due to the fact that they contain biologically active ingredients of natural origin added (in most cases) to give functional foods the required targeted preventive and therapeutic properties. Such ingredients include vitamins and essential macronutrients (potassium, calcium, sodium, carbon, oxygen, etc.) and trace elements (selenium, zinc, iodine, iron, molybdenum, etc. - over 30 in total), dietary fiber, lactic acid bacteria and probiotics, antioxidants, polyunsaturated fatty acids, etc.

Over the last 10 to 20 years, production and consumption of FF have been increasing in the vast majority of countries. The main countries include the USA, Canada, Western Europe, Japan, and Australia. There, there is a wide range of functional foods. Thus, in Japan, FF account for almost 50%, and in the USA, Europe and Australia - for 20-30% of all manufactured food [1]. In Russia, the FF consumer market is not developed and presented mostly by imported goods.
The global FF consumer market is formed by, mainly, functional diary products (about 60%). At the same time, food technology experts believe that in the coming years the most promising direction will be the development of functional foods based on a complex of biologically active substances of plant origin enriched with raw materials with high nutritional potential [2].

Such raw material source, in our opinion, can be obtained from cucurbit cultures (desert gourd/watermelon (*Citrullus*), melon, pumpkin), which have good taste and high nutritional properties as determined by the high content of vitamins, macronutrients and trace elements, easily digestible carbohydrates and other biologically active substances. Cucurbit crop seeds, rich in vegetable oil, have high nutritional value. Cucurbit seed oil, especially obtained from desert gourds, watermelons and pumpkins, has great taste, rich in vitamins and is as good as the best edible oils [3, 4].

Russia is the world leader in the area of land under cultivation and gross harvest of cucurbit crops. The main areas of their cultivation are concentrated in the southern regions of the country - the Lower Volga region and the North Caucasus. The in the area of land under cultivation is currently around one million hectares and the annual fruit harvest volume ranges from 3 to 4 million tons.

Current cucurbit fruit harvest volumes do not meet the demand. Therefore, crop breeders were tasked with increasing the production of cucurbit products up to 7.9 million tons and the annual fruit consumption up to 20.3 kg per person in the population, in the near future by introducing scientific achievements.

The main cucurbit crop in Russia is represented by *Citrullus* species. Fields under these crops account for 70-85% of all cultivated land under cucurbit crops. The remaining lands under gourds are used for melon and pumpkin [5–8]. Cultured *Citrullus* species include watermelon (*C. Adulis Pang*) and desert gourd (*C. Colocynthoides Pang*).

Watermelon fruit is a nutritionally valuable product forming a part of a healthy diet. These fruits are high in carbohydrates, mainly sugars, with fructose accounting for 85% thereof. Compared to watermelons, desert gourds have larger fruits (up to 50 kg), harder greenish pulp which is also not as sweet. Fruits of desert gourds can be spherical, ovoid or pear-shaped; white or green colored. Watermelon skin is dense, light green, pulp is light colored, with a pleasant fresh smell, characteristic of watermelons. Seeds of the desert gourd are dark green. The storability of the desert gourd is high due to a large pectin content. The desert gourd does not require any special cultivation technologies, pesticide and fertilizer treatments, and is drought tolerant. In Russia, it can be grown in the same areas as the watermelon.

For a variety of products made from cucurbit, their pulp is pureed using grinders or pulping machines. Mechanical action on watermelon, melon or pumpkin tissue breaks it down into individual cells or cell conglomerates. At this, cell walls can get destroyed and their contents come out.

Watermelon juice and pulp contain easily digestible carbohydrates, per 100 g of product: monosaccharides – glucose 2.4 g, fructose – 4.3 g; disaccharides (sucrose) – 2.0 g; polysaccharides – hemicellulose 0.1 g; fiber – 0.5 g; starch – 0.1 g; pectin – 0.5 g. The average mass fraction of organic acids is: citric acid: 0.02g, malic acid: 0.1 g. The average vitamin content per 100 g is: β-carotene about 0.1 mg; vitamin C – 7 mg; B6 – 0.09 mg; niacin – 0.24 mg; riboflavin – 0.03 mg; thiamine – 0.04 mg; folacin – 8 µg.

Large amount of delicate fiber contained in watermelons is beneficial for good digestion, contributing to gastrointestinal motility without causing meteorism, accelerates the removal of excess cholesterol and toxic substances from the body. Due to the health benefits, watermelon is recommended as a part of the diet for patients with kidney and urinary tract, liver, and gallbladder disorders, gout, arthritis, atherosclerosis, hypertension, anemia, diabetes mellitus, constipation, as well as for people with occupational and other exposure to toxic agents.

Watermelon is a very useful dietary component for patients with obesity, since its pulp is low in calories (100 g – about 38 kcal) and can be used in large amounts to simulate satiety, and pectic substances for beneficial effects on intestinal microflora. Watermelon is also a valuable human food. Nutritional value of watermelons is due to a large amount of carbohydrates, vitamin C, and minerals. However, depending on the biological characteristics of the variety, geographical area, technology and...
even the year of cultivation, the nutritional value of fruits varies significantly, with sugar content ranging from 3.75 to 11.84%, dry substances 5.04 to 12.52%, vitamin C and pectic substances, respectively, 2.73 to 7.46 mg % and 1.21 to 2.12 %. Water content in fruits ranges from 88.90 to 94.92%. Watermelon pulp also contains, on average, 0.76% of nitrogenous substances, 0.6% of fat, 0.4% of fiber, and 0.36% of ash.

Studies on the quantitative and qualitative composition of pulp have shown that young unripe fruits contain monosaccharides, predominantly glucose. As watermelons grow and ripen, they accumulate sugars where fructose prevails, and by the end of ripening, fruits contain also sucrose. The sweetest part of the fruit is its center, less sweet is the top, and the lowest sugar content is in the base of the fruit. Watermelons also contain starch, but it is only found in green fruits (up to 3%). The amount of pectic substances in the pulp is very low: 0.48% in the central part and 0.10% at the base; as the watermelon matures, this amount further decreases. Desert gourd varieties contain up to 1.5% pectin substances. Due to its high sugar content, watermelon juice is of exceptional value for use in the food industry, in particular as a sugar substitute in diets.

During fruit processing for watermelon juice, 31% of mass accounts for watermelon rinds (fruit outer rind and sub-rind layer), which can be used as a secondary raw material for extraction of pectic substances [7, 9, 10]. Watermelon juice is used for production of "honey" – nardek, and different parts of the fruit are used for production of candied fruits, jelly, syrup, marmalade, jam, and mushmellow. Unripe watermelon fruits can be used for pickling [10–13]. However, there are nearly no effective production technologies for watermelon and desert gourd processing. At the same time, the analysis of variety-specific and technological properties of watermelon and desert gourd fruits grown, for example, in Krasnodar Krai farms, shows a real opportunity to use some varieties for industrial processing.

In order to expand the range and increase FF production volumes for further research, for our study we have selected such desert gourd and watermelon varieties that met the requirements for technological properties and yields in our region in order to develop the method for their complex processing.

2. Materials and methods
The objects of this study were desert gourd and watermelon fruits grown in Krasnodar Krai. Desert gourd fruits were of varieties Diskhim and Pektinovyy. Fruits are large, cylindrical, light green, with an indistinct spotty pattern. Seeds are green. Medium-late varieties, yield 300 – 600 centner/ha. Watermelon fruit varieties: Leader, Ranniy Kubani, Astrakhanskiy. Leader (early ripening) variety has an average fruit weight of up to 3.0 kg, with a thin rind of dark green color. Fruits have spherical shape. This variety is characterized by a high content of sugars and good taste.

Ranniy Kubani (early ripening) plants have fruits of spherical or blunt oval shape. Surface smooth or slightly segmented, light green with stripes. Rind is medium thick, flexible. Pulp is intense pink, grainy, tender. Fruits weight is up to 3.0 kg.

Astrakhanskiy variety (mid-season ripening). Fruits have a spherical or slightly oblong shape, with smooth and even rind. Surface is dark green with light stripes. Pulp is bright red. Fruit weight is 8 – 10 kg.

For experimental studies, standard and modern methods of physicochemical analysis were used. Mass fraction of dry substances was determined using a refractometer, mass fractions of total (titrable) acids, sugars, and vitamin C were determined by standard titration. Total content of pectic substances was determined using calcium pectate method as the most commonly used in evaluation of industrial pectin-containing raw materials. Analytical characteristics of pectic substances were determined by conductometric titration, and complexing ability was determined by standard complexometric titration.

Samples of watermelon/desert gourd varieties were selected in the regions of their industrial cultivation in the consumption-ready maturity stage. For analysis, three types of segments were cut from each fruit. Segments were cleared of pulp, leaving rind and sub-rind tissue. Segments obtained
from each variety were combined, disintegrated, and then the average sample was isolated and analyzed for specified parameters in 3 replicates.

3. Results

Table 1 shows the results of physicochemical testing of the studied cucurbits samples.

**Table 1.** Physicochemical parameters of the studied samples of *Citrullus* species varieties

| Parameters                              | Characteristics of desert gourd varieties | Characteristics of watermelon varieties |
|-----------------------------------------|------------------------------------------|----------------------------------------|
| Mass fraction of dried substances, %   | Pektinovyy 3.89±0.1                      | Leader 3.11±0.1                        |
|                                         | Diskhim 3.52±0.1                         | Ranniy Kubani 3.34±0.1                 |
| Mass fraction of total (titrable) acids, % | 0.12±0.05                               | 0.13±0.05                             |
|                                         | Leader 0.13±0.05                         | Ranniy Kubani 0.14±0.05                |
|                                         | Ranniy Kubani 0.15±0.05                  | Astrakhanskiy 0.15±0.05                |
| Mass fraction of vitamin C, mg%         | Pektinovyy 9.45±0.1                      | Leader 8.69±0.1                        |
|                                         | Diskhim 8.86±0.1                         | Ranniy Kubani 8.75±0.1                 |
|                                         | Leader 8.69±0.1                         | Astrakhanskiy 8.81±0.1                 |
| Mass fraction of sugars, %              | Pektinovyy 2.68±0.1                      | Leader 2.28±0.1                        |
|                                         | Diskhim 2.94±0.1                         | Ranniy Kubani 2.48±0.1                 |
|                                         | Leader 2.28±0.1                         | Astrakhanskiy 2.58±0.1                 |

The results of analysis summarized in Table 1 demonstrate a high content of dry substances in the rind of different varieties of *Citrullus* fruits. The dry substance content varies from 3.52 to 3.89% in desert gourds and from 3.11 to 4.20% in watermelon varieties. The content of total (titrable) acids is similar in all varieties ranging from 0.12% in the Pektinovyy variety to 0.15% in the Astrakhanskiy variety. Vitamin C content varies slightly and is 2.68 - 2.94 mg% in desert gourd varieties and 2.28 - 2.58 mg% in watermelon varieties. Sugar content varies from 2.28% in the Leader variety to 2.94% in Diskhim fruits.

In order to assess the value of the studied raw material for use in the industrial production of pectin and pectin products, the content of pectic substances and their fractional composition were determined. The results of this analysis are shown in Figure 1.

**Figure 1.** Fractional composition of pectic substances in different *Citrullus* species varieties, % of mass of dry substances: 1 – Pektinovyy, 2 – Diskhim, 3 – Leader, 4 – Ranniy Kubani, 5 – Astrakhanskiy

The data shown in Figure 1 suggest desert gourds and watermelons being one of the sources of industrial raw material for pectin production. Although the content of soluble pectin is low and varies from 0.81 to 0.92% in desert gourd varieties (Pektinovyy and Diskhim), and ranges from 0.89 to 0.96% in watermelon varieties (Leader, Ranniy Kubani, Astrakhanskiy), the protopectin content of all varieties studied is quite high and ranges from 7.95% in the Diskhim variety to 11.32% in the Astrakhanskiy variety. Accordingly, the total content of pectic substances in all *Citrullus* samples is quite high: from 8.76% (Diskhim) to 12.21% (Astrakhanskiy).
In order to evaluate qualitative variables of pectin’s of the raw material studied, analytical characteristics of pectin’s were investigated to determine the feasibility of use of the obtained pectin’s for production of functional products. The results obtained are summarized in Table 2.

Table 2. Analytical characteristics of pectin’s in different varieties of Citrullus species

| Parameters                        | Desert gourd varieties | Watermelon varieties |
|-----------------------------------|------------------------|----------------------|
|                                   | Pektinovyy | Diskhim | Leader | Ranniy Kubani | Astrakhanskiy |
| Mass fraction of free carboxyl groups, % | 5.9        | 6.0     | 5.6    | 5.7         | 5.6            |
| Mass fraction of esterified carboxyl groups, % | 10.8       | 11.2    | 10.0   | 12.3        | 11.6           |
| Mass fraction of methoxyl groups, % | 4.9        | 5.8     | 4.3    | 5.4         | 4.7            |
| Mass fraction of acetyl groups, %  | 0.08       | 0.07    | 0.09   | 0.09        | 0.08           |
| Degree of esterification, %       | 66.7       | 71.6    | 66.8   | 70.2        | 70.5           |
| Mass fraction of polygalacturonic acid, % | 60.1       | 62.7    | 55.8   | 57.1        | 61.1           |

The data in Table 2 show a high content of free carboxyl groups in isolated pectin samples, which indicates their good complexing abilities. All samples have an esterification degree above 50%, which allows determining the conditions of formation and/or condensation of food compositions. An additional factor indicating the possibility of conventional use of pectic substances from Citrullus plants is their low content and high mass fraction of polygalacturonic acid.

To study detoxification properties of pectin isolated from Citrullus fruits, we evaluated the complexing ability of pectin’s obtained from different varieties of Citrullus species. The results of these tests are shown in Figure 2.

Figure 2. Complexing ability of different varieties of Citrullus species: 1 – Pektinovyy, 2 – Diskhim, 3 – Leader, 4 – Ranniy Kubani, 5 - Astrakhanskiy

The results of analysis confirm a high complexing ability of the obtained pectin’s, which ranges from 318 mg Pb2+/g pectin in the Ranniy Kubani variety to 388 mg Pb2+/g pectin in the Pektinovyy variety. Pectin complexing ability of other varieties fall within these limits. Based on the study results, we developed a process flow diagram for complex processing of Citrullus (desert gourd and watermelon) fruits (Figure 3).

The studied varieties of desert gourd and watermelon fruits grown in Krasnodar Krai which is in the south of Russia - Diskhim, Pektinovyy, Leader, Ranniy Kubani and Astrakhanskiy - can be used for production of functional foods which present a healthy trend accompanying the development of the modern human society.

High incidence of such disorders as diabetes mellitus, obesity, cardiovascular diseases, etc. raise the need to include such biologically active compounds as pectic substances in a healthy human diet.
EU 432/2012 recommends including pectic substances in a diet to lower blood cholesterol and glucose levels.

![Diagram of process flow for pectin extract from Citrullus fruits](image)

**Figure 3.** Process flow diagram for pectin extract from *Citrullus* fruits

It was found that the highest total pectin content was in fruits of the Astrakhanskiy and Ranniy Kubani varieties ranging from 12.21% and 11.59% by mass of dry substances, respectively, while the lowest was in the Diskhim variety (8.76%). At the same time, in almost all studied varieties of fruits the mass fraction of protopectin in the rind was higher relative to the content of hydrated pectin.

The results of evaluation of analytical characteristics of pectic substances showed that pectin’s of *Citrullus* fruits were highly esterified and have a relatively high content of galacturonic acid (with the highest in Leader, Astrakhanskiy and Diskhim varieties), methoxyl group (Diskhim and Ranniy Kubani), free carboxyl group Pektinovyy) and low content of acetyl group (Diskhim and Pektinovyy).

These results suggest the expediency of expanding the processing volumes of investigated varieties of *Citrullus* species for production of functional foods used for prevention of diseases related to metabolic disorders.

### 4. Conclusion

Results of the study of watermelons and desert gourds demonstrated that their complex processing is feasible and reasonable. *Citrullus* pulp is expedient to be used for production of juice, "honey" (nardek), jelly, syrup, marmalade, pastilles and jam.

Equally valuable are also seeds of watermelons. They can serve as a raw material source for production of valuable oil rich in biologically active substances.
The rind of watermelon varieties, in addition to a relatively low-tonnage candied rind production can be considered as a potential source for production of liquid pectin-containing products. Full fruits of desert gourds can also be used for the same purposes.

The current volume of the Russian market of pectin-containing products is $80-100 million, while the capacity of the food pectin market is at least twice higher. As functional foods become the main trend in the modern society, the demand for pectin-containing foods is growing. This, in turn, causes the expansion of the range of these products. In Europe, consumption of these products grows due to food manufacturers' refuse to use ingredients of animal origin, in particular gelatin.

Forty percent (40%) of the world market of food pectin-containing products is occupied by drinks, confectionery and canned goods. Pectin use is expected to show a similar trend over the forecast period. At the same time, the market will grow by an average of 7.5%.

Thus, the need to expand the range of alternative sources of pectic substances makes it expedient to master the technology of a complex processing of various types of cucurbits, in particular watermelon and of desert gourd varieties.

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