The use of negative temperatures during storage and transportation of apple fruits

S V Avilova¹, A A Gryzunov¹ and V N Kornienko¹

¹All-Russian Scientific Research Institute of Refrigeration Industry (VNIKHI), Branch of FGBNU “V.M. Gorbatov Research Center for Food Systems” RAS, 12, Kostyakov St., Moscow, 127422, Russian Federation

E-mail: mail@vnihi.ru

Abstract. The main task on the way of vegetable produce from producer to consumer is reducing losses and preservation of its physical, chemical, nutritional and organoleptic properties for a long time. Refrigeration, being the basis of all up-to-date technologies for separate sections of the continuous cold transport chain, allows prolonging shelf life of fruit and vegetable products without considerable loss of quality. The paper presents research results of the negative temperature influence on keeping capacity of apple fruits, grown in the Moscow region. During storage, the control batch was stored in a chamber at (1 ± 0.5) °C and the experimental one at minus (2 ± 0.5) °C. It was revealed that physicochemical properties, typical of each variety, determined the degree of resistance of fruits to various storage conditions. The interconnection between the concentration of soluble substances in fruits and their resistance to low temperatures was defined. The researchers managed to reduce fruit diseases as well as the rate of decline in the level of organic acids, sugars, pectin and tannins in comparison with conventional storage technologies using positive (1 ± 0.5) °C temperatures. The commercial output increased by (4.9 – 13.6) %, depending on the apple variety; natural mass loss of a number of investigated fruits decreased to 5% during 6 months of storage. It has been established that maintaining minus (2 ± 0.5) °C temperature conditions during storage and transportation allowed reducing losses up to 15% and increasing shelf life 1.2 - 1.5 times.

1. Introduction
Traditionally, apple fruits present a considerable portion in the Russian fruit market. However, lately, the tendency to reduce apple consumption has been observed [1]. The major reasons were the relative high cost of imported apples, and the failure of the domestic producers of fruits and vegetables to meet consumers’ demand for cheap fruits owing to imperfection of the resource and technical base of storage and transportation as well as insufficient optimization of logistics schemes by local suppliers [2].

Currently, the Russian fruit market has undergone a turnaround. According to independent experts the portion of apples, produced in the Russian Federation, accounts about 70% [1]. A maximal preservation of the crop gives the possibility to provide the population with fruits of high quality in the course of the year. Therefore, the urgent task is to implement high-efficiency technologies of apple storage together with putting into operation new fruit storehouses [3].

Refrigeration that is the basis of all up-to-date technologies used in separate sections of the continuous cold transport chain (CCTC) makes it possible to prolong fruit and vegetable shelf life
minimizing significantly quality losses at the expense of the maximal retarding all physiological and biochemical processes. The storage process includes the CCTC technological stages: postharvest transportation, pre-cooling, cold storage, transportation using refrigerated vehicles, storage before realization [4, 5]. The main task on the way of vegetable products from producer to consumer is to reduce losses and preserve physical, chemical, dietetic and organoleptic properties for a long period of time.

2. Problem statement

The application of near-cryoscopic temperatures is one of the possible methods of fruit, berry and vegetable storage [6, 7]. However, at negative storage temperatures, a number of problems arise associated with the changes of quality and marketable state of apples, deterioration of general organoleptic characteristics, reduced resistance to infectious diseases, and shortened shelf life due to the transition of the moisture in them into a solid state. “Renet Semirenko”, “Renet champagne”, “Jonathan”, “Rozmary” and other varieties show quality lowering at low subcryoscopic storage temperatures (near minus 3 °C). On the contrary, most varieties, which are stored at the temperature slightly higher than cryoscopic one, show good organoleptic characteristics [8].

Therefore, it is important to study the keeping capacity of different varieties of apples as well as their transportability in the range of near-cryoscopic and subcryoscopic temperatures.

3. Materials and methods

The objective of this research was to define the possibility of apples, grown in the Moscow region, to be stored and transported at negative temperatures. Studies were aimed at solving the problems, specifying the relationship between internal processes in fruit tissues and their external manifestations with fruit losses during storage and transportation at minus (2 ± 0.5) °C.

The subjects of study were the following varieties: “Antonovka vulgaris”, “Kuybishhevskoe”, “Podarok Grafskomu”, “Welsey”, “Lobo”. The fruits met the requirements of the first marketable grade according to GOST 21122–75.

During storage, the control batch was stored in a chamber at (1 ± 0.5) ° C temperatures recommended by GOST 27819–88, and the experimental one at minus (2 ± 0.5) °C. IS-203.4 metering apparatuses (measurement accuracy ± 0.1 °C) were used to control air temperatures in the free space of the net storage volume of the chamber as well as on the surface of the fruits. The number of control points of air temperature and the location of the sensors were determined in accordance with the recommendations of GOST 27819–88. Relative humidity was maintained in the range from 93% to 95%, and was controlled using a TEMP-3.20 single-channel thermohygrometer (humidity measurement range 0 – 100 %).

Studies of physicochemical indices of the apple keeping capacity were carried out using the methods of the Department of fruits and vegetables storage and processing of the Russian State Agricultural University of K.A. Timiryazev Moscow Agricultural Academy [9].

4. Results and discussion

The following indices were used as criteria for estimation of fruit keeping capacity: tissue firmness, content of sugars, acids, pectin, tannins, and coloring substances before and after storage. Physicochemical characteristics of the apple varieties selected for studying before and at the end of the studies are shown in Tables 1 and 2.

It was defined that “Lobo”, “Welsey”, “Podarok Grafskomu” varieties had a stronger peel and a relatively high pulp density. There was also a higher content of sugars, pectin and tannins (Table 1). The concentration of sugars in these varieties decreased slower: for the “Lobo” variety towards the end of the storage the decrease was by 3.3%, while for the “Antonovka vulgaris” – by 5.2%.

Organic acids account for a rather significant portion of soluble dry substance in fruits. In our studies, this value ranged from 0.63% to 0.73% before storage, depending on the variety. The varieties
“Antonovka vulgaris”, “Welsey”, “Lobo” were remarkable for a higher content of organic acids (Table 2).

During further storage the content of acids in fruits decreased continuously, and the rate of decreasing differed depending on the variety. Table 2 gives the data on the degree of influence of different temperature conditions on the metabolism of organic acids in various varieties, and consequently, on their keeping capacity.

### Table 1. Physicochemical characteristics of apples before storage and after 6 months of storage at minus (2 ± 0.5) °C

| Variety                  | Tissue firmness, g/mm² | Content, % |  |  |  |  |  |  |
|--------------------------|------------------------|------------|---|---|---|---|---|---|
|                          | skin                   | pulp       | sugars | pectin | tannins | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| “Lobo”                   | 612                    | 568        | 420    | 368    | 13.8   | 10.5 | 3.5 | 2.7 | 0.28 | 0.22 |
| “Welsey”                 | 518                    | 450        | 302    | 284    | 13.0   | 9.4  | 3.0 | 2.6 | 0.24 | 0.20 |
| “Podarok Grafskomu”      | 546                    | 455        | 283    | 243    | 12.6   | 7.6  | 2.7 | 1.9 | 0.19 | 0.15 |
| “Kuybyshevskoe”          | 428                    | 320        | 215    | 180    | 10.5   | 6.5  | 2.2 | 1.6 | 0.15 | 0.12 |
| “Antonovka vulgaris”     | 340                    | 280        | 248    | 220    | 11.3   | 6.1  | 2.5 | 1.8 | 0.16 | 0.12 |

1 – before storage; 2 – after 6 months of storage

So, towards the end of storage the content of organic acids in the “Antonovka vulgaris” variety decreased about 2.4 times at (1 ± 0.5) °C at a highest initial value (0.73%), and 2 times at minus (2 ± 0.5) °C; in the “Welsey” variety (initial content of 0.72 %) it decreased 1.38 times and 1.14 times, respectively. The “Lobo” variety (initial acid content of 0.70%) turned out to be the most stable relating to this index - the decrease of only 1.23 times at positive and 1.08 times at negative storage temperatures.

### Table 2. Change of the content of organic acids in apples after 6 months of storage

| Variety                  | Content of organic acids in apples, %, Before storage | After storage at temperatures |
|--------------------------|------------------------------------------------------|-------------------------------|
|                          |                                                      | (1 ± 0.5) °C | minus (2 ± 0.5) °C |
| “Lobo”                   | 0.70                                                 | 0.57                         | 0.65                         |
| “Welsey”                 | 0.72                                                 | 0.52                         | 0.63                         |
| “Podarok Grafskomu”      | 0.69                                                 | 0.35                         | 0.45                         |
| “Kuybyshevskoe”          | 0.63                                                 | 0.32                         | 0.43                         |
| “Antonovka vulgaris”     | 0.73                                                 | 0.30                         | 0.36                         |

During storage, the consumption of organic acids in fruits occurs faster than sugars, which, most likely, is due to their direct involvement in oxidation transformations, while sugars must be preliminarily pre-phosphorylated.

The greatest amount of organic acids is found in the fruit pulp; in the skin, their quantity is much less. During storage, because of different acidity of certain fruit tissues, the process of decarboxylation of the malic acid at different intensity takes place (malic acid makes up 70% of all organic acids in fruits). For this reason, the scald of the “Antonovka vulgaris” and “Kuybyshevskoye” varieties began in certain parts of the fruits, which were characterized by a lower acid content and a faster rate of acid consumption. The “Lobo” variety showed a smooth and slight reducing in acids at minus (2 ± 0.5 °C) (Table 2).

The degree of resistance of fruits to various storage conditions was determined by physicochemical properties, typical of each variety. The results of the experiments, cited in Table 3, showed that there was a clear tendency towards the increase of qualitative indices of stored products at temperature...
decreasing. The affection of fruits by various diseases at minus (2 ± 0.5) °C decreased significantly as compared to the positive temperature condition: from 4.9% for the “Lobo” variety to 13.6% for the “Antonovka vulgaris” one (Table 3).

Table 3. Natural mass loss, physiological changes in apple tissues and commercial output after 6 months of storage depending on storage temperature

| Variety                  | Fruit natural mass loss, % | Fruit affection by diseases, % | Commercial output, % |
|--------------------------|----------------------------|--------------------------------|----------------------|
|                          | (1 ± 0.5) °C | minus (2 ± 0.5) °C | (1 ± 0.5) °C | minus (2 ± 0.5) °C | (1 ± 0.5) °C | minus (2 ± 0.5) °C |
| “Lobo”                   | 7.6          | 4.1                | 9.1           | 4.2          | 90.9         | 95.8         |
| “Welsey”                 | 8.6          | 5.0                | 12.8          | 4.8          | 87.2         | 94.2         |
| “Podarok Grafskomu”      | 9.2          | 5.7                | 10.3          | 8.7          | 89.7         | 91.3         |
| “Kuybyshevskoe”          | 10.8         | 7.4                | 30.3          | 21.8         | 69.7         | 78.2         |
| “Antonovka vulgaris”     | 12.1         | 8.2                | 52.0          | 38.4         | 48.0         | 61.6         |

Keeping capacity of apples is their ability to be preserved during a certain time without significant mass losses, injury by physiological disorder and phytopathogenic microorganisms as well as without deterioration of vendible and food characteristics. The fruit quality, formed during the growing process and changed during the movement through the CCTC stages, and its keeping capacity are interrelated and determined by the physiological and biochemical state of the fruit depending on the temperature storage and transportation conditions (Table 3). It was defined that the commercial output increased by 8.5% for the “Kuybyshevskoe” variety and by 13.6% for the “Antonovka vulgaris” one when applying lower temperatures. Besides, natural mass losses of these varieties decreased by 3.4% and 3.9%, respectively. Concerning the “Lobo” variety the commercial output was of 4.9% and mass losses of 3.5%. The “Welsey” variety showed the commercial output of 7.0% and mass losses of 3.6%.

5. Conclusion
Results from studies indicated that storage and transportation of apples at negative temperatures within the temperature range of minus (2 ± 0.5) °C led to a considerable retardation of natural physiological reactions in them.

Moreover, the nature, speed and depth of qualitative and quantitative changes depended on biological particularities of the variety. In the course of the experiments it was found that the chemical composition of fruits determined the degree of fruit resistance to physiological disorders under different conditions of storage.

Also, it was established that the ability of fruits to adapt to low temperatures depended on the concentration of soluble substances. “Lobo”, “Welsey”, “Podarok Grafskomu” varieties adapted well to near-cryoscopic temperatures. As a result, they will be of high nutritional value, of good marketable quality, and safe when reaching a consumer after going through all CCTC stages in strict compliance with temperature conditions offered.

Storage and transportation of apple varieties cited using the refrigerating technology offered, allow reducing losses up to 15% and increasing shelf life 1.2-1.5 times, at the same time, preserving high food value as compared to current technologies applying positive temperatures recommended by standards.
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