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EFFECTS OF STORAGE CONDITIONS ON THE QUALITY OF UNRIPE HAZELNUTS IN THE HUSK

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ABSTRACT

The purpose of the study was to assess the storability of unripe hazelnuts in the husk of four cultivars: 'Hall's Giant', 'Catalan', 'Webb's Prize Cob' and 'Cosford'. The nuts were stored in normal and controlled atmospheres, and in Xtend® bags for three months. A quality assessment was performed based on the following parameters: weight of the nut in the husk and without the husk, weight of the kernel, percentage of nuts with husk attached, dry matter content in kernels, infection with fungal diseases, and the presence of physiological disorders. The study demonstrated that hazelnuts stored in Xtend® bags and under a controlled atmosphere had a higher weight for the nut in the husk and without the husk, as well as a higher weight of the kernel and water content when compared to batches of hazelnuts stored in a normal atmosphere. The percentage of nuts remaining in the husk was also higher when stored under such conditions. For the majority of investigated cultivars the storage in Xtend® bags, and to a lesser extent under normal atmosphere conditions, resulted in a substantial increase in nuts infected with fungal and abiotic diseases. Among investigated cultivars, 'Hall's Giant' turned out to be the most resistant to storage diseases.

Key words: fresh hazelnut, controlled atmosphere, Xtend® bags, morphological features, dry matter, storage diseases

INTRODUCTION

Only 5% of hazelnut kernels are consumed in an unprocessed form; most of them are used after processing to enrich chocolate and confectionery products (Anonymous 1995). Hazelnuts are usually consumed after they reach full harvest maturity, when it is easy to detach them from the husk. At this stage they reach the highest nutritional value (Piskornik 1994; Thompson et al. 1996; Wieniarska et al. 2004). After reaching their harvest maturity, and after postharvest drying, hazelnuts can be stored at 0-2 °C and 60-70% air humidity for up to two years (Koyuncu et al. 2005; Leuty et al. 2012; Ghirardello et al. 2013). Hazelnuts stored at temperatures above 10 °C and humidity above 70% are more susceptible to infections with molds and contamination with mycotoxins (Simsek et al. 2002; Campbell et al. 2003; Navarro 2006). Hazelnuts in the husk, picked before reaching physiological maturity, are much rarer on the market. Some consumers are more willing to buy this type of hazelnut, before the full ripening of fruits if available on the market. Consumers also feel convinced that nuts in the husk are fresh and were harvested in the same year. An argument supporting the consumption of unripe hazelnuts sold in the husk is their higher content of polyphenols and some fatty acids, as well as better palatability (Ebrahem et al. 1994; Farinelli et al. 2001; Ciemniewska-Żytkiewicz et al. 2015). The higher water content, reflected in higher weight, with 41% share of the husk, is an advantage, important for producers (Ebrahem et al. 1994; Zdyb 2012; Ciemniewska-Żytkiewicz et al. 2015).

Although the unripe hazelnuts in husk are characterized by significantly shorter storability than the fully ripe nuts, there is a distinct lack of information regarding the storage of unripe hazelnuts in the husk. Limited studies aimed at storage of unripe hazelnuts under modified atmosphere

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conditions have been carried out by Italian scientists (Moscetti et al. 2012). According to their results, the application of modified atmosphere for the storage of unripe, fresh hazelnuts had a significant impact on maintaining not only their chemical composition, but also physical and organoleptic characteristics.

With regard to the storage of ripe hazelnuts, current literature clearly indicates that for this type of fruit, controlled and modified atmosphere conditions may have a positive impact on their quality and nutritional value (Keme et al. 1980; San Martin et al. 2001; Mencarelli et al. 2008; Massantini & Contini 2009; Ghirardello et al. 2013). The results of numerous experiments on the storage of different kinds of ripe nuts suggest that controlled and modified atmosphere, aside from having a positive effect on the sensory features and chemical composition, can reduce nut weight losses, thus enabling longer storage (Maté et al. 1996; Maskan & Karataş 1998; Mexis et al. 2009; Christopoulos & Tsantili 2011; Ghirardello et al. 2014, Christopoulos & Tsantili 2015).

Among different kinds of modified atmosphere storage, the method using Xtend® bags has become more and more popular, as it can be used by producers which don't have access to controlled atmosphere facilities. Due to respiration of fresh products closed in Xtend® bags, the oxygen concentration inside the bag decreases, while at the same time the amount of carbon-dioxide increases. Simultaneously, as the product transpires, the relative humidity in the bag increases, however, the controlled diffusivity of the Xtend® material allows any excess moisture to escape, keeping the RH at the level 90-95%, which is highly favorable for storage and shelf-life extension (Artes et al. 2000; Aharoni et al. 2008). Such storage conditions seem to be beneficial for fresh unripe hazelnut storage, especially as an alternative, where modified atmosphere conditions are available for producers or retailers equipped only with standard cold storage.

The purpose of the presented study was to evaluate the effect of different storage conditions on the quality of unripe hazelnuts in the husk stored for up to three months. The nut quality expressed by weight losses, de-husking tendency and the susceptibility to spoilage was investigated for nut batches stored in normal and controlled atmosphere conditions including the Xtend® bags as well as after a simulated shelf-life test.

MATERIALS AND METHODS

The experiment was carried out at the Research Station, University of Warmia and Mazury (UWM) in Olsztyn (Poland), in 2013-2014, on the fruit of four hazelnut cultivars: 'Hall's Giant' (HG), 'Catalan' (Cat), 'Webb's Prize Cob' (WPC) and 'Cosford' (Cos). Unripe hazelnuts were harvested manually, three weeks before reaching physiological maturity (HG and Cos on August 23rd, 2013 or 2014, Cat and WPC on September 2nd, 2013 or 2014). All hazelnuts at harvest were in the husk (100%).

Immediately after harvest, the nuts were chilled to 5 °C. The nuts were kept for three months in the following conditions: normal atmosphere (NA – standard cold storage, 0-1 °C, 85-95% humidity); controlled atmosphere (CA – 3% O_2 : 3% CO_2, 85-95% humidity) and Xtend® MA/MH Packaging (Modified Atmosphere Packaging bags) intended for stone fruit, capacity 5 kg (StePac, Israel). The Xtend® bags with nuts were stored in a normal atmosphere at 0-1 °C and 85-95% humidity. Air composition inside the Xtend® bags was measured twice before opening them (after two- and three-month storage) in three replicates using a gas analyzer (WITT OXYBABY® M+ O_2/CO_2). After two months of storage the modified atmosphere inside Xtend® bags consisted of 19.2% O_2 and 2% CO_2 (for HG and Cos), and 18% O_2 and 3.4% CO_2 (for WPC and Cat); after three months it amounted to 18.1% O_2 and 3% CO_2, and 18.4% O_2 and 3.1% CO_2, respectively for the same groups of cultivars. Nuts stored under NA and CA were packed 20 kg in 0.3 m^3 air-tight containers made of polyethylene (PE) with PMMA-Plexiglas lids. Nuts stored in Xtend® bags were packed 5 kg. The experiment was twice replicated in two consecutive years. The 1 kg samples of nuts for each variety and storage variant were taken for the assessment of morphological parameters in two replicates. The percentage of nuts in the husk and without husk, and their infection with diseases were analysed on 10 kg samples in two replicates. Additionally, after harvest and a three-month storage, hazelnuts in the husk were stored for one week at a room temperature of 21-23 °C and air humidity 40-60% (simulated shelf-life test).

The quality parameters of hazelnuts were monitored at harvest, then again after being subjected to a 1 week simulated shelf-life test (0M + 1W). The nuts being stored for two and three months were assessed just after removing out of the store (2M + 0W and 3M + 0W) and after one week of simulated shelf-life test applied for nuts stored for three months (3M + 1W). The following parameters were evaluated: weight of a hazelnut in the husk, weight without the husk (in-shell) and weight of the kernel (for shelled nuts). For each combination, the dry matter content was determined using a gravimetric method (drying to constant weight at 105 °C). Before weighing, nuts with husk attached were counted, and the results were converted into percent. The percentage of infection of nuts with fungal diseases and the occurrence of physiological disorders were assessed after a three-month storage. Nuts with visible signs of fungal infection or physiological disorders unsuitable for marketing were categorized as infected. Hazelnuts affected by physiological disorders clearly had overripe husks and shells, manifested mainly by the dark-brown color of the outer tissue. No preparation controlling development of pathogens during storage was not applied in the orchard before harvest.

Data obtained from the experiment were analysed statistically using one-way analysis of variance (ANOVA) based on mean values from two seasons. The effect of the storage period on the quality parameters of nuts was analysed separately for each cultivar and storage variants. The effect of storage conditions was analysed separately for each hazelnut cultivar after two and three months of storage and one week of simulated shelf-life. Differences between means were analysed with t-Tukey's test at significance level $\alpha = 0.05\%$ for the weight of nuts in the husk and without husk and weight of the kernel, and at $\alpha = 0.01\%$ for dry matter content.

RESULTS

The statistical analysis demonstrated a significant effect of storage conditions and storage time on the quality characteristics of the investigated hazelnuts. Moreover, the analysed parameters were strongly modified depending on the cultivar. The highest weight, and not different from that after harvest, was found for HG, Cat and WPC nuts in the husk stored in Xtend® bags for three months or also for two months for WPC (Table 1). There were no differences in the weight between CA and Xtend® bags for the WPC stored through three months. Regardless of the storage time, the greatest losses in the weight of nuts in the husk were found for Cos nuts. When considering the losses of weight of nuts in the husk during the simulated one week shelf-life test, the losses for freshly picked nuts varied between 27 (for HG and WPC) and 43% (Cos) of the initial weight. The observed weight losses during one week of shelf-life after three month of storage were more diversified and depended on kind of atmosphere and ranged between 12-18% for NA, 34-36% for CA and 36-50% for Xtend® bags. Although apparently the weight losses during shelf-life after NA and CA stored nuts were lower than that found for freshly picked batches, the final weigh of nuts was almost twice lower than for these at harvest, with little differences between storage variants.

The weight of husk free nuts at harvest was on average 30% lower than those with husk (Table 1 & 2). Nuts without husk stored in Xtend® bags lost significantly less their weight but in WPC and Cos there were no differences between CA and Xtend® bags variants (Table 2). For the HG, there were no differences depending on the storage variant after two months and for WPC after three months of storage. The weights of WPC nuts stored in Xtend® bags after two and three months, and in CA after two months were comparable to the weight at harvest. A similar relationship was observed for HG nuts after three-month storage in Xtend® bags. Similarly as for nuts in the husk, during the simulated shelf-life test, the weight of de-husked nuts decreased significantly, however the losses were not greatly influenced by storage conditions.

The lowest loss in kernel weight was reported for nuts of all cultivars stored in Xtend® bags, both after a two- and three-month storage, and for WPC and Cos stored for two months in CA (Table 3).

Table 1. Changes in the weight of hazelnuts in the husk during storage and after simulated shelf-life test. The weight of a single nut (g) is expressed as the mean for seasons 2013-2014

Cultivars	Storage conditions	Storage period: months (M) + weeks of shelf-life (W)				
		At harvest	0M + 1W	2M + 0W	3M + 0W	3M + 1W
'Hall's Giant'	NA	6.8 a	4.3 cd	5.2 b B	4.8 bc B	3.9 d A
	CA	6.8 a	4.3 c	5.3 b AB	5.0 b B	3.3 d B
	Xtend®	6.8 a	4.3 c	6.0 b A	6.8 a A	3.4 d B
'Catalan'	NA	6.9 a	5.0 b	4.8 bc C	4.3 c C	3.6 d AB
	CA	6.9 a	5.0 b	5.4 b B	5.2 b B	3.4 c B
	Xtend®	6.9 a	5.0 c	6.1 b A	6.3 ab A	4.0 d A
'Webb's Prize Cob'	NA	5.9 a	4.3 b	4.5 b C	4.1 b B	3.4 c A
	CA	5.9 a	4.3 c	5.5 ab B	5.2 b A	3.7 d A
	Xtend®	5.9 a	4.3 b	6.1 a A	5.7 a A	3.6 c A
'Cosford'	NA	5.7 a	3.2 b	3.3 b B	3.1 bc C	2.7 c A
	CA	5.7 a	3.2 c	4.0 b A	3.7 b B	2.4 d B
	Xtend®	5.7 a	3.2 c	4.2 b A	4.4 b A	2.5 d AB

Means followed by the same letter are not significantly different at $\alpha = 0.05$, according to Tukey's test. Small letters in a line mark the effect of storage period for each storage condition and cultivar separately. Capital letters in a column mark the effect of storage conditions for each cultivar and storage period separately – after two and three months of storage and one week of simulated shelf-life. NA - normal atmosphere, CA - controlled atmosphere, Xtend® - packaging bags (0-1 °C, 85-95% RH).

Table 2. Changes in the weight of hazelnuts without husk during storage and after simulated shelf-life test. The weight of a single nut (g) is expressed as the mean for seasons 2013-2014

Cultivars	Storage conditions	Storage period: months (M) + weeks of shelf-life (W)				
		At harvest	0M + 1W	2M + 0W	3M + 0W	3M + 1W
'Hall's Giant'	NA	4.8 a	3.7 bc	4.1 b A	3.9 bc B	3.5 c A
	CA	4.8 a	3.7 b	3.8 b A	3.7 b B	2.9 c B
	Xtend®	4.8 a	3.7 b	4.1 b A	4.6 a A	3.0 c B
'Catalan'	NA	4.8 a	4.3 b	3.9 bc B	3.6 c C	3.2 d A
	CA	4.8 a	4.3 b	4.0 b B	4.0 b B	3.0 c A
	Xtend®	4.8 a	4.3 b	4.5 ab A	4.6 ab A	3.2 c A
'Webb's Prize Cob'	NA	4.3 a	3.7 b	3.7 b B	3.4 bc B	3.0 c A
	CA	4.3 a	3.7 b	4.2 a A	4.0 ab A	3.2 c A
	Xtend®	4.3 a	3.7 b	4.4 a A	4.2 a A	3.1 c A
'Cosford'	NA	3.7 a	2.7 b	2.7 b B	2.6 bc C	2.3 c A
	CA	3.7 a	2.7 c	3.1 b A	2.9 bc B	2.1 d B
	Xtend®	3.7 a	2.7 c	3.1 b A	3.3 b A	2.2 d AB

Explanation, see Table 1

Table 3. Changes in the weight of hazelnut kernels during storage and after simulated shelf-life. The weight of a single nut kernel (g) is expressed as the mean for seasons 2013-2014

Cultivars	Storage conditions	Storage period: months (M) + weeks of shelf-life (W)				
		At harvest	0M + 1W	2 M + 0W	3M + 0W	3M + 1W
'Hall's Giant'	NA	2.1 a	1.5 b	1.7 b AB	1.5 b B	1.2 c A
	CA	2.1 a	1.5 b	1.6 b B	1.5 b B	1.0 c B
	Xtend®	2.1 a	1.5 c	1.8 b A	2.1 a A	1.0 d B
'Catalan'	NA	2.1 a	1.9 a	1.9 a B	1.5 b C	1.3 c A
	CA	2.1 a	1.9 ab	2.0 ab AB	1.8 b B	1.2 c A
	Xtend®	2.1 ab	1.9 b	2.2 a A	2.2 a A	1.3 c A
'Webb's Prize Cob'	NA	2.1 a	1.6 b	1.7 b B	1.5 b C	1.2 c A
	CA	2.1 a	1.6 b	2.0 a A	1.8 b B	1.3 c A
	Xtend®	2.1 a	1.6 b	2.1 a A	2.2 a A	1.3 c A
'Cosford'	NA	1.7 a	1.1 b	1.1 b B	1.0 b C	0.9 c A
	CA	1.7 a	1.1 c	1.4 b A	1.3 b B	0.7 d B
	Xtend®	1.7 a	1.1 c	1.5 b A	1.6 ab A	0.8 d AB

Explanation, see Table 1

Storage of nuts in NA resulted in the greatest loss in their kernel weight, but HG nuts had the greatest loss in kernel weight in CA after two-month storage. The weight of the kernel in Cat hazelnuts stored in Xtend® bags for two and three months was higher than their weight at harvest. The kernel weight in WPC nuts stored in Xtend® bags for two and three months and in HG stored for three months was similar to the kernel weight at harvest. For WPC nuts, this correlation was also found under CA conditions, and, exceptionally for Cat nuts after two-month storage in NA. A significant effect of storage conditions on the kernel weight after one week of simulated shelf-life was found for HG and Cos cultivars, and lower losses were recorded in nuts stored in NA.

The dry matter content in kernels of HG nuts stored in NA and CA was higher compared to the nuts stored in Xtend® bags (Table 4). The dry matter content in kernels was the highest for WPC nuts stored in NA for three months and for Cos nuts stored in NA for two and three months. Irrespective of cultivar, the dry matter content in the kernel was lowest in the nuts stored in Xtend® bags and showed a tendency to decrease slightly with storage time elongation. In the case of Cat, regardless of storage duration (two and three months), the storage atmosphere did not influence dry matter content (Table 4). Generally for NA and CA conditions, the dry matter increased successively during storage. After three months of storage and the successive shelf-life test the dry matter content, on average, was almost twice higher than for nuts at harvest. The one week shelf-live test reduced nut moisture content more than during two-three months in cold storage, which resulted in substantial increases of dry matter content.

The percentage of husk losses differed significantly between cultivars (Table 5). Cat and Cos were de-husked easily already during the simulated shelf-life of freshly picked nuts, which amounted to 46 and 35%, respectively. Cultivars HG and WPC did not show a tendency to de-husk, neither during the shelf-life test just after harvest, nor during cold storage. Generally, nut storage in NA stimulated the de-husking process, which was especially revealed for Cat and Cos cultivars. After the shelf-life test following the storage, they lost up to 90% of husks, while in the comparable conditions the losses for WPC were not more than 11%.

Fungal diseases and physiological disorders most frequently affected Cat and at the lowest extent Cos nuts, and least frequently the HG nuts (10-14%), regardless of the storage conditions (Fig. 1). The highest percentage of healthy nuts in Cat, WPC and Cos cultivars was found after storage in CA. Cat nuts stored in Xtend® bags were infected in 93% and Cos in 54%.

Table 4. Changes in the dry matter content of hazelnut kernels in the husk during storage and after simulated shelf-life. The dry matter content (%) is expressed as the mean for seasons 2013-2014

Cultivars	Storage conditions	Storage period: months (M) + weeks of self-life (W)				
		At harvest	0M + 1W	2M + 0W	3M + 0W	3M + 1W
‘Hall’s Giant’	NA	46.3 c	59.5 b	57.7 b A	65.5 b A	84.7 a A
	CA	46.3 c	59.5 b	56.4 bc A	57.9 bc A	88.2 a A
	Xtend®	46.3 c	59.5 b	46.4 c B	44.7 c B	86.2 a A
‘Catalan’	NA	52.0 b	59.8 b	56.0 b A	65.4 b A	85.7 a A
	CA	52.0 b	59.8 b	53.2 b A	57.4 b A	86.9 a A
	Xtend®	52.0 b	59.8 b	52.6 b A	52.7 b A	85.1 a A
‘Webb’s Prize Cob’	NA	57.3 d	75.3 b	69.8 c A	71.7 bc A	91.5 a A
	CA	57.3 c	75.3 ab	61.2 bc AB	64.7 bc A	88.7 a A
	Xtend®	57.3 c	75.3 b	56.4 c B	54.2 c A	86.0 a A
‘Cosford’	NA	54.1 c	68.5 b	66.6 b A	71.2 b A	90.5 a A
	CA	54.1 b	68.5 b	53.7 b B	59.8 b AB	90.6 a A
	Xtend®	54.1 c	68.5 b	47.0 c B	44.5 c B	89.3 a A

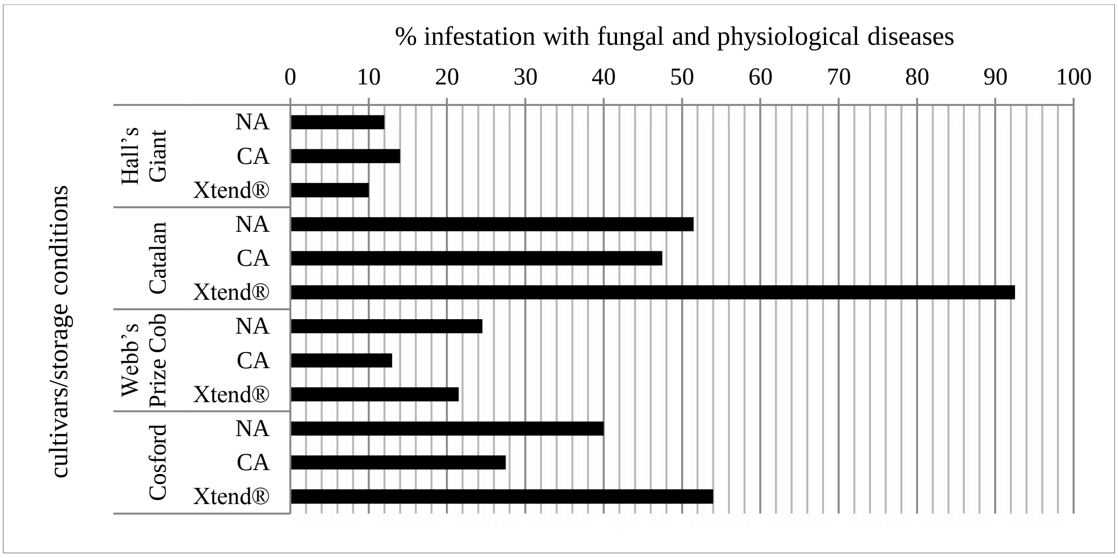
Means followed by the same letter are not significantly different at $\alpha = 0.01$, according to Tukey’s test. Small letters in a line mark the effect of storage period for each storage condition and cultivar separately. Capital letters in a column mark the effect of storage conditions for each cultivar and storage period separately – after two and three months of storage and one week of simulated shelf-life. NA - normal atmosphere, CA - controlled atmosphere, Xtend® - packaging bags.

Table 5. Percentage of hazelnuts in the husk and without husk during storage and after simulated shelf-life test in the years 2013-2014 (%)

Cultivars	Storage conditions	Storage period: months (M) + weeks of shelf-life (W)				
		At harvest	0M + 1W	2M + 0W	3M + 0W	3M + 1W
‘Hall’s Giant’	NA	100/0*	93/7	97/3	97/3	60/40
	CA			100/0	97/3	55/45
	Xtend®			100/0	100/0	69/31
‘Catalan’	NA	100/0	54/46	49/41	53/47	10/90
	CA			76/24	64/36	9/91
	Xtend®			93/7	96/4	40/60
‘Webb’s Prize Cob’	NA	100/0	92/8	99/1	98/2	90/10
	CA			100/0	100/0	89/11
	Xtend®			100/0	100/0	93/7
‘Cosford’	NA	100/0	65/35	72/28	64/36	20/80
	CA			84/16	73/27	15/85
	Xtend®			97/3	93/7	25/75

*number of hazelnuts in the husk/number of hazelnuts without husk

NA – normal atmosphere, regular cold storage, CA – controlled atmosphere, Xtend® – packaging bags



NA – normal atmosphere, CA – controlled atmosphere, Xtend® – packaging bags

Fig. 1. Degree of infestation with fungal and physiological diseases of hazelnuts in the husk after three months of storage in the years 2013-2014 (in %)

DISCUSSION

The assessment of nut weight at harvest indicated that the husk accounted on average for 30% of the total nut weight. Zdyb (2012) reported that the husk can constitute up to 41% of the total weight of a hazelnut. This is important for the producers of hazelnuts, as the weight of nuts in the husk is higher at harvest, and also after a storage.

The highest weight of nuts in the husk and without husk, as well as the weight of the kernels, was found in the hazelnuts stored in Xtend® bags and, for some cultivars, also in CA. The values of these parameters correlated with higher water content in nuts. Also over-ripening was much slower in nuts stored in Xtend® bags compared to NA, because of limited oxygen migration or its low concentration. Similar findings on the content of water in the kernels of unripe nuts stored for two weeks in modified atmosphere were made by Moscetti et al. (2012). A significant effect of modified and controlled atmosphere on the water content in the kernels of stored ripe nuts was reported by Keme et al. (1980), Ghirardello et al. (2013) and Guiné et al. (2015).

The higher weight of kernels in the Cat nuts compared to the weight of nuts at harvest could be associated with physiological changes taking place during the post-harvest ripening in the storage period. In addition, this cultivar has a fleshier husk and thick shell (Piskornik et al. 1989; Zdyb 2012), which protect the kernel against water loss and hence weight loss.

An important quality parameter for the nuts in the husk is their ability to remain in that state, as the de-husking process not only diminishes their attractiveness, but also impacts losses of total nut weight. The strength of husk adherence depended on hazelnut cultivar and storage conditions, but was physiologically associated with the maturing of nuts. The adherence of the husk was lowest in long-husked hazelnut cultivars. Farinelli et al. (2001) and Zdyb (2012) reported that the quality of hazelnuts assessed was based on the adherence of the husk to the shell, and the husk length mainly depends on the cultivar and maturity phase. In our experiment, the effect of storage conditions causing easier detachment of the husk from the shell was associated with faster loss of water by nuts, which, combined with higher levels of atmospheric oxygen, accelerated their ripening (Table 4 & 5). The storage of ripe, pre-dried nuts under conditions of high oxygen levels results in the faster transformation of nutrients inside nuts, and hence over-ripening (Keme et al. 1980; San Martin et al. 2001; Ghirardello et al. 2013).

Nuts stored in Xtend® bags were more severely affected by fungal diseases and physiological disorders, than those stored in other conditions, especially at CA. High water content in nuts connected with high oxygen levels (mean 18.5%) inside Xtend® bags promoted the postharvest diseases development. In the case of cultivars more susceptible to storage disorders, like Cos or Cat (Fig. 1), the storage in Xtend® bags caused 54 and 93% of nut losses, respectively, which indicates a strong need for adapting both the kind of Xtend® bags and careful cultivar selection. The major factors impact fungal growth during the storage of nuts are higher water content in nuts, temperature, and air humidity over 70% (Simsek et al. 2002; Campbell et al. 2003; Navarro 2006). Studies investigating the storage of fruits in Xtend® bags indicated that the adjustment of package type to the specific type of fruit allows for maintaining optimal humidity during storage, which largely limits the development of storage diseases (Aharoni et al. 2008). In our experiment, the highest percentage of nuts unaffected by disease was found for storage in CA conditions. The low oxygen concentration and the presence of carbon dioxide during nut storage in CA effectively inhibited their respiration (Keme et al. 1980; San Martin et al. 2001; Ghirardello et al. 2013), and at the same time limited the development of fungal diseases and physiological disorders (Leuty et al. 2012).

CONCLUSIONS

1. Three-month storage in Xtend® bags and in CA resulted in higher weight of hazelnuts (both with and without the husk), higher kernel weight as well as higher water content and percentage of nuts with adhering husk when compared to batches stored in a normal atmosphere.
2. For two of the four investigated cultivars stored in Xtend® bags, small weight losses caused an almost complete loss of commercial value due to being heavily infected with fungal and abiotic diseases, which indicates the need for further studies on both Xtend® bags and cultivar selection.
3. The highest percentage of nuts with attached husk after storage was found to be for ‘Hall’s Giant’ and ‘Webb’s Prize Cob’ cultivars. These cultivars showed a low tendency to de-husk, both during cold storage and simulated shelf-life.
4. Among the investigated cultivars ‘Catalan’ turned out to be the most susceptible, while ‘Hall’s Giant’ the most resistant to the development of fungal diseases and physiological disorders during storage. Irrespective of storage conditions, after three months of storage the infection of the latter did not exceed 14%.

REFERENCES

Aharoni N., Rodov V., Fallik E., Porat R., Pesis E., Lurie S. 2008. Controlling humidity improves efficacy of modified atmosphere packaging of fruits and vegetables. Acta Horticulturae 804: 121-128. DOI: 10.17660/ActaHortic.2008.804.14.

Anonymous 1995. Fındık Ekonomik Raporu, Fiskobirlik, Giresun. (in Turkish)

Artes F., Villaescusa R., Tudela J.A. 2000. Modified atmosphere packaging of pomegranates. Journal Food Science. 65: 1112-1116. DOI: 10.1111/j.1365-2621.2000.tb10248.x

Campbell B.C., Molyneux R.J., Schatzki T.F. 2003. Current research on reducing pre- and post-harvest aflatoxin contamination of US almond, pistachio and walnut. Toxin Reviews. 22: 225-266. DOI: 10.1081/TXR-12002409.

Christopoulos M.V., Tsantili E. 2011. Effects of temperature and packaging atmosphere on total antioxidants and colour of walnut (*Juglans regia* L.) kernels during storage. Scientia Horticulturae. 131: 49-57. DOI: 10.1016/j.scienta.2011.09.026.

Christopoulos M.V., Tsantili E. 2015. Oil composition in stored walnut cultivars – quality and nutritional value. European of Journal Lipid Science and Technology. 117: 338-348. DOI: 10.1002/ejlt.201400082.

Ciemniewska-Żytkiewicz H., Pasini F., Verardo F., Bryś J., Koczoń P., Florenza Caboni M. 2015. Changes of the lipid fraction during fruit development in hazelnuts (*Corylus avellana* L.) grown in Poland. European of Journal Lipid Science and Technology. 117: 710-717. DOI: 10.1002/ejlt.201400345.

Ebrahem K.S., Richardson D.G., Tetley R.M. 1994. Effects of storage temperature, kernel intactness and roasting temperature on vitamin E, fatty acids and peroxide value of hazelnuts. Acta Horticulturae 351: 677-684. DOI: 10.17660/ActaHortic.1994.351.75.

Farinelli D., Tombesi A., Boco M., Trappoloni C.S. 2001. Hazelnut (*Corylus avellana* L.) kernel quality during maturity in central Italy. Acta Horticulturae 556: 553-558. DOI: 10.17660/ActaHortic.2001.556.80.

Ghirardello D., Contessa C., Valentini N., Zeppa G., Rolle L., Gerbi V., Botta R. 2013. Effect of storage conditions on chemical and physical characteristics of hazelnut (*Corylus avellana* L.). Postharvest Biology and Technology 81: 37-43. DOI: 10.1016/j.postharvbio.2013.02.014.

Ghirardello D., Zeppa G., Rolle L., Gerbi V., Contessa C., Valentini N., Botta R., Griseri G. 2014. Effect of different storage conditions on hazelnut quality. Acta Horticulturae 1052: 315-318. DOI: 10.17660/ActaHortic.2014.1052.44.

Guiné R.P.F., Almeida C.F.F, Correia P.M.R. 2015. Influence of packaging and storage on some properties of hazelnuts. Food Measure 9:11-19. DOI: 10.1007/s11694-014-9206-3.

Keme T., Vitali F., Messerli M., Nappucci R., Shejbal J. 1980. Preservation of chemical and organoleptic parameters in different varieties of hazelnuts in nitrogen and in air. In: Schejbal J. (Ed.), Controlled atmosphere storage of grains. Developments in Agricultural Engineering 1: 343-358.

Koyuncu M.A., Islam A., Küçük M. 2005. Fat and fatty acid composition of hazelnut kernels in vacuum packages during storage. Grasas Aceites 56(4): 263-266.

Leuty T., Galic D., Bailey P., Dale A., Currie E., Filotas M. 2012. Hazelnut in Ontario – growing, harvesting and food safety. Omafra Factsheet 12-011, 12. www.omafra.gov.on.ca/english/crops/facts/12-011.htm

Massantini R., Contini M. 2009. The consumption of fresh hazelnut: quality and storage. Acta Horticulturae 845: 635-639. DOI: 10.17660/ActaHortic.2012.940.37.

Maskan, M., Karataş Ş. 1998. Fatty acid oxidation of pistachio nuts stored under atmospheric conditions and different temperatures. Journal of Science of Food and Agriculture 77: 334-340. DOI: 10.1002/(SICI)1097-0010(199807).

Maté J.I., Saltveit M.E., Krochta J.M. 1996. Peanut and walnut rancidity: Effects of oxygen concentration and relative humidity. Journal of Food Science 61: 465-469. DOI: 10.1111/j.1365-2621.1996.tb14218.x.

Mencarelli F., Forniti R., DeSantis D., Bellincontro A. 2008. Effects of inert atmosphere and temperature for dried hazelnuts storage. Ingredienti Alimentari 39: 16-21.

Mexis S.F., Badeka A.V., Riganakos K.A., Karakostas K.X., Kontaminas M.G. 2009. Effect of packaging and storage conditions on quality of shelled walnut. Food Control 20: 743-751. DOI: 10.1016/j.foodcont.2008.09.022.

Moscetti R., Frangipane M.T., Monarca D., Cecchini M., Massantini R. 2012. Maintaining the quality of unripe, fresh hazelnuts through storage under modified atmospheres. Postharvest Biology and Technology 65: 33-38. DOI: 10.1016/j.postharvbio.2011.10.009.

Navarro S. 2006. Modified atmospheres for the control of stored-product insects and mites. In: Heaps J.W. (Ed.), Insect management for food storage and processing, Second Edition. AACC International, St. Paul, MN, USA, pp. 105-146.

Piskornik Z., Mazur A., Korfel J., Koralkowska K., Maziarz B., Dębski J. 1989. The resistance of hazel (*Corylus avellana*) to hazelnut weevil (*Curculio nucum* L. – *Coleoptera*, Curculionidae). Part II. The physicochemical characteristics of the pericarp and dynamics of nut development and cultivar resistance to the pest. Acta Agrobotanica 42(1/2): 153-164.

Piskornik Z. 1994. Hazelnut culture in Poland – the past, present and future in outline. Acta Horticulturae 351: 49-54. DOI: 10.17660/ActaHortic.1994.351.3.

San Martin M.B., Fernández-García T., Romero A., Lopez A. 2001. Effect of modified atmosphere storage on hazelnuts quality. Journal of Food Processing and Preservation. 25: 309-321. DOI: 10.1111/j.1745-4549.2001.tb00463.x.

Simsek O., Arici M., Demir C. 2002. Mycoflora of hazelnut (*Corylus avellana* L.) and aflatoxin content in hazelnut kernels artificially infected with *Aspergillus parasiticus*. Food/Nahrung, 46(3): 194-196. DOI: 10.1002/1521-3803(20020501).

Thompson M.M., Lagerstedt H.B., Mehlenbacher S.A. 1996. Hazelnuts. In: Janick J., Moore J.N. (Ed.), Fruit breeding 3: Nuts. John Wiley & Sons, p. 125-184.

Wieniarska J., Szember E., Szot I., Murawska D. 2004. The comparison of quality of three cultivars of hazelnut *Corylus avellana* L. Acta Scientiarum Polonorum, Hortorum Cultus 3(1): 55-60.

Zdyb H. 2012. Leszczyna. Powszechne Wydawnictwo Rolnicze i Leśne, Warszawa, 248 p. (In Polish)