

THERMAL QUARANTINE OF APPLES AS A FACTOR FORMING ITS MECHANICAL PROPERTIES

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Summary. The paper presented an attempt at application of thermal treatment to the apples of Gala and Jonica cultivars, stored in a regular cold store and in an ULO chamber (1.5% oxygen + 2.4% carbondioxide). The effects of the following parameters: time of storage, change of storage conditions and thermal treatment (quarantine) were analysed as affecting elastic characteristics of apple flesh, which is an important factor to maintain the high quality of fruit during storage and market turnover. The stored apples were successively taken from both chambers (every 30 days) and heated for 96 hrs at the temperature of 39 deg C. Next, the fruit were stored for 17 days at the temperature of 6 and 20 deg C. The effect of quarantine was compared with the control fruit. Cylindrical samples (d=13 mm, h=10 mm) were taken from apple flesh and subjected to compression and double compression tests (TPA). Under the mentioned conditions the quarantine retained higher elasticity and cohesion of the apple flesh samples, both fresh and stored in ULO chamber. Heating of apples being more ripened (taken from regular cool-store) reduced flesh elasticity in apples of Gala cultivar or there were no significant differences in comparison to control apple sample (for Jonica cultivar).

Key words: apples, storage, thermal quarantine, mechanical properties.

INTRODUCTION

Apples (*Malus domestica* Borkh.) are among those fruits that have a great economic importance. The world production of apples is currently estimated at approx. 53 million tons [Jaeger 2001] and is higher by about 50% compared to the production level of 1980. In Poland annual production of apples is about 2 million tons including approximately 500 thousand tons being appreciated as dessert varieties. The process of fruit storage is complex, and the final effect of the storage is dependent on numerous factors.

The first group of factors that affect fruit storage are those that depend on the initial properties of the stored material, related to their variety's properties, cultivation conditions in the period of ripening, stage of ripeness at harvest, etc.

The second group of factors includes those related to the storage conditions: storage duration, temperature in the storage chamber, humidity, concentration of O₂, CO₂ and ethylene [Saltveit 2003]. Storage of various apple cultivars under the same conditions may yield totally different results [Tomala 2002, Lange 1995].

Highly important for the quality of apples are the conditions of their storage after their removal from the storage chamber. Tu et al. (2000) observed that apples (Braeburn, Jonagold) stored at 20°C at relative humidity of 30, 65 and 95% display varied quality traits. Firmness and apple mass losses in the course of storage were slow under conditions of high humidity (95%), but those conditions caused an appearance of mealiness of apple meat. Similar studies were conducted by Johnston (2002) who estimated changes in the textural parameters (firmness, tissue softening) of apples of Granny Smith and Pacific Rose cultivars during their storage at 0.5°C, and then at 20°C, i.e. under such conditions as can be frequently encountered in commerce. Apple softening takes place in three stages – first is the phase of slow softening, then the loss of firmness is more intensive. In the third stage of storage the loss of firmness in time becomes stabilised at a constant low level.

The run and the quality of the process of apple storage are closely related with precise determination of harvest ripeness of the apples [Lange 1995, Tomala 2002].

Fellman (2003) stored apples with varied harvest ripeness under CA conditions as well as in a conventional refrigerated storage facility. On the basis of sensory analysis he observed that optimum test and flavour values of the fruit were obtained immediately prior to their reaching the climacteric point (determined on the basis of ethylene concentration). When apples getting into the chamber were more ripe at the moment of harvest, the time to reach an optimum flavour after removal from CA was notably reduced.

Johnson (2003) proposed removal of excess ethylene from the chamber in the course of storage, spraying fruit surface with AVG after harvest, or combination of those two measures. Fruits sprayed with AVG were notably firmer than the control sample. Good results were also obtained through the removal of ethylene from the storage chamber. When both measures were applied simultaneously, higher values of strength traits of the fruits (firmness) continued for a longer time, but this was accompanied by frequent darkening of the seed pockets. Other methods for maintaining higher textural parameters include spraying with a solution of CaCl₂ prior to harvest [Tomala 2002], precise determination of harvest time [Lange 1995], or measures aimed at rapid stabilisation of conditions of controlled atmosphere [Skrzyński 1995, Verhoven 1995].

Veltman et al. (2003) presented a dynamic system of control (DCS) that can be accepted as the successor of the traditional system of atmosphere control. Instead of maintaining a permanent stabilised level of atmosphere components, they were changed using ethanol vapours, product of fermentation, as the indicator. When their concentration reached a specific value, the level of oxygen was automatically raised (by about 0.1%) so as to stop the fermentation of fruit flesh. The level of O₂ concentration was always close to the compensation point, but closely controlled by the dynamic changes taking place in the fruit material.

Apples are among those fruits that are extensively and frequently studied in terms of their mechanical properties. The tissue of apple flesh is considered to be a homogeneous structure, but the flesh of the fruit displays various properties that depend on variety features. Differences in mechanical strength are due to the fact that in various cultivars the intercellular space is filled with gaseous phase to varying degrees. The structure of fruit is a mixture of solids, liquid and gas [Johnston 2001b].

The textural parameters of fruit materials are often tested with instrumental (rheological) methods consisting in the application of external load and determination of changes in the material under its effect [Alvarez 2002, De Long 2000]. Another direction of study is based on utilisation of non-destructive effects [De Belie 2000, Chen 1995, Chen 1993, Paulus 1997] for prediction of material behaviour in processing, transport and storage processes.

THERMAL QUARANTINE OF FRUIT

Thermal treatment (quarantine) of fresh fruit and vegetables was used as early as the nineteen thirties [Hallman 2000, Neven 2000, Lurie 1998] for the purpose of pest control (fungi, mildew) in fresh agricultural materials. Post-harvest heating is applied for disinfection and disinsectisation of an increasingly large group of materials, including flowers, fruits and vegetables [Lurie 1998]. Among researches involved with such problems there is agreement that thermal treatment conducted at temperatures above 35°C is conducive to retarded ripening of various fruit species [Lurie 1998]. Usually, thermal treatment is performed within temperature range of 35-46°C, using air, humidified air or water as heat sources. The duration of treatment with warm air is 12-96 h. This is a process classified among the LTLT (Low Temperature Long Time) group of thermal processes. Shelie (2000) studied the applications of such heating media for the quarantine of mango, papaya, grape-fruits and oranges. Notable greater rates of heating were obtained for water and humidified air. The content of CO₂ and O₂ within the fruit was related to the heating medium employed. Modified gas composition of the internal atmosphere was conducive to improved effectiveness of thermal treatment as disinfection measure. The results of the study indicate that heating in air, under conditions that inhibit fruit respiration, does not predispose the fruit to damage. Enforced circulation of dried air with modified O₂ and CO₂ composition may have promising application for fruit disinfection in the future. Susceptibility or tolerance to thermal treatment of various materials depends on the level of thermally resistant proteins at the time of harvest, and on the post-harvest production of proteins, caused by the thermal shock [Paull 2000].

One of the most important effects of thermal quarantine is high mortality rate of pathogens (fungi, mildew, larvae, fruit flies) subjected to the quarantine treatment. Insects, as heterothermic organisms, are particularly sensitive to heat. Studies on the metabolism of those organisms under various thermal conditions indicate a certain adaptation on their part to changing thermal conditions [Neven 2000].

The advantages resulting from the application of thermal quarantine are not limited to insect destruction, limitation of fruit softening or stoppage of the production of ethylene. Such treatment may help improve the firmness of fruits in storage, which is of enormous importance for transport and trade. The effect of improved firmness can also be achieved through soaking fruit in 0.6-4% solutions of CaCl₂ [Valle 1998, Whitaker 1997, Lurie 1996]. Tomala (2002) reports that good results can be obtained by spraying fruits with a solution of CaCl₂ about 10-12 days prior to their harvest. Apples treated with such spraying have notably greater firmness after long-term storage.

Infiltration with calcium chloride can be combined with thermal quarantine [Whitaker 1997, Lurie 1996]. Whitaker studied the effect of heating of apples cv. Golden Delicious at a temperature of 38°C (0-4 days) and of infiltration with 2% CaCl₂ on textural parameters of the fruit after storage. He determined the content of lipids during the quarantine and after 15 weeks of storage at 0°C. The effect of the treatment on the content of lipids in the layer beneath the fruit skin was more pronounced after treatment at 38°C than after soaking in CaCl₂ alone or when the infiltration was combined with the heating. Damage to cell wall membranes during heating for 1-2 days gave an unfavourable effect for further storage. Better effects were obtained after 3-4 days of heat treatment.

Apart from studies on storage of apples under conditions of quarantine a number of model studies have been conducted, the objective of which was determination of the effect of storage under various conditions on physical features of fruit and changes in their ripening [Johnston 2001a, Johnston 2001b, Watkins 2000, Shelie 2000, Tang 2000].

Intensive studies conducted in recent years on post-harvest thermal treatment of plant materials are a promising way of controlling not just the texture but also the taste values of the stored

materials. However, those are laboratory and empirical experiments, based on a variety of methods and focused on individual fruit species or cultivars.

Application of thermal treatment of fruit material after the harvest is difficult from the technical point of view. Heating of large amounts of material within a short period of time (conditions during harvest) and at a suitable rate is not an easy task, considering that the use of warm air will extend the duration of the operation due to its low thermal capacity.

Of interest from the technological point of view is quarantine application to smaller batches of material already in storage and assessment of the effects of the treatment with relation to its physical properties before it reaches the market. Therefore, what is important from the practical point of view is an extensive research that would take into account such factors as variable stage of ripeness of the material and industrial conditions of storage.

MATERIALS AND METHODS

The material used in the study came from an orchard of an area of approx. 20 ha, located 10 km from Nałęczów. The stands of apple trees (*Gala* and *Jonica*) whose fruits were used in the study were located near the place of their subsequent storage. The apple trees grew on M9 rootstock and their age was, on average, about 5 years. Harvest of apples of all the cultivars was made in the period from 27th September to 1st October, 2006. Harvest ripeness of the apples was determined on the basis of the starch test. Apples for the tests were taken from the first batch (first harvest time) that was meant for long-term storage.

Immediately after harvest the fruits were placed in refrigerated chambers located within the orchard area. A part of the fruits (approx. 50%) were stored in a conventional refrigerated storage shed, while the other fruits were stored under conditions of controlled atmosphere (ULO). After the chamber was closed and sealed, it was filled with nitrogen from a generator so as to reduce the level of oxygen to 5-6%. ULO conditions, i.e. O₂ concentration below 2%, stabilised through the respiration of the fruits. The ULO chamber was equipped with a high-efficiency CO₂ adsorber that removed excess of the gas, reducing the risk of occurrence of surface burn, while during the stabilisation of the chamber parameters low concentration of CO₂ accelerated the uptake of excess oxygen.

The level of O₂ was 1.4-1.5% at the initial period of storage and 1.6-1.7% at the final stage of storage. The gradual increase in concentration of O₂ was necessary to preserve a certain reserve of oxygen to prevent an occurrence of anaerobic processes. Anaerobic respiration begins for most apple cultivars at concentrations below 1% O₂ for fresh apples. The level of anaerobic respiration threshold (compensation point) is not constant and increases with extension in the time of storage. Concentration of CO₂ was stabilised at the level of 2.2 – 2.4%. Storage temperature in both chambers was 1.5-2°C. In the ULO chamber the condition of the atmosphere was controlled. Readouts of atmosphere parameters were taken automatically every 30 minutes. In the ULO chamber measurement equipment was employed for control of O₂ and CO₂ levels, operating in a coupled system. Measurement of the level of O₂ was made with the paramagnetic method, while the content of CO₂ was determined with a meter operating on the principle of IR absorption. Control of the condition of the atmosphere consisted in taking samples of gas from the ULO chamber to a chamber containing the metering equipment and located on the outside of the ULO chamber, and performing the measurements. The time needed for taking a reading was about 15s. The measurements were taken with an accuracy of 0.01% by volume of the shares of particular components of the atmosphere.

The experiment was divided into post-harvest testing of the material and 5 in-storage stages. It was assumed that the duration of storage of the fruits in both the conventional storage shed and in the ULO chamber would be 150 days. The first stage of the experiment was conducted on fresh

apples, the remaining stages – on apples taken from both storage chambers. Fruits from conventional storage were sampled at 30-day intervals, counting from the date of their placement in storage. Material from the ULO chamber was sampled also every 30 days, counting from the date of stabilisation of ULO conditions in the chamber.

The fruits samples from the storage chambers were divided into 5 parts:

- apples for estimation of textural parameters after their removal from storage (variant A),
- material for storage at 6°C without thermal quarantine (variant B),
- material for storage at 6°C after thermal quarantine (variant C),
- material for storage at 20°C without thermal quarantine (variant D),
- material for storage at 20°C after thermal quarantine (variant E).

Prior to the measurements, apples from the five groups were subjected to thermal stabilisation for 24 hours at 20°C.

After removal from the storage chambers the fruits were placed in chambers previously heated to 39°C. Control of the conditions in the chambers was performed by means of temperature recorder type Vectron MRT-06-2. The temperature was controlled both in the air of the chamber and in the flesh of the heated apples. The measurements were taken by means of Pt-Mo thermocouples, with an accuracy to 0.1°C. Readouts were recorded every 5 minutes.



Fig. 1. Sample forming

From the central part of the apple (Fig.1.) a slice was cut, about 15 mm thick, so that the planes of cutting were perpendicular to the axis of the fruit. Next, using a cylindrical knife with a diameter of $\phi=13\text{mm}$, cylindrical core samples with a height of $h=10\text{ mm}$ were taken (Fig. 2).



Fig. 2. Cylindrical core samples of apple flesh

The diameter of the core samples was determined on the basis of preliminary tests consisting in computer image analysis of slices cut from the apples of each cultivar. The aim of the image analysis was the determination of distribution, within the fruit structure, of seed pockets, bundles of vessels, and calculation of their distances from the fruit skin.

The height of the core samples was determined on the basis of literature data [Paoletti 1993, Alvarez et al. 2002] and on our own measurements of geometric features of experimental material.

Apple flesh core samples were subjected to compression using an Instron 4302 apparatus with Instron series IX software. Compression tests were conducted always at a constant rate of 50mm/min. The coefficient of sample deformation was 50%

During the compression the following parameters were recorded:

- force required to destroy the sample
- section inclination within the elastic range
- work of deformation
- hardness I and II in TPA test
- cohesiveness in TPA test

Results and discussion

Due to the rather complex form of the experiment, the results were arranged in accordance with the following order: variants of storage were designated with letters A-E, and thus:

- A – samples taken from storage (ULO and conventional refrigerated storage),
- B – samples from secondary storage for 21 days at 6°C (after removal from primary storage)
- C – results for samples after thermal quarantine (39°C, 4 days) and then stored (6°C, 17 days)
- D – results for samples stored at 20°C
- E – samples stored (20°C, 17 days) after thermal quarantine (39°C, 4 days).

Material stored under unfavourable conditions (variant D) displayed low values of strength parameters (Fig. 3).

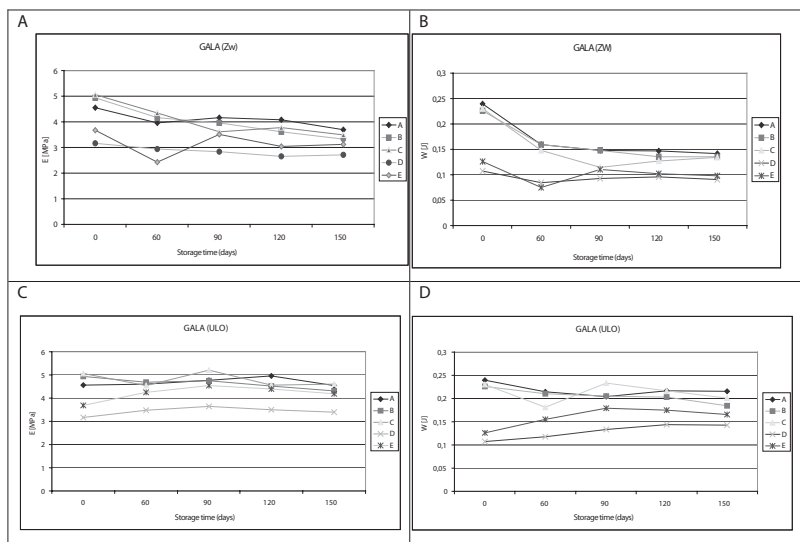


Fig. 3. Changes in strength parameters of apples cv. Gala stored under various conditions; A – modulus of elasticity (refrigerated storage), B – work of deformation (refrigerated storage), C – modulus of elasticity (ULO), D – work of deformation (ULO)

This relationship was observed for most parameters of apples of both Gala and Jonica cultivars. This concerns the modulus of elasticity E_m and work of deformation W , and hardness of samples T. The thermal quarantine caused significantly higher values of the modulus of elasticity and work of deformation for fruits of cv. Gala from ULO storage only for the variant E. Changes in the values of E_m and W were insignificant for all the variants of storage of Jonica apples from conventional storage (Fig. 4A, 4B).

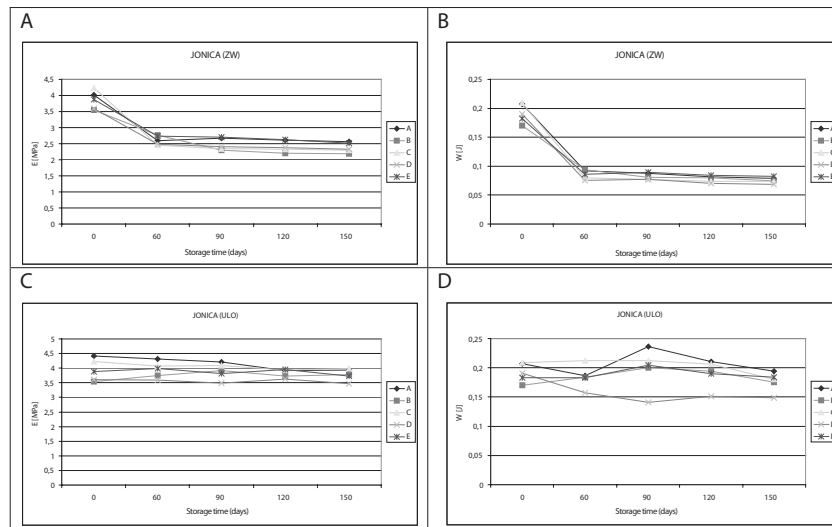


Fig. 4. Changes in strength parameters of apples cv. Jonica stored under various conditions; A – modulus of elasticity (refrigerated storage), B – work of deformation (refrigerated storage), C – modulus of elasticity (ULO), D – work of deformation (ULO)

The application of thermal quarantine caused that higher values of W were retained in variant E for material from the ULO chamber (Fig. 4D). Changes in the values of work of deformation for the fruits stored in the refrigerated chamber were dynamic (Fig. 3B, 4B). The values of modulus of elasticity and work of deformation for the material from the ULO chamber were stable. The results of the PTA test (Fig. 5 and 6) are convergent with the results of the compression test.

The cohesiveness of apple flesh samples (Fig. 5B, D and 6B, D) varied for the two studied cultivars in a similar manner. The parameter did not display changes in values for the Gala cultivar stored in variant D (Fig. 5B, 5D), which means that storage under ULPO conditions does not affect the cohesiveness of samples during secondary storage under unfavourable conditions. The value of that parameter, for both chambers and variants, was approx. 0.04. Jonica (Fig. 6B and 6D) is a cultivar more susceptible to changes in storage conditions. The cohesiveness of its flesh in the ULO chamber and in variant D was higher by about 50% than in refrigerated storage, but at the same time significantly lower (Fig. 6D) than in the remaining storage variants. Similar values were obtained in measurements of hardness T1 and T2 of samples of both cultivars.

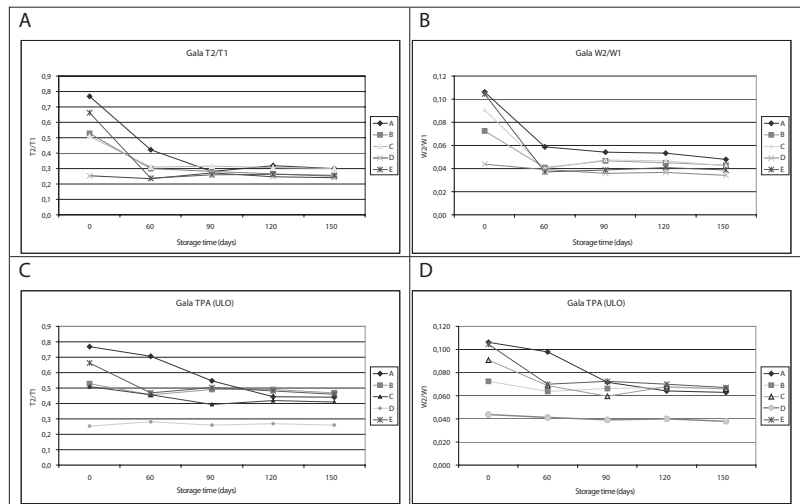


Fig. 5. Results of TPA test for fruits of Gala cultivar stored under various conditions: A – hardness I and II (refrigerated storage), B – cohesiveness (refrigerated storage) C – hardness I and II (ULO), D – cohesiveness (ULO)

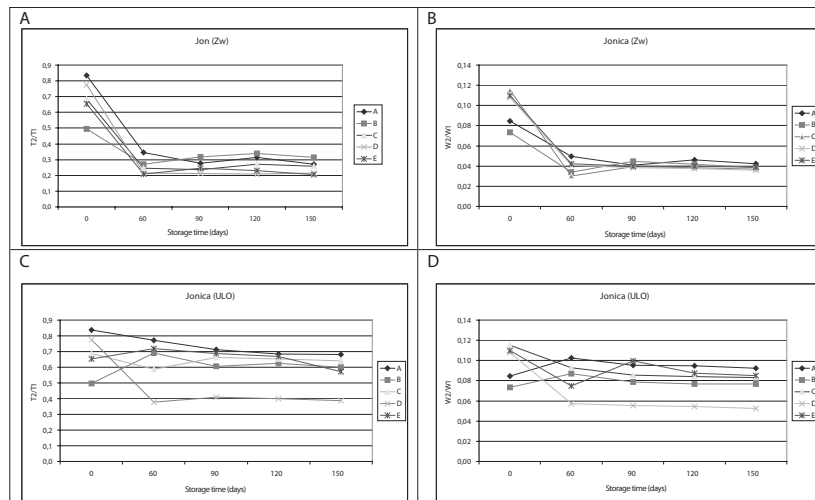


Fig. 6. Results of TPA test for fruits of Jonica cultivar stored under various conditions: A – hardness I and II (refrigerated storage), B – cohesiveness (refrigerated storage) C – hardness I and II (ULO), D – cohesiveness (ULO)

CONCLUSION

Thermal quarantine is a physical treatment that does not interfere with the chemical composition and does not cause unfavourable changes in fruit material structure. The presented study

on two apple cultivars indicates that it can be applied for material at various phases of storage ripeness. The effect of quarantine (with relation to retention of strength properties of the material) was more pronounced in material stored under ULO conditions which, as it is known, reduce the rate of fruit ripening. The duration of storage had an unfavourable effect on the retention of high strength properties in the conventional refrigerated storage chamber. This is due to the faster rate of fruit respiration under such conditions. Thermal quarantine can be applied without any significant deterioration of the strength properties, which is important from the viewpoint of trading and transport of the material. On the other hand the treatment takes notable time to perform and is not really economical in application at a larger scale. The proposed procedure of fruit storage, in spite of its cognitive values, may never find its way to practical application due to the energy consumption levels involved. Studies of this type should be developed with a broad sensory analysis, the results of which could help obtain a more detailed assessment of the balance of such a treatment.

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KWARANTANNA TERMICZNA JABŁEK JAKO CZYNNIK KSZTAŁTUJĄCY ICH WŁASNOŚCI MECHANICZNE

Streszczenie. W przedstawionej pracy wykonano próbę zastosowania zabiegu termicznego dla jabłek odmiany Gala oraz Jonica przechowywanych w chłodni zwykłej jak i komorze ULO ($1,5\%O_2 + 2,4\%CO_2$). Analizowano wpływ takich czynników jak czas składowania, zmiana warunków przechowywania oraz obróbki termicznej (kwarantanny) na kształtowanie właściwości sprężystych miąższu jabłek, które są ważnym czynnikiem wpływającym na utrzymanie wysokiej jakości owoców podczas składowania oraz obrotu towarowego. Owoce podczas składowania pobierano sukcesywnie z obu komór (co 30 dni) a następnie ogrzewano przez 96h w temperaturze $39^{\circ}C$. Surowiec składowano po tym zabiegu przez 17 dni w temp. $20^{\circ}C$ oraz $6^{\circ}C$. Efekt kwarantanny porównywano z próbą kontrolną. Z miąższu owoców pobierano próbki walcowe ($d=13mm$, $h=10mm$), które poddawano testom ściskania oraz ściskania podwójnego (TPA). Kwarantanna przeprowadzona w tych warunkach powodowała utrzymanie wyższej sprężystości oraz spoistości próbek miąższu owoców świeżych oraz przechowywanych w komorze ULO. Ogrzewanie surowca znajdującego się w stanie bardziej zaawansowanej dojrzałości (pobieranego z chłodni zwykłej) powodowało spadek sprężystości miąższu owoców odmiany Gala lub brak istotnych różnic w porównaniu z próbą kontrolną (odmiana Jonica).

Słowa kluczowe: jabłka, przechowywanie, kwarantanna termiczna, właściwości mechaniczne.