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INFLUENCE OF HYPOBARIC STORAGE ON THE QUALITY OF GREENHOUSE CUCUMBERS

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Abstract

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The aim of this study was to investigate the effect of hypobaric (10, 50 and 100 kPa) conditions and storage time on selected color, textural and chemical indicators of quality of greenhouse cucumbers. The smallest changes in total color difference, chroma and hue of cucumbers were observed in the samples stored at 10 kPa. The highest values of force at bioyield and energy to bioyield after 30 days of storage, as derived from a puncture test, at 48.7 N and 0.172 J, respectively, were observed in cucumbers kept at 10 kPa. After 30 days of storage, the cucumbers kept under hypobaric conditions underwent less extensive changes in dietary fiber, pectin and sugar content in comparison with those stored under atmospheric conditions. Hypobaric storage was found to contribute to the preservation of cucumber quality.

Key words: hypobaric storage, greenhouse cucumber, quality indicators

Introduction

Greenhouse cucumbers are among the most important vegetable crops in the Polish food industry, and production reached 224 000 tons in 2009 (Anonymous, 2009). Cucumbers which are consumed or processed directly after harvest deliver the greatest health benefits. However, this is not always possible, and the storage of fresh cucumbers may be necessary. The storage of raw food materials, including greenhouse cucumbers, is one of the challenges for food manufacturers and the agricultural and food industry. Fresh greenhouse cucumbers are perishable, and regardless of the degree and type of processing, they undergo physical, chemical and biological changes that affect their shelf-life and quality. Various storage methods are applied to maintain the quality of fresh greenhouse cucumbers.

Two storage methods, refrigeration storage (RS) and controlled atmosphere storage (CA), are applied in commercial storage of fresh cucumbers. The optimal RS temperature varies with the product, and temperatures of around 0°C are mostly commonly applied. Some products, including cucumbers, are sensitive to low temperature, and the recommended temperature range for refrigerated cucumbers is 10 to 12.5ºC at 95% RH (Saltveit, 2004). Storage temperatures below 10°C cause chilling injury in 2 to 3 days, and rapid loss of quality are observed at 15°C (Saltveit, 2004). CA storage does not effectively preserve the quality of fresh cucumbers. The fruit should be kept in an atmosphere with less than 2% O_2 content and less than 10% CO_2 content, at 12.5°C (Saltveit, 2004). Both RS and CA methods have certain disadvantages. Hakim et al. (1999) observed that biochemical and physiological processes in cucumbers are sensitive to low temperature. The same authors also demonstrated that when low temperatures were applied during RS, the investigated processes were not equally affected. The above indicates that low temperature refrigeration leads to high probability of cucumber spoilage. Symptoms of chilling injury include water-soaked spots, pitting and tissue collapse. Most fresh vegetables respond favorably to CA treatment. The preservation of their sensory and nutritional quality, prolonged storage life and lower risk of chilling injury are determined by the type of commodity, atmospheric concentrations of O_2 and CO_2, storage temperature and storage time (Wang, 1993; Wang and Qi, 1997). The above findings suggest that the metabolism of CA-stored cucumbers is difficult to control.

Storage under hypobaric conditions (HC) poses an alternative to RS and CA storage methods. HC storage systems are comprehensive, and they also protect commodities

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against ethylene-independent deterioration, including desiccation, decay and insect infestation (Burg, 2004; Salunkhe and Wu, 1973). Wu et al. (1972) tested the effect of various pressure levels on the ripening of stored tomatoes. Greenhouse and field-grown tomatoes were stored at 100, 62.8, 37.1 and 13.6 kPa. In the cited experiment, the ripening of green tomatoes kept under HC conditions was delayed, and their long-term viability was achieved. Green tomatoes refrigerated at 12.7°C and stored at 100, 62.8 and 37.1 kPa ripened in 35, 65, 87 days, respectively. During 100-day storage at 13.6 kPa, tomatoes did not ripen, and their quality did not deteriorate. When placed in a storage chamber, at 12.7°C and atmospheric pressure, they took seven days to maturity.

Bangerth (1973) reported that HC storage results in a longer shelf-life of apples, currants, tomatoes, parsley, cucumbers, peppers and spinach in comparison with that reported for RS and CA storage techniques. Knee (2000) demonstrated a positive impact of HC storage on celeriac, lettuce, tomatoes, broccoli, grapefruit, melons and strawberries in comparison with conventional methods. Chen et al. (2013) found that hypobaric storage at 50 kPa was most effective in preventing the increase in bamboo shoots firmness and allied accumulations of lignin and cellulose. Burg (2004) observed that the shelf-life of cucumbers can be extended up to 49 days when low pressure storage was applied. A positive influence of HC storage on the shelf-life and quality of green asparagus was reported by Li et al. (2006) and Li and Zhang (2006). Tovar et al. (2011) applied vacuum (34 kPa) for 20 min and exogenous ethylene for 30 min to ripening mango fruit.

As a result of the treatment, the normal ripening period was shortened by three days. Despite its positive effects, raw biological materials are not stored under hypobaric conditions on an industrial scale due to the relatively high costs of the required equipment. Industrial manufacturers use vacuum packing to extend the shelf-life of fruits and vegetables (Wang et al., 2001). Hypobaric storage is still not commercially applied to greenhouse cucumbers. The aim of this study was to investigate the effect of hypobaric storage on the rate of changes in overall color parameters, firmness and chemical composition of greenhouse cucumbers.

Materials and Methods

Materials

The experimental material were DELTA STAR cucumbers (Rijk Zwaan) grown at the Experimental Station in Łęgajny. Cucumbers were grown on mineral wool with standard fertilizers of calcium-potassium nitrate, potassium monophosphate, potassium-magnesium sulfate and a fertilizer containing microelements. The growing season lasted from July 10 to November 15. Plant density was 2/m^2. Cucumbers were harvested three times a week. The fruit were harvested and selected manually to eliminate mechanical damage. The cucumbers used in this experiment were harvested at the beginning of September and October. They were fresh, healthy, and free from mold and mechanical damage.

Storage

The experimental cucumbers were stored at 10 and 50 kPa, and control cucumbers – at 100 kPa, at a temperature of 14°C and relative air humidity of 98%. Thirty randomly selected sampling units were harvested from each treatment. They were divided into three equal groups and placed in containers at sub atmospheric pressure. Every container could be opened without changing the atmosphere of the remaining containers. Fresh cucumbers (day 0) and cucumbers stored for 10, 20 and 30 days were analyzed for weight loss, color, mechanical properties and chemical composition (at different pressure values).

The experimental stand consisted of nine vacuum containers of stainless steel, with a capacity of 0.0125 m^3 each, which formed three sets. Sub atmospheric pressure was produced with a vacuum-sling-vane pump (AT20, TEPRO Koszalin) and with vacuum relief valves (MDH-2-2 and 2AW-QS-6, FESTO) between container sets. The pressure in each set was measured with a PC-28 sensor (APLISENS) and maintained by the Excel 50 XL 50-MMI (Honeywell) controller. The containers were placed in a cold room with a temperature control system that enabled abrupt changes within a range of 0^{0}C to 15^{0}C. Temperature was controlled by three VT20T heat sensors. Relative air humidity was measured with a capacitive thin-film sensor (FH9726-21R, AHLBORN) within an accuracy of ± 4%. A vessel containing water was placed at the bottom of the container to maintain the desired relative air humidity. Outdoor ventilation was provided by HE-2-1/8-QS-6 valves (FESTO).

Color

The color parameters of cucumbers were determined using the Miniscan XE Plus (Hunter & Associates Laboratory, Hunter Lab, USA) spectrophotometer for a standard illuminant D65, 10˚ observer and 8˚ diaphragm. Measurements were performed on 10 randomly selected samples. Changes in L^*, a^* and b^* color space of stored cucumbers were determined. Absolute changes in color, ΔE^*, chroma, ΔC^* and hue ΔH^* were calculated according to formulas (1-4).

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{1}$$

$$\Delta C^* = \sqrt{(a^*)^2_{samp} + (b^*)^2_{samp}} - \sqrt{(a^*)^2_{fresh} + (b^*)^2_{fresh}} \tag{2}$$

$$\Delta H^* = \sqrt{(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2}, \quad (3)$$

where:

$$\Delta L^* = L^*_{fresh} - L^*_{samp.};$$

$$\Delta a^* = a^*_{fresh} - a^*_{samp}; \ \Delta b^* = b^*_{fresh} - b^*_{samp} \quad (4)$$

ΔC^* - Chroma difference; ΔE^* - Total color difference; ΔH^* - Hue difference; L*, a*, b* - CIELAB color space parameters

Mechanical properties

Penetration tests of single cucumbers were performed in 15 replications on 10 randomly selected samples, using an Instron Universal Testing Machine, model 4301 (High Wycombe, Bucks, UK) equipped with a load cell of 1 kN, flat-end steel plunger with a diameter of 8 mm and a 30-mm-long stainless steel cylindrical probe. The loading rate during the penetration test was set at 0.5 mm/s.

Chemical analysis

Sugar content was determined according to the Lane-Eynon method (PCS, 1990). In order to determine reducing sugar content, an alkaline solution of copper salt was subjected to hot reduction by direct titration of a protein-free solution in the presence of methylene blue, without inversion. Total sugar content was determined after inversion with concentrated hydrochloric acid. Further procedures were identical as those applied to reducing sugars. The insoluble fraction of dietary fiber was extracted according to Asp et al. (1983). The pectin fraction was extracted by the method proposed by Sabir et al. (1976). The fractions were purified by rinsing with 95% ethanol, 30 cm^3 of ethanol and water mixture (1:1) and 50 mL/L HCl, as described by Borowska et al. (2003).

Statistical analysis

Experimental data were verified statistically using regression analysis, nonlinear estimation and ANOVA in a completely randomized block design. The significance of differences between treatments was determined by one-way analysis of variance using Duncan's multiple range tests ($p \leq 0.05$). Calculations were performed using STATISTICA 9.0 (StatSoft Inc., USA) software.

Results and Discussion

Color

Color is one of the most important sensory attributes of cucumbers which influences consumer acceptance, and it can be used as a quality indicator to evaluate deterioration caused by storage (Yahia et al., 2008). Changes in total color, chroma and hue of greenhouse cucumbers stored under 10, 50 and 100 kPa for 10, 20 and 30 days are shown in Figure 1. All three color indices of stored cucumbers were

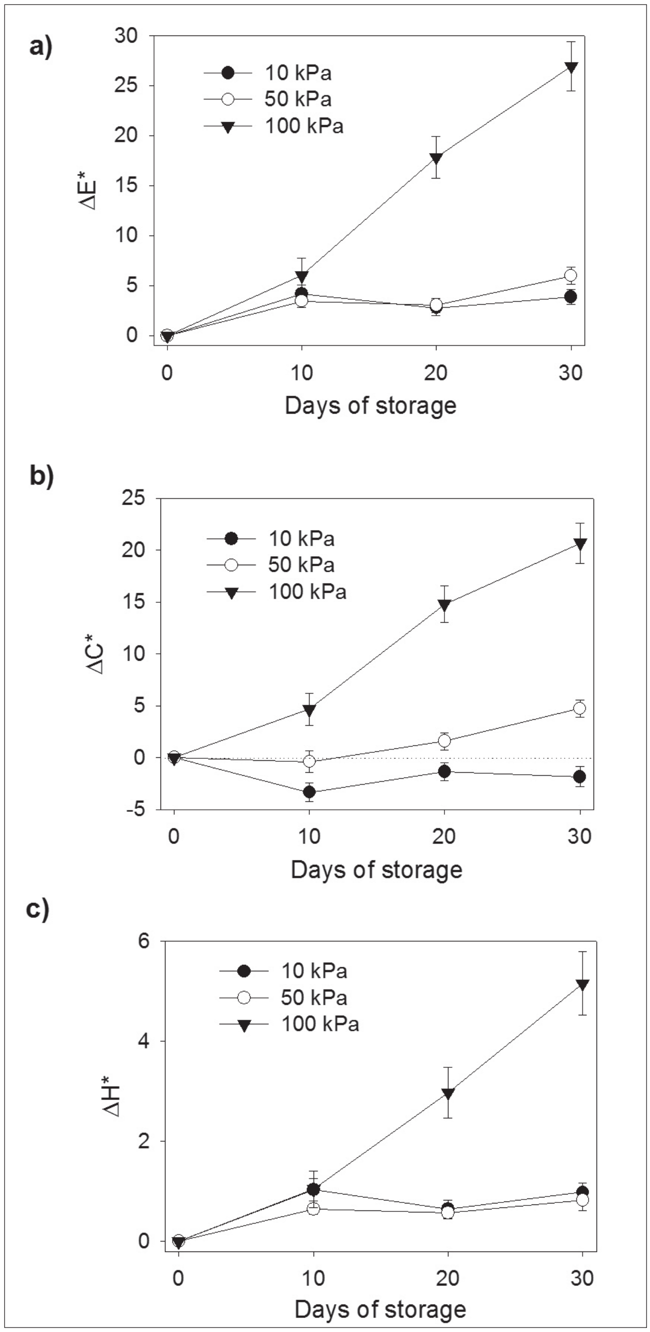

Fig. 1. Total changes in color, ΔE*, chroma, ΔC* and hue ΔH* of cucumbers

equally affected by the time of storage and the applied pressure. Samples stored in ambient conditions (100 kPa, 14°C) were characterized by significant changes in color indices in comparison with fresh cucumbers. The differences in E^*, C^* and H^* color parameters of ambient-stored cucumbers increased with storage time. The color indices of cucumbers stored in sub atmospheric pressure were more similar to those observed in fresh samples than in cucumbers stored at 100 kPa. After 30 days of storage, the overall difference in color between fresh cucumbers and samples stored at 10 and 50 kPa was stabilized at a level of 4 and 6, respectively. Similar trends were observed with regard to changes in chroma and hue. Significant ($p \leq 0.05$) undesirable changes in color were found in cucumbers stored at 100 kPa, whereas no significant differences in color indices were noted in samples stored at 10 and 50 kPa ($p \leq 0.05$). A decrease in chroma values in cucumbers stored at 10 kPa can be attributed to chlorophyll degradation during storage. Color stability in cucumbers stored at 10 and 50 kPa may be explained by slower metabolism at low pressure and the accompanying retardation of processes which transform chlorophyll to carotenoids under hypobaric conditions.

Temperature of 7–10°C, 95% relative humidity and 2-week storage are the optimal storage and shipping conditions for cucumbers (Yahia et al., 2008). Changes in color, such as yellowing, are a sign of aging and deterioration in quality. The observation that the acceptable color of stored cucumbers is preserved for longer indicates that hypobaric storage can extend the shelf-life of greenhouse cucumbers.

Mechanical properties

Horticulturists define firmness as the force required to penetrate a mechanical probe into a fresh product for a pre-specified distance as a measure of firmness (Lu et al., 2004). Firmness is a common indicator of fruits' and vegetables' resistance to damage during handling or shipping, and it is one of the key textural properties of fresh cucumbers that directly influence eating quality and consumer acceptance. Quasi-static methods for measuring force at a given level of deformation during penetration by elastic or a rigid Magness-Taylor (MT) puncture probe are widely used to determine the firmness of fruits and vegetables (Lu et al., 2004). Mohsenin (1989) demonstrated that the bioyield point could be a better indicator of fruit firmness than MT puncture because this measure extends beyond the elastic deformation of fruit tissue.

The textural properties of foods, including firmness, change with time and are determined by parameters such as ambient air temperature, humidity, composition and pressure (Lu and Abbott, 2004). The firmness of cucumbers stored at 10, 50 and 100 kPa is shown in Figure 2. Both firmness indicators, force at bioyield and energy to bioyield, were equally influenced by vacuum level and duration of storage. The smallest decrease in force at bioyield of 2.5 N was observed after 30 days for cucumbers stored at 10 kPa, and the final value of force at bioyield was 48.7 N. The samples stored at 50 and 100 kPa were characterized by significantly ($p < 0.05$) lower value of force at bioyield which amounted to 45.9 N. The energy to bioyield of samples stored at 10 kPa was stabilized at 0.172 ± 0.02 J, and it was not correlated with storage time. In cucumbers stored at 50 kPa, energy to bioyield decreased slightly after 10 days, it increased after 20 days, and became stabilized at the level observed in samples stored at 10 kPa for 30 days. A successive increase in energy to bioyield was noted in cucumbers stored at 100 kPa. In a study by Chen et al. (2004), hypobaric storage significantly slowed down the respiratory rate, which inhibited the loss of water and firmness in Huanghua pears. Zhang at al. (2005) found that hypobaric treatment reduced the respiratory rate, inhibited the activity of amylase and ascorbic acid oxidase,

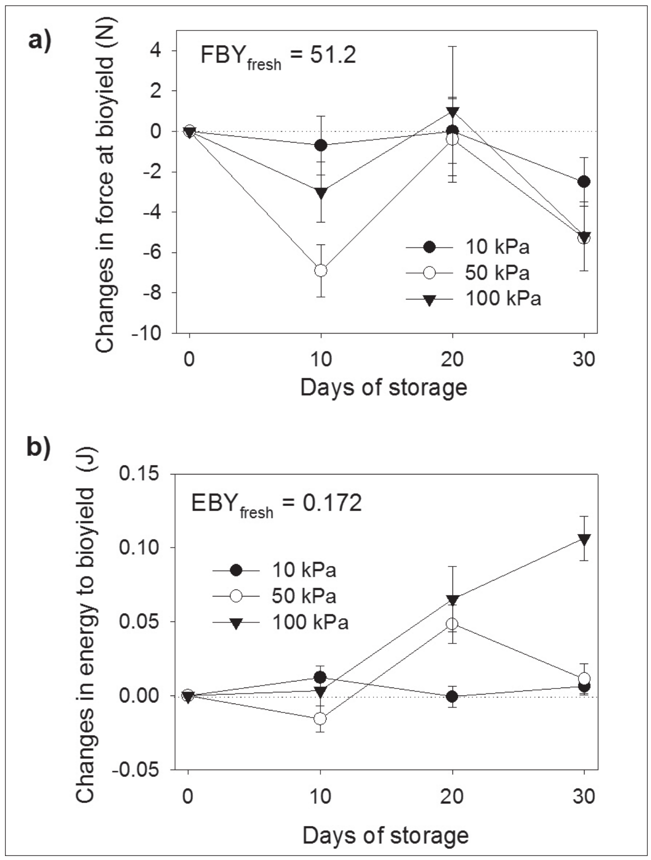

Fig. 2. Changes in cucumbers' force at bioyield and energy to bioyield

slowed down degradation rates of starch and ascorbic acid, inhibited the proliferation of mold spores, reduced fruit rot and maintained the firmness of jujube fruit. In the present study a similar effect was observed in greenhouse cucumbers stored at low pressure storage with regard to firmness.

Chemical composition

The rate of changes in dietary fiber and pectin content of cucumbers stored at 10, 50 and 100 kPa for 10, 20 and 30 days is depicted in Figure 3. Pectin content was equally dependent on storage time and pressure. It is evident from Figure 3 that in all of the analyzed samples, the changes in pectin content were magnified with the time of storage. The smallest and the highest increase in pectin content were noted in samples stored for 30 days at 10 and 100 kPa, respectively. The dietary fiber content of stored cucumbers was correlated with both storage time and pressure. Less pronounced changes in dietary fiber content were reported in cucumbers stored at 10 and 50 kPa than in samples stored at 100 kPa. The smallest changes in dietary fiber were observed in samples stored for 30 days at 10 kPa. It is generally known that chemical and physiological processes determine the texture of foods, including fruits and vegetables (Basuny et al., 2009). Liu et al. (2003) correlated the firmness of cucumbers with their fiber and pectin content. They found that cucumbers with higher fiber content and lower pectin content were characterized by greater firmness. All of the samples were stored at high humidity which was practically equal to complete saturation; therefore, moisture loss in stored cucumbers was low. An analysis of 10 samples stored for 30 days at 10 kPa revealed that an increase in pectin levels was accompanied by a minor drop in firmness, and the above results are consistent with the findings of Jiang et al. (2009).

The cited authors studied the influence of hypobaric conditions on Golden Boy cucumbers and concluded that samples stored for 20 days at 10°C under low pressure were

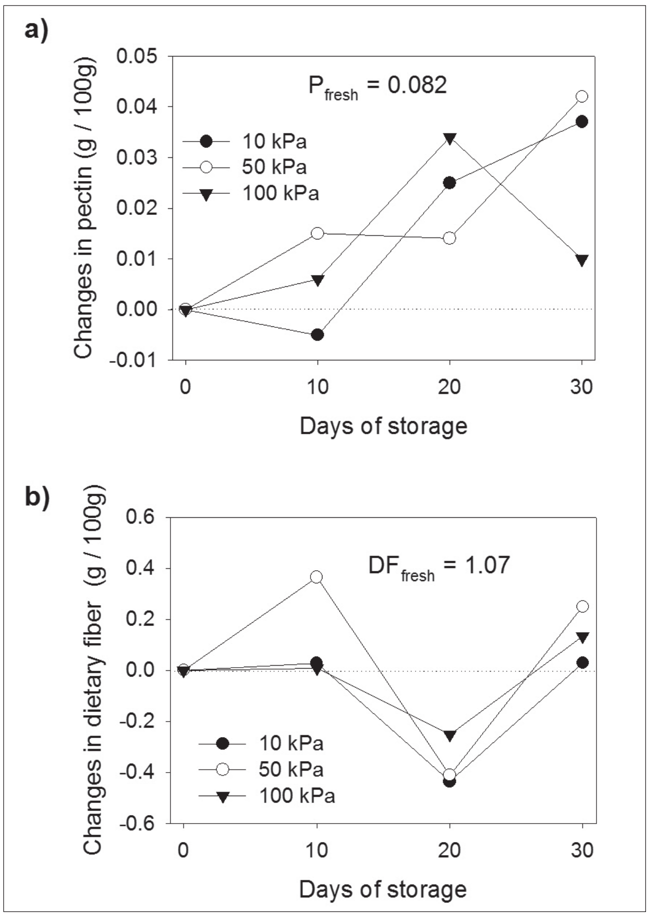

Fig. 3. Changes in the pectin and dietary fiber content of cucumbers

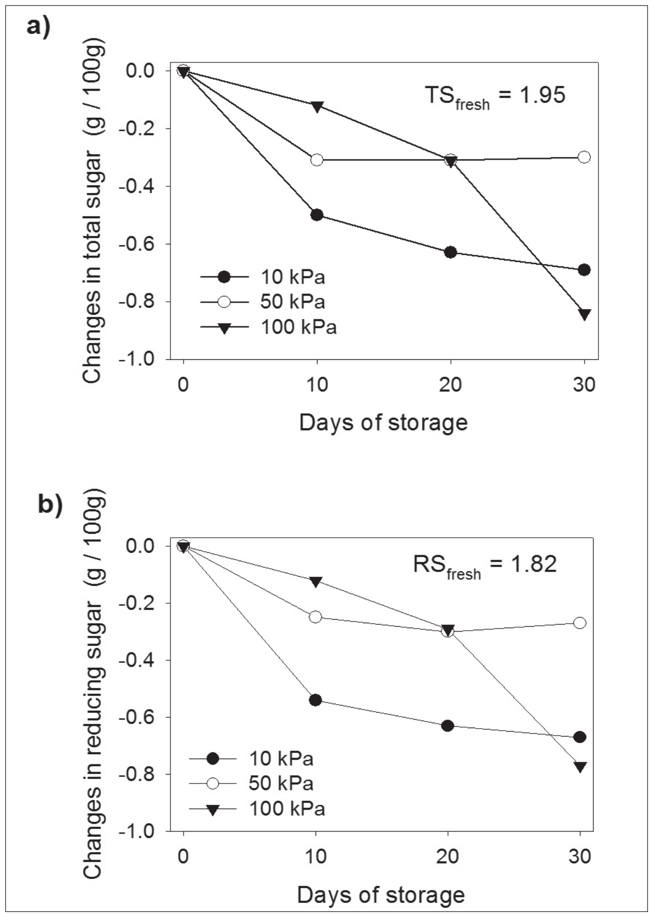

Fig. 4. Changes in the total sugar content and reducing sugar content of cucumbers

characterized by supreme quality indicators, including firmness, water loss and yellowing rate, in comparison with cucumbers stored at atmospheric pressure. Hypobaric storage can reduce the drop in dietary fiber content and minimize the increase in the pectin content of cucumbers, and these observations stand in agreement with the results of textural evaluation.

The rate of changes in total sugar and reducing sugar content of cucumbers stored for 10, 20 and 30 days at 10, 50 and 100 kPa are shown in Figure 4. The total sugar content and reducing sugar content were equally influenced by pressure and storage time. After 30 days of storage, the total sugar content of cucumbers kept at 10, 50 and 100 kPa decreased from 1.95 to 1.26, 1.65 and 1.11 g/100 g, respectively. Similar changes were observed in reducing sugar content whose concentrations after 30 days of storage decreased from 1.82 to 1.15, 1.55 and 1.05 g/100 g in samples stored at 10, 50 and 100 kPa, respectively. Cucumbers kept under low pressure maintained higher sugar content than ambient-stored samples. The above observations suggest that hypobaric storage can minimize the reduction in cucumbers' total sugar content and reducing sugar content. Sugars are utilized as substrates and sources of energy for respiratory metabolism. High sugar levels preserve the desirable quality of cucumbers stored under hypobaric conditions.

Conclusions

Hypobaric storage poses an alternative for refrigeration storage and controlled atmosphere storage. The desirable properties of greenhouse cucumbers stored in vacuum were maintained for up to 30 days. Hypobaric treatment consistently delayed postharvest fungal decay of greenhouse cucumbers without significant affecting color, chemical composition and firmness. Smaller changes in color, firmness, content of dietary fiber, pectin and sugar were reported in fruits stored at 14°C under hypobaric conditions (10 and 50 kPa) than in samples kept under atmospheric pressure. In vacuum-stored cucumbers, the variations in color, firmness and dietary fiber levels were determined at less than 5% in comparison with fresh cucumbers. Cucumbers stored at hypobaric conditions were characterized by higher overall quality.

References

Anonymous, 2009. Statistical Yearbook of Poland. Central Statistics Office, Warsaw (Pl).

Asp, N. G., C. G. Johansson, H. Hallmer and M. Siljeström, 1983. Rapid enzymic assay of insoluble and soluble dietary fiber. J. Agric. Food Chem., **31**: 476-482.

Bangerth, F., 1973. Zur Wirkung eines reduzierten Drucks auf Physiologie, Qualität und Lagerfähigkeit von Obst, Geműse und Schnittblumen. *Gartenbauwissenschaft*, **38** (6): 479-508.

Basuny, A. M. M., D. M. M. Mostafa and A. M. Shaker, 2009. Relationship between chemical composition and sensory evaluation of potato chips made from six potato varieties with emphasis on the quality of fried sunflower oil. World J. Dairy Food Sci., **4** (2): 193-200.

Borowska, J., M. Kowalska, S. Czaplicki and R. Zadernowski, 2003. Effect of hydrothermal processing on carrot carotenoids changes and interactions with dietary fiber. Nahrung/Food, **47** (1): 46-48.

Burg, S. P., 2004. Postharvest physiology and hypobaric storage of fresh produce. CABI Publishing, Wallingford, UK.

Chen, W. X., H. Y. Gao, J. L. Mao, H. J. Chen and Y. J. Zhou, 2004. Research on technology of storage for hypobaric storage of Huanghua pear. Food Sci., **25** (11): 326-329 (Ch).

Chen, H., J. Ling, F. Wu, L. Zhang, Z. Sun and H. Yang, 2013. Effect of hypobaric storage on flesh lignification, active oxygen metabolism and related enzyme activities in bamboo shoots. *LWT - Food Sci. Technol.,* **51**: 190-195.

Hakim, A., A. C. Purvic and B. G. Mullinix, 1999. Differences in chilling sensitivity of cucumber varieties depends on storage temperature and the physiological dysfunction evaluated. *Postharvest Biol. Technol.*, **17** (2): 97-104.

Jiang, W., S. Wang, J. Meng and Q. Song, 2009. Effect of hypobaric storage on preservation of cucumbers. Storage Process, **9** (4): 16-18 (Ch).

Knee, M. and D. Aggarwal, 2000. Evalution of vacuum containers for consumer storage of fruits and vegetables. *Postharvest Biol. Technol.*, **19**: 55-60.

Li, W. and M. Zhang, 2006. Effect of three-stage hypobaric storage on cell wall components, texture and cell structure of green asparagus. *J. Food Eng.*, **77** (1): 112-118.

Li, W., M. Zhang and H. Yu, 2006. Study on hypobaric storage of green asparagus. *J. Food Eng.*, **73** (3): 225-230.

Liu, C., Q. He and Z. Yu, 2003. Relationship between fruit texture and tissue structures, fiber content, pectin content on cucumber. *China Veg.*, **5**: 3-7 (Ch).

Lu, R. and J. A. Abbott, 2004. Force deformation techniques for measuring texture. In: D. Kilcast (Ed.), Texture in Food: Volume 2: Solid Foods, Boca Raton, Florida, USA: CRC Press, pp. 109-145.

Mohsenin, N. N., 1989. Physical Properties of Plant and Animal Materials. New York, Gordon and Breach Science Publisher.

PCS, 1990. Fruit and vegetable products. Preparation of samples and testing methods. Determination of sugar content and nonsugar extract. Warsaw, Poland: Polish Committee for Standardization. PCS reference No. PN–90/A–75101.07 (Pl).

Sabir, M. A., F. Sosulski and S. J. Campbell, 1976. Polymetaphosphate and oxalate extraction of sunflower pectins. J. Agric. Food Chem., **24**: 348-350.

Saltveit, M. E., 2004. Cucumber. In: K. Gross (Ed.) The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. *USDA Agric. Handbook*, (66). http://www.agrichill.net/handbook/cucumber.pdf (accessed January 2nd, 2013).

Salunkhe, D. K. and M. T. Wu, 1973. Effects of subatmospheric pressure storage on the ripening behavior and some chemical changes on certain deciduous fruits. *J. Am. Soc. Hortic. Sci.*, **98**: 113-116.

Tovar, B., E. Montalvo, B. M. Damián, H. S. García and M. Mata, 2011. Application of vacuum and exogenous ethylene on Ataulfo mango ripening. LWT - Food Sci. Technol., **44**: 2040-2046.

Wang, C. Y., 1993. Approaches to reduce chilling injury of fruits and vegetables. *Hortic. Rev.,* **15**: 63-95.

Wang, C. Y. and L. Qi, 1997. Controlled atmosphere storage affects quality and chilling susceptibility of cucumbers. *J. Food Qual.*, **20** (6): 559-566.

Wang, L., P. Zhang and S. J. Wang, 2001. Advances in research on theory and technology for hypobaric storage of fruit and vegetable. Storage Process, **5**: 3-6 (Ch).

Wu, M. T., S. J. Jadhav and D. K. Salunkhe, 1972. Effects of sub-atmospheric storage on ripening of tomato fruits. *J. Food Sci.*, **37**: 952-956.

Yahia, E. M., M. I. El-Tamzini, A. A. F. El-Saied and S. E. D. Al-Yateem, 2008. Training manual on postharvest handling and marketing of horticultural commodities. FAO, Cairo, Egypt.

Zhang, Y. L., J. Q. Han and R. G. Zhang, 2005. Study on fresh-keeping physiological activity of Dong Jujube using low temperature combined with hypobaric and ozone treatments. Scientia Agricultura Sinica, **38** (10): 2102-2110 (Ch).

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