Original research article
Section: Food Quality and Functionality

Effect of Package Type on Selected Parameters of Nutritional Quality of Chill-Stored White Sauerkraut

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Brassica vegetables, including white cabbage, both fresh and sour (*Brassica oleracea* L. var. *capitata* L.), contain a lot of valuable metabolites which are effective in chemoprevention of cancer as documented by numerous studies. This work investigates the effect of different packaging types; low density polyethylene (PE-LD) and metalized polyethylene terephthalate (PET met/PE) with polyethylene bags on selected quality parameters in chill-stored white sauerkraut. Sauerkraut was subjected to refrigerated storage for 4 months. Every month, stored sauerkraut was analyzed in terms of vitamin C, total phenolic compounds content and antioxidant activity. Statistical analysis demonstrated that the type of packaging had a significant influence on the antioxidant activity of chilled stored sauerkraut.

INTRODUCTION

Fermentation of vegetables based on lactic acid bacteria is one of the oldest forms of food preservation in the world. In this part of Europe, white cabbage, both fresh and sour, is one of the vegetables consumed in the largest quantities throughout the year; traditionally added to meat and high-fat foods conducing cancer transformation. Due to high consumption and availability throughout the year, cabbage could potentially be a significant element in chemoprevention of cancer [Cabello-Hurtado *et al.*, 2012; Kusznierewicz *et al.*, 2008]. From the dietary point of view, *Brassica* vegetables, *e.g.* white cabbage, are a rich source of valuable vitamins with antioxidant properties, including vitamin C, PP, β-carotene, folic acid and α-tocopherol and mineral compounds such as calcium, selenium, potassium, magnesium, and iron as well as antioxidants such as flavonoids, polyphenols and glucosinolates. Among non-nutritive compounds, it can be highlighted the presence of fiber, which is positively affecting intestinal peristalsis and goitrogens which have a negative effect on the human body. The latter, reducing the iodination of tyrosine, can lead to hypothyroidism [Girgin & El Nehir, 2015; Kapusta-Duch *et al.*, 2012; Peñas *et al.*, 2015]. Sauerkraut, despite the losses of some compounds during fermentation, retains a high nutritional value and it is additionally enriched with precious compounds positively affecting the consumers' health. Furthermore, its flavour raises significantly and contributes to increasing consumption compared to the raw cabbage.

Lactic acid is a valuable constituent produced during fermentation process; the properly fermented raw material contains about 1600 mg/100 g fresh weight of this acid. From a chemical point of view, it is a 2-hydroxypropanoic or α-hydroxypropionic acid, which demonstrates preservative properties due to its ability to inhibit the growth of coliforms and *Clostridium bacteria*. The acid protects products against enzymatic and chemical reactions contributing to changes in color, stability or appearance. In the human body, this acid acts as a protective layer of the skin and it is also involved in the defensive mechanisms occurring in the mucous membranes [Dinkova-Kostova & Kostov, 2012; Gagné *et al.*, 2015].

Nowadays, consumer demand for healthier and safer food products has prompted research on novel preservation techniques. The key elements responsible for the quality of food are the technologies used to process raw materials as well as the methods of food preservation. Temperatures used in chilling range from 0 to 10°C – the optimum temperature for the majority of the stored vegetables. Such values contribute to growth inhibition of pathogenic microorganisms, lower activity of enzymes, and limit the metabolic processes in vegetables [Costa *et al.*, 2011; Gómez-Estaca *et al.*, 2014].

Vitamin C and total polyphenols content in vegetables depends on several factors but mainly on the cultivar, stage of maturity at harvest, site and method of cultivation, agrotechnique, climatic conditions, storage, as well as technology of processing and preservation [Hounsome *et al*., 2009]. Various technological treatments such as cooking, pre-processing (washing, peeling, grinding) and storage may lead to significant declines in antioxidants, particularly in vita-

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min C. Vitamin C is highly labile, and long-term storage has a negative influence on its content. It has been reported that long-term storage, high temperatures or physical and chemical damage of the product enhance its losses [Grajek (*ed.*), 2007; Peñas *et al.*, 2015]. Preliminary treatment of vegetables (peeling and cutting) leads also to enzymatic decomposition of total polyphenols or their decomposition due to the presence of oxygen. In addition, the long-term storage intensifies the processes of enzymatic or chemical oxidation of these substances to an extent depending on environmental factors such as, among others, temperature, pH, water activity, time and the access to oxygen [Ninfali & Bacchiocca, 2003]. Changes in the antioxidant activity in vegetables during their storage can be associated with changes in the level of antioxidants, for example, flavonoids, phenolic acids, amino acids, ascorbic acid, tocopherols and some pigments as well as with their mutual interactions [Chu *et al.*, 2002].

In view of the above, a contemporary man is searching for effective methods of food storage to minimize losses occurring during this process. Hence, studies are conducted all over the world to find a method which will be beneficial from both nutritional and economic point of view and the use of which is inexpensive but efficient enough to maintain a natural composition of the stored product [Ambrosone & Tang, 2009].

The role of packaging is quite wide and one of the most important functions of packaging is to protect the product against the external conditions as well as mechanical damages. Vegetables are a delicate raw material for storage; hence, the choice of suitable packaging has a strong influence on their quality. Packaging should be adjusted to physicochemical properties of the product such as, for example, its chemical composition or physical state. Selections of suitable packaging materials ensure a high quality of products with regard to their sensory and nutritional characteristics [Van Ooijen *et al.*, 2016]. Muratore *et al.* [2015] have included the type and effectiveness of the packaging in a group of parameters characterizing the quality of food. The packaging is an integral part of the product. For the quality of stored food products, storage conditions are equally important. Soured products are usually stored in wooden, metallic or plastic barrels.

Barrier properties of the laminates used are the most important features of packaging. Plastic materials used for packaging should demonstrate good barrier properties for gas. They should also be hermetic against oxygen, water vapor, flavorings, carbon dioxide and nitrogen. Several factors can influence the barrier properties of a packaging material, like food contact and environmental conditions such as temperature and relative humidity. Permeates diffusion across a film is influenced by the film structure, film permeability to specific gases or vapour, thickness, area, temperature, difference in pressure, or concentration gradient across the film. The PE-LD properties include low permeability to water vapor and good permeability to gases, especially carbon dioxide [Hussein *et al.*, 2015]. Aluminum foil (very thin sheeting with thickness from 0.00017 inch–4 μ to 0.0059 inch–150 μ) is unique in providing essentially complete barrier to light, oxygen, or water vapor transmission. The coating reduces the permeability of the film to these factors. The properties of the film remain, such as higher toughness, the ability to

be heat sealed, and a lower density at a lower cost than an aluminum foil. This gives metallized films some advantages over aluminum foil and aluminum foil laminates. The controlled permeation extends the shelf life [Dunn, 2015]. Individual packages, called also direct or internal, are characterized by limited capacity. The main task of such packaging type is to protect the product against quantitative as well as, to a slight extent, qualitative losses. Packaging may preserve the shelf life of minimally-processed products [Muratore *et al.*, 2015].

In this work, the bags made from the metalized polyethylene terephthalate foil (PET met/PE) were used, which are not applied to pack vegetables in the industry. The aim of this paper was to examine and compare white sauerkraut, which was chill-stored for four months, in terms of changes in the vitamin C, total polyphenols content as well as antioxidant activity. The experimental material was packed in two ways: in low density polyethylene (PE-LD) bags and in metalized polyethylene terephthalate (PET met/PE) bags. With a view to this goal, the research hypothesis tested was that the vitamin C, total polyphenol contents and antioxidant activity in sauerkraut chill-stored for four months in two different packaging types differed statistically significantly.

To our best knowledge, this is the first study to analyze the effect of cold storage in different packaging types (especially innovative is one of presented packaging type – metalized foil made from PET met/PE) on the selected antioxidative properties of the chill-stored white sauerkraut. This study was also aimed at increasing the consumer's knowledge about the biological value of the sauerkraut, particularly with regard to the presence of such antioxidants as vitamin C and total polyphenols as well as antioxidant activity. In addition, the results should help to choose the container which will be the most suitable for the chilled storage of white sauerkraut.

MATERIAL AND METHODS

Material

The experimental material consisted of fresh white sauerkraut (the *'Stone head'* variety), purchased in five different shops of Krakow. Acquisition of the research material was aimed at reflecting the situation of the average consumer, who buys the vegetable at the market places. Vegetables were analyzed before packaging and after 1, 2, 3 and 4 months of chilled storage in two types of packages: in low density polyethylene (PE-LD) bags with the zipper closure (foil density: 0.91–0.92 g/cm^3) and in bags of similar size made of laminate: metalized polyethylene terephthalate (PET met/PE) (a polymer from the polyester group, obtained through a polycondensation reaction between dimethyl terephthalate (DMT) and ethylene glycol (GE), CAS number: 25038–59–9, density 1.370 g/cm^3) with polyethylene. The bags made of the laminate PET/met PE after packaging of the analyzed material were hermetically sealed using a welding machine. This packaging was innovative and had an interesting alternative for commonly used string bag, made of PE-LD.

The representative samples obtained were then stored at chilled conditions (4–5°C) in a fridge for four subsequent months. There were a total of 8 bags, 4 from each package

sort, containing an average of half a kilogram of the material analyzed. Packages were opened consecutively with the expiry of the research.

Analytical methods

Sauerkraut taken before packing and after the established periods of chilled storage from every container was collected and then homogenized using a homogenizer (CAT type X 120, CAT Scientific, Inc., USA) in order to obtain a mean representative sample.

Adequately prepared mean representative samples of vegetables were analyzed for vitamin C content – expressed as a sum of ascorbic and dehydroascorbic acid [PN-A--04019:1998]. Simultaneously, 70% methanol extracts were prepared. The content of vitamin C was determined as the sum of ascorbic acid and dehydroascorbic acid using 2,6-dichlorophenoloindophenol according to the Polish Standard [PN-A-04019:1998]. An oxalic acid solution was used for extraction of ascorbic acid.

The content of total phenols in the extracts was determined spectrometrically (at a wavelength of 760 nm using a RayLeigh UV-1800 spectrophotometer (Beijing Rayleigh Analytical Instrument Corporation (BRAIC), China) according to the Folin-Ciocalteu procedure [Poli-Swain & Hillis, 1959] and calculated as chlorogenic acid equivalents (CGA) (in milligrams) per 100 g of fresh or dry weight, based on a standard curve.

The method involved colorimetric determination of the content of the colored solution of ABTS$^{•+}$ free radical (2, 2'-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) which was reduced by the antioxidants present in the tested product [Re et al., 1999]. The absorbance was measured at a wavelength of 734 nm using a RayLeigh UV-1800 spectrophotometer (Beijing Rayleigh Analytical Instrument Corporation (BRAIC), China). Values obtained for each sample were compared to the concentration–response curve of the standard Trolox solution and expressed as micromoles of Trolox equivalent to gram of fresh or dry weight (TEAC).

Statistical analysis

All analyses were carried out in three parallel replications (n=3) and standard deviations (SD) were calculated for the obtained mean values. The one-way and two-way analysis of variance was employed to verify the significance of differences between the content of vitamin C, polyphenols and differences in the ABTS$^{•+}$ free radical scavenging ability in the vegetables examined as affected by the process used (chilled storage) and the type of package used. The one-way analysis of variance was used to find the significance of differences between the mean values of the parameters investigated for the vegetable stored in two different types of package. The two-way analysis of variance was employed to establish the significance of differences between values of the parameters evaluated for the chill-stored vegetable depending on package type and chill-storage duration. The Statistica 9.1. PL software was applied for all calculations. The significance of differences between mean values was checked with the Duncan's multiple range test; differences were found significant at p≤0.05.

RESULTS AND DISCUSSION

The results are discussed based on the dry matter (d.m.), thus eliminating the effect of water dilution on changes in the level of a constituent per a weight unit of the experimental material; as a result, only the effect of the technological process applied has been shown.

Vitamin C

Prior to packaging, the content of vitamin C in sauerkraut was 214.7 mg/100 g d.m. (Table 1). In the vegetables chill-stored for 4 months, vitamin C losses were as follows: in the products kept in the PE-LD bags: 46.6, 51.3, 36.4, and 51.7%; while in those stored in the PET met/PE bags: 51.6, 48.9, 46.8 and 53.6%, compared to the non-stored sample (Figure 1).

Therefore the type of packaging used had no significant effect (p>0.05) on vitamin C content in the chill-stored white sauerkraut.

The content of vitamin C in sour cabbage depends on its content in the raw material, sauerkraut acidity and storage conditions. According to literature, vitamin C content in raw white cabbage fluctuates broadly between 18.0 and 54 mg/100 g fresh vegetable [Bahorun et al., 2004; Chu et al., 2002; Davey et al., 2000; Hrncirik et al., 2001; Jarczyk & Płocharski, 2010; Pfendt et al., 2003; Puupponen-Pimia et al., 2003]. Our results are similar to those reported by Peñas et al. [2015], who observed a vitamin C content of 20.1 mg/100 g in sauerkraut.

The large variation in the results could be attributed to different parameters of cultivation and post-harvest storage, or to different varieties studied. The content of vitamin C in the stored product depends, to a large extent, on vitamin level in the raw non-stored product.

This study revealed that vitamin C content in sauerkraut chill-stored in two different types of packages for 4 months decreased by 52.6% compared with the non-stored sauerkraut.

Czech & Rusinek [2012] observed losses of this vitamin reaching 10.5% and 38.5% in raw white cabbage after storage at 0°C for 30 and 60 days, respectively. In the same study, the losses in vitamin C content determined in red cabbage were smaller: 8.2% after 30 days of storage and 34.9% after 60 days. Peñas et al. [2015] found that the content of vitamin C in natural fermented cabbage decreased significantly during conventional storage, and retentions of 77%, 50% and 35% were observed after 1, 2 and 3 months, respectively. Martinez-Villaluenga et al. [2009] reported that the fermentation process of cabbage led to significant reductions of this compound. Hounsome et al. [2009] found the loss of ascorbic acid in white cabbage of as much as 80% during 3-month storage at 1°C compared to the fresh vegetable and a 50% decrease after 6-month chill-storage under identical conditions. There were no statistically significant changes with regard to dehydroascorbic acid. Many authors have received similar results [Grajek (ed.), 2007], which are consisted with those obtained in this work.

According to Nath et al. [2011], however, there were no considerable changes in vitamin C content in chill-stored broccoli which was packed in the polypropylene (PP) micro perforation bags, in comparison with the vegetable be-
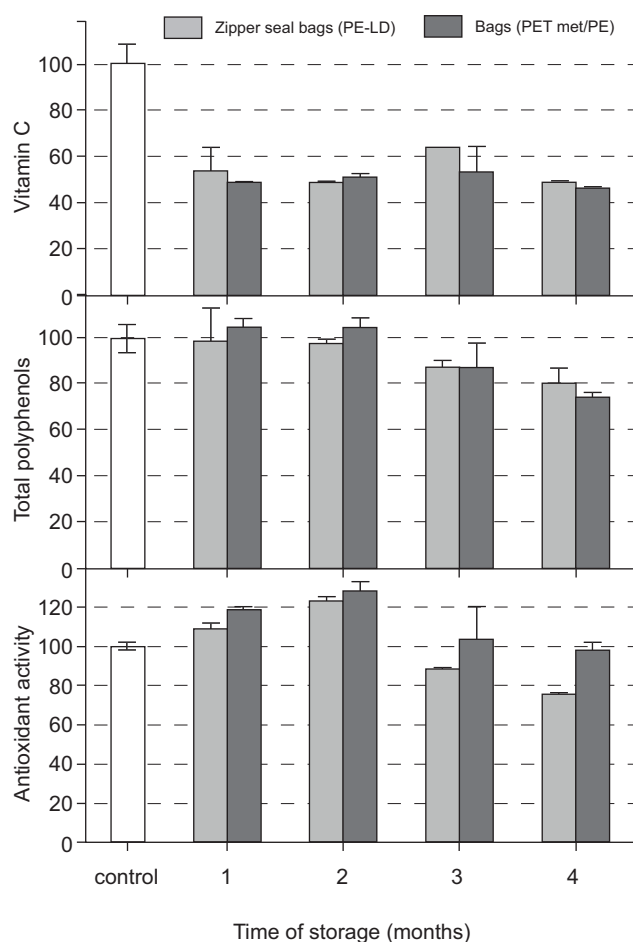
FIGURE 1. Changes in the content of vitamin C, total polyphenols and antioxidant activity in sauerkraut packed in two different types of bags (PE-LD and PET met/PE) during 4 months of chilled storage. The values are given as % of control – assuming the results obtained for fresh sample as 100%.

TABLE 1. Content of vitamin C in chill-stored white sauerkraut (mg/100 g d.m.).

Type of processing	Vitamin C	
Before storage	214.7±19.3[a]	
Cool storage	Type of packaging	
	Zipper seal bags (PE-LD)	Bags (PET met/PE)
1 month	114.7±22.9[bc]	103.9±0.08[bc]
2 months	104.5±1.66[bc]	109.7±2.80[bc]
3 months	136.6±0.22[b]	114.2±24.5[bc]
4 months	103.6±2.50[bc]	99.7±0.66[bc]
Mean value for packaging	134.8±45.1[A]	128.4±46.9[A]

Values are presented as mean value ± standard deviation (n=3). The values denoted with the same letters do not differ statistically significantly at p≤0.05.

Total polyphenols

The content of total polyphenols was expressed as chlorogenic acid equivalent (Table 2). After 3- and 4-month chilled storage, losses observed in total polyphenols in sour white cabbage were significant (p≤0.05) and were respectively: 12.2 and 19.4%, in the PE-LD bags; and 12.3 and 25.0% in the PET met/PE bags, compared to the values determined prior to packaging (Figure 1).

This study proved that the packaging type had no significant effect on the level of total polyphenols in the white sauerkraut stored under chilled conditions (Table 2).

The results obtained in the present study as well as literature data indicate a great diversity in the results presented by various authors. This proves considerable variability of the analyzed parameter. The total polyphenols content in the examined sour white cabbage reached 108.7 mg/100 g fresh product (expressed as chlorogenic acid). According to literature data, the content of total polyphenols in white cabbage ranges broadly from 15.3 to 58.0 mg/100 g fresh vegetable [Bahorun *et al.*, 2004; Chu *et al.*, 2002; Heo & Lee, 2006; Proteggente *et al.*, 2002]. The highest total polyphenol content in white cabbage (203.0 mg/100 g fresh vegetable) has been determined by Wu *et al.* [2004], the results being calculated and expressed as gallic acid. In turn, Ciska *et al.* [2005] determined the total polyphenol content in white cabbage at 572.0 mg/100 g (expressed as gallic acid), which agrees with the findings of Heimler *et al.* [2006] – 531.0 mg/100 g vegetable d.m. (also expressed as gallic acid); although, according to Ismail *et al.* [2004] the content of total polyphenols reached 1107.0 mg/100 g. Vinson *et al.* [1998], Podsędek *et al.* [2004], and Kaur & Kapoor [2002], who calculated total polyphenols per catechin, found the following values: 20.6, 15.0, and 92.5 mg/100 g fresh vegetable, respectively.

Literature data usually show the content of total polyphenols in *Brassicas* with reference to kaempferol, gallic acid and catechin. Vegetables are primarily a source of polyphenolic compounds from the group of phenolic acids, since the proportion of flavonoids to the total polyphenol content ranges from 4% in white cabbage and Italian cabbage to 39%

fore packaging. According to the findings of Kalt [2005], losses in vitamin C in broccoli after 6 days of storage in air, were within the range of 75–85%. Apart from the activity of oxygen, vitamin C content in the plant material can also be affected by high temperatures, trace amounts of metals and enzymes as well as the method used to prepare the material for analyses [Martinez-Villaluenga *et al.*, 2009]. Wieczorek & Traczyk [1995] reported losses of 28 and 39% in vitamin C in shredded white cabbage after 4 and 24 h, respectively. The relative air humidity also considerably affects losses of vitamin C. Low humidity responsible for rapid wilting of vegetables, similarly as an increase in the concentration of ethylene, contribute to a significant decrease in vitamin C content [Lee & Kader, 2000]. However, Czapski & Szwejda [2006], who examined three species of fermented white cabbage, found that a 4-week period of chilled storage led to an increase in vitamin C content in sauerkraut compared to the initial value. Further 8-week chilled storage contributed to a decrease of vitamin C content, on average, by 4%, and after further 12 weeks by 23%, when compared to the vegetable before storage.

In the available literature, there is no data concerning changes in this constituent in sour white cabbage which was chill-stored in various packages.

TABLE 2. Content of total polyphenols in chill-stored white sauerkraut (mg CGA/100 g d.m.).

Type of processing	Total polyphenols	
Before storage	1120.6±68.9[a]	
	Type of packaging	
Cool storage	Zipper seal bags (PE-LD)	Bags (PET met/PE)
1 month	1110.0±158.3[a]	1180.0±40.2[a]
2 months	1101.3±18.4[a]	1181.5±39.0[a]
3 months	983.6±33.5[b]	982.5±119.4[b]
4 months	903.2±74.9[bc]	840.9±19.3[c]
Mean value for packaging	1043.7±116.6[A]	1061.1±147.8[A]

Values are presented as mean value ± standard deviation (n=3). The values denoted with the same letters do not differ statistically significantly at p≤0.05.

TABLE 3. Antioxidant activity in chill-stored white sauerkraut (μm Trolox/g d.m.).

Type of processing	Antioxidant activity	
Before storage	192.0±3.56[cd]	
	Type of packaging	
Cool storage	Zipper seal bags (PE-LD)	Bags (PET met/PE)
1 month	208.5±6.51[c]	228.6±1.95[b]
2 months	236.1±4.53[ab]	246.6±7.73[a]
3 months	169.7±1.15[e]	199.8±31.7[cd]
4 months	144.6±2.31[f]	189.4±5.80[d]
Mean value for packaging	190.2±32.4[B]	211.3±26.6[A]

Values are presented as mean value ± standard deviation (n=3). The values denoted with the same letters do not differ statistically significantly at p≤0.05.

in red cabbage [Chun *et al.*, 2004; Karadeniz *et al.*, 2005]. According to literature data, the content of flavonoids other than derivatives of flavonols and flavones is low in vegetables. White cabbage contains over 20 compounds of quercetin and kaempferol, including quercetin and kaempferol 3-sophoroside-7-glucoside and kaempferol 3,7-diglucoside) as well as their forms acylated with hydroxycinnamic acids [Bahorun *et al.*, 2004; Nielsen *et al.*, 1998].

As proved by Grajek (*ed.*) [2007], the concentration of phenolic acids may increase or decrease during the growth of *Brassica* vegetables, whereas during storage it decreases rapidly. In the case of polyphenolic compounds, which are very diverse in terms of structure and properties, conditions of the extraction from raw materials are no less important than methods of analysis. Large discrepancies in the values of total polyphenols reported by the aforementioned authors may be due to different methods used to extract polyphenolic compounds from raw materials; they applied both 50 and 70% methanol, and 70 or 80% acetone as well as 70% acetone acidified with acetic acid. Another reason may be a different manner in which the results are calculated depending on the applied standard. As it was observed in this work, after chilled storage for 4 months, the content of total polyphenols in sauerkraut decreased significantly (32.7%) compared with the non-stored sauerkraut. The factors affecting significantly the changes in the level of polyphenolic compounds include duration and temperature of cold storage as well as the degree of damage to vegetable tissue [Martinez-Valverde *et al.*, 2002]. Bunea *et al.* [2008] found that losses of total polyphenols in the spinach chill-stored for 24 and 72 h were 7.6% and 11.6% respectively when compared to the fresh vegetable. Vina & Chaves [2006] investigated the effect of chilled storage at 0°C and 4°C for 0, 7, 14, 21 and 28 days on the content of total phenolic compounds in portioned celery leaves packaged in polystyrene trays (PS) and sealed with PVC foil. The authors stated that at the end of the experiment the content of these constituents in the vegetable stored at 0°C remained unchanged, while in those stored at 4°C it increased slightly by 25%. On the other hand, Amanatidou *et al.* [2000] dem-

onstrated an 8-fold increase in total polyphenols in the sliced carrot stored at 8°C for 12 days compared to the fresh vegetable. Gil-Izuaredo *et al.* [2002] reported an increase in chlorogenic acid content in artichoke stored at temperatures ranging from 0 to 7°C for 14 days; the increase was greater in internal than external parts of the vegetable. Babic *et al.* [1993] observed both an increase and a decrease in chlorogenic acid content in minimally-processed carrot after maximum three days of storage at 4°C. According to the aforementioned authors, an increase in the content of phenolic compounds was probably caused by the physiological response of vegetables to their infection and damage. In the eight lettuce varieties and three endive varieties stored in the dark at 1°C and humidity of 98%, the total content of flavonoid glycosides decreased substantially by 7–46% after 7 days of storage, except for one lettuce variety characterized by a relatively less content of these compounds [DuPont *et al.*, 2000].

Storage in different packages had no significant effect (p>0.05) on the content of total polyphenols in sauerkraut. However, there is no literature data on the impact of these types of packages on selected health-promoting properties of foods stored in them.

Antioxidant activity

Antioxidant activity in white sauerkraut has been calculated as as micromoles of Trolox equivalent per gram of dry weight (Table 3). The following significant changes (p≤0.05) of the antioxidant activity were observed in the sauerkraut after 2-, 3- and 4-month chilled storage in the PE-LD bags: +23.0% (an increase in antioxidant potential) and -11.6 and -24.7% (a decrease), in comparison with the non-stored vegetable (Figure 1).

In the vegetables kept in the PET met/PE bags, a significant increase in this parameter was noted only after 1- and 2-month chilled storage, which accounted for 19.1 and 28.4% respectively, compared to the vegetable prior to packaging.

It was proved that the type of packaging had a significant (p≤0.05) effect on the antioxidant potential of chill-stored

sour cabbage. The sour cabbage from the PET met/PE bags had a higher antioxidant activity than the sour cabbage from the PE-LD zipped bags (Table 3).

In the present study, the antioxidant activity assayed in sauerkraut before packaging agrees with the findings of Ciska *et al.* [2005], who determined the antioxidant activity in cabbage sauerkraut at 20.0 μmol Trolox eq./g fresh vegetable. Other authors reported lower values of the antioxidant activity in white cabbage before fermentation, *i.e.* between 1.3 and 13.6 μmol Trolox eq./g fresh vegetable [Cao *et al.*, 1996; Cieślik *et al.*, 2005; Peñas *et al.*, 2015; Podsędek *et al.*, 2006; Szajdek & Borowska, 2004; Ou *et al.*, 2002; Wu *et al.*, 2004]. After 4 months of chilled storage, the antioxidant activity decreased in white cabbage sauerkraut stored in both types of packages; its losses compared to sauerkraut before packaging were 36% in the sauerkraut stored in the PE-LD bags and 12.9% in the sauerkraut stored in the PET met/PE bags. This confirms the findings of Murcia *et al.* [2009], who found decreases in the antioxidant activity of various vegetables, *i.e.* by 3% in broccoli, by 4% in cauliflower and by 34.1% in zucchini after 7 days of storage at 4°C, compared to fresh vegetables. On the other hand, no significant changes of the antioxidant activity were observed by Peñas *et al.* [2015], during the storage of naturally obtained sauerkraut both at conventional and N_2-enriched atmospheres. Kusznierewicz *et al.* [2010] observed that the process of fermentation increased 3–4-fold the antioxidant activity of cabbage. Sun *et al.* [2009], also reported an increased antioxidant activity in spontaneously fermented Chinese cabbage. According to Vina & Chaves [2006], taking into account different storage temperatures (0, 4, and 10°C), the antioxidant capacity of celery leaves did not differ significantly after 28 days. The authors observed that the antioxidant potential of cut celery initially decreased after 7 days of storage and then increased after 2 weeks, regardless of storage temperature. It has been proved that for the examined temperatures there was a linear correlation between the antioxidant capacity and changes in vitamin C content during storage of celery. As reported by Gil *et al.* [1999], the antioxidant activity of spinach was decreasing throughout a 7-day period of storage at 10°C both in the air and in the modified atmosphere (CO_2 and O_2).

In this study, however, the antioxidant activity of the sauerkraut stored in PET met/PE bags was significantly higher than in that kept in the PE-LD bags. There is no literature data on the impact of these types of packages on the selected health-promoting properties of the foods stored in them. Nath *et al.* [2011] found no significant changes in the antioxidant activity of broccoli after 144 h of its chilled storage in the micro-perforated bags from the polypropylene (PP) film; whereas, after this time, a 49.5% decline in the antioxidant activity was observed in the broccoli packed in perforated plastic bags.

The differences in the results obtained in the course of this work, compared to literature data may arise from, as in the case of polyphenols, different experimental conditions (the storage temperature and times, other packaging material or their) as well as from the analyzed vegetable species, and various methods applied for antioxidant activity determination (FRAP, ABTS, DPPH, ORAC methods).

CONCLUSIONS

Refrigerated storage of sauerkraut for 4 months caused a statistically significant reduction in the constituents examined: on average by 52.6% in vitamin C; 32.7% in total polyphenols and 24.4% in antioxidant activity, regardless of a type of the packaging used. It has also been proved that the type of the packaging used did not affect significantly the content of vitamin C and total polyphenols. On the other hand, the antioxidant activity of the sauerkraut stored in PET met/PE bags was significantly higher than in that kept in the PE-LD bags. Finally, the results of this work enabled the choice of the container, which will be the most suitable for the storage of white sauerkraut, which is bag made of laminate: metalized polyethylene terephthalate (PET met/PE) with polyethylene. However, further studies are still necessary to evaluate other aspects (different storage time, other packaging materials, additional technologies, *etc*.) that could improve the quality features of the chilled stored white sauerkraut.

RESEARCH FUNDING

CONFLICT OF INTEREST

Authors declare no conflict of interest.

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