THE EFFECT OF PACKAGE TYPE ON SELECTED PARAMETERS OF NUTRITIONAL QUALITY OF THE CHILLED STORED RED SAUERKRAUT

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ABSTRACT

The key elements responsible for the quality of food are the technologies used to process raw materials and preserve obtained products. The aim of this paper was to investigate the effect of package type (bags made from low density polyethylene [PE-LD] and the metallized polyethylene terephthalate [PET met/PE foil]) on selected quality parameters of the chilled stored red sauerkraut. Vegetables were analyzed before packaging and after 1, 2, 3 and 4 months of chilled storage in two types of a package. It has been found that the package type used had no statistically significant ($P > 0.05$) effect on vitamin C, total polyphenols, thiocyanates contents and antioxidant activity of the chilled stored red sauerkraut.

PRACTICAL APPLICATIONS

Red cabbage is commonly occurring in a diet as an additive to meat dishes and other rich-in-fat products, which favor tumor transformation. Due to high consumption and availability throughout the year cabbage, both fresh and sour could potentially be a significant element in chemoprevention of cancer. Sauerkraut, despite the losses in some components, retains a high nutritional value and is additionally enriched with precious constituents positively affecting the consumers' health. Furthermore, its flavor raises significantly that, in turn, contributes to increasing consumption compared to the raw cabbage. Vegetables are a delicate raw material for storage. Selections of suitable packaging materials guarantee high quality of products with regard to their sensory and nutritional characteristics.

INTRODUCTION

Currently, much attention is given to the influence of a diet on human health. Numerous epidemiological studies indicate that the diet rich in plant products reduces the risk of developing chronic noncommunicable diseases, which include, among others, atherosclerosis, cardiovascular disease, obesity, diabetes and cancer (Dos Reis *et al.* 2015; Shahidi and Ambigaipalan 2015). *Brassica* vegetables are consumed in large quantities in European countries as well as China, Japan or India. Reasonable prices, availability on the local market and popularity among consumers are their characteristic features. Due to fairly common consumption, these vegetables can be considered as an important source of nutrients in the human diet (Kusznierewicz *et al.* 2008; Hounsome *et al.* 2009; Kapusta-Duch *et al.* 2012).

Anticarcinogenic properties of *Brassica* vegetables are determined by a high content of secondary metabolites in these vegetables, particularly glucosinolates as well as the presence of other bioactive compounds which play an important role in human health. Mechanism of protective action of the glucosinolate degradation products is associated with the induction of enzymes responsible for detoxification in the gastrointestinal tract tissues; particularly glutathione transferase removing active forms of carcinogens. Tests on animals along with *in vitro* studies showed that the breakdown products of glucosinolates suppress the cancer cell division and accelerate the controlled death of cells with damaged DNA (Cabello-Hurtado *et al.* 2012; Girgin and El 2015).

Due to the presence of vitamin C and E, carotenoids and antioxidant enzymes such as catalase, superoxide dismutase

(SOD) and peroxidase, *Brassica* vegetables are a source of valuable antioxidants, while the presence of polyphenols and sulfur organic compounds causes that they also exhibit antimutagenic activity. Red cabbage is known in alternative medicine for numerous beneficial properties and used to relieve edema, heal burns, skin lesions, improve digestion and mitigate pain during arthritis (Dominguez-Perles *et al.* 2014). Red cabbage is attractive for consumers not only because of its crucial dietetic values and taste, but also due to its intense purple/red color, caused by the presence of anthocyanins. The red cabbage is a rich and important source of anthocyanins in human diet. Belonging to the family of Brassicaceae this plant was originated from Asia and is now widespread throughout the world (Wiczkowski *et al.* 2015). Anthocyanins are the main compounds among phytochemicals found in red cabbage and they are considered to have cardio-protective, anti-neurodegenerative, vision-improving, diabetes-preventing and anticarcinogenic properties. The occurrence of such compounds in food determines its functional and health-promoting nature (Kapusta-Duch *et al.* 2012; Norberto *et al.* 2013).

Currently, there is growing demand for natural, safe and functional foods. Consumers are interested in foods which have positive inputs to health, but contain no chemical additives or preservatives. Fermentation of vegetables based on lactic bacteria is one of the oldest forms of food preservation in the world. This process runs due to lactic acid fermentation and the products obtained are characterized by longer shelf life, are microbiologically safe, easy digestible, simultaneously showing different properties than the initial raw material (Gagné *et al.* 2015). Among the fermented *Brassica* products, sauerkraut is a well-known traditional food made from shredded, brined white cabbage, commonly consumed in Europe.

With regard to food packaging, its most important function is to protect a product from mechanical damage due to external factors as well as to extend its shelf life. In the case of unit packages, which are characterized by small volume, the purpose of their use is to create specific microclimate in products in order to maintain the highest quality of a product in appropriate storage conditions (Van Ooijen *et al.* 2016). The selection of suitable material and form of packaging for a particular food product depends on many factors. Among these, the most important are those directly related to the physicochemical properties of the packaged product. These include: chemical composition (easily degradable chemical substances, enzymes, water content, etc.); physical state of the product (solid, various types of fluids); texture; porosity as well as storage time and conditions in which the product will be kept until its use by the consumer (cooling conditions, exposure to light, temperature and humidity) (Saravacos and Kostaropoulos 2016). Plastic materials which are used for packaging should exhibit good barrier properties toward gases. They should be hermetic against oxygen, water vapor, flavorings, carbon dioxide and nitrogen (Thompson 2015). The polyethylene family is most commonly used as the food packaging material. From the chemical point of view, polyethylene is manufactured from ethylene – the simplest substance in the homologous series of olefins. The low density polyethylene (PE-LD) is produced by the free-radical polymerization method at 100–300C under the pressure of 100–250 MPa; hence its second name: high-pressure polyethylene. PE-LD is almost an ideal material for extrusion processing and is chiefly utilized as a homogeneous film, a layer in laminates or a coating. The PE-LD properties include low permeability toward water vapor and good toward gases, particularly to carbon dioxide (Hussein *et al.* 2015).

Polyesters are produced by polycondensation of difunctional organic acids and difunctional alcohols, usually aliphatic, named glycols. As for packaging, the most important representative thereof is polyterephthalate of ethylene glycol (PET), obtained due to synthesis of terephthalic acid or its ester dimethyl terephthalate with ethylene glycol. PET has good optical properties, high stiffness, hardness and thermal resistance (Wani *et al.* 2015). The metallization is a special process of coating, in which the surface of foil is covered with the thin layer of aluminum vapor. The metallizing process of plastic foils is performed to achieve protection against light, which is a factor initiating the oxidative processes, and – what is most spectacular – to increase the barrier properties of packaging material (Fink 2016). For example, the oxygen permeability (cm^3/m^2 24 h, 0.1 MPa – dry gas) of the LDPE film (thickness 30 μm) is 4,000 and 50 for not metallized and metallized foils, respectively, whereas, in the case of the PET film (thickness 12 μm) the oxygen permeability is 100 (not metallized) and 0.5 (metallized) (Kelly 1989). A number of products require the reduction of oxygen against air. However, in the case of respiring products, like for example vegetables, a small amount of oxygen should penetrate through the film to control respiration and ripening of the packaged product. Otherwise, the product is exposed to deterioration and possible growth of pathogenic anaerobic bacteria (Wani *et al.* 2015). Unit packaging is characterized by small volume and its main task is to create the specific microclimate for products, so that, under suitable storage conditions they maintained high quality as long as possible. Sauerkraut is packed primarily in the bags made from the low density polyethylene (PE-LD) foil, the thickness of which is 40–60 μm. They are nontoxic, have a low price and are easy to stain.

To our best knowledge this is the first study determining the effect of cold storage in different packaging type (especially innovative is one of presented packaging type – metallized foil made from PET met/PE) on selected antioxidative properties of the chilled stored red sauerkraut. Different packaging materials influence the quality of the stored products diversely. Therefore, the study of the effect of packaging material on the selected quality parameters is relevant. The selection of the experimental material was also innovative, since red sauerkraut is less popular than white sauerkraut or pickled cucumbers. Furthermore, as far as we know, there is little in the available literature on the chilled storage of red sauerkraut, and virtually no works dealing with new types of packaging, like the packaging made of metallized foil, proposed in this work.

The weakness of vegetables is their seasonal availability and fact that they are perishable. In view of the above, food technology is focused on discovering and establishing the methods of storage, which will least affect their chemical composition. The aim of this paper was to examine and compare red sauerkraut, which was chilled stored for four subsequent months, in terms of changes in the dry mass, vitamin C, total polyphenols, thiocyanates content as well as antioxidant activity. The experimental material was packed in two ways: in low density polyethylene (PE-LD) bags and in metallized polyethylene terephthalate (PET met/PE) bags.

Another aspect was to popularize red sauerkraut among consumers, especially because of its strong pro-health properties as well as to help in the selection of such packaging intended for chilled storage, which to the largest extent would protects the product against the losses of valuable components.

MATERIAL AND METHODS

The experimental material consisted of fresh red sauerkraut (*Brassica oleracea* L. var. capitata L. f. rubra, the "*Langedijker*" variety), purchased in five sites of direct sales in the city of Krakow. Acquisition of the research material was aimed at reflecting the situation of the average consumer, who buys the vegetable on the market places. Vegetables were analyzed before packaging and after 1-, 2-, −3 and 4-month periods of chilled storage in the two types of the package: in the low density polyethylene (PE-LD) bags (Ekopack, Poland) with the zipper closure (foil density: 0.91–0.92 g/cm^3; size: 230 × 320 mm); and in the bags of the similar size made of the laminate: metallized polyethylene terephthalate (PET met/PE) (a polymer from the polyester group, obtained through a polycondensation reaction between dimethyl terephthalate (DMT) and ethylene glycol (EG), 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 (4–5C) in a fridge for four subsequent months. There were a total of eight bags, four from each package sort, containing an average of half a kilogram of material analyzed. Packages were opened consecutively with the expiry of the research.

ANALYTICAL METHODS

The experimental material taken before packing and after the established periods of chilled storage from each type of packaging (zipper bags and bags made of the laminate) was collected and then homogenized using a homogenizer (CAT type × 120, CAT Scientific, Inc., Paso Robles, CA) in order to obtain a mean representative sample.

The dry matter of the prepared samples of vegetables was determined according to Polish Standard PN-90/A-75101/03 (Polish Standard 1990). The determination principle comprised determining the decrease in mass upon removal of water from the product during thermal drying at the temperature of 105C, under normal pressure conditions. Adequately prepared mean representative samples of vegetables were analyzed also for vitamin C content according to Polish Standard PN-A-04019:1998 (Polish Standard 1998) and thiocyanates according to Brzozowska (2004). Simultaneously, 70% methanol extracts has been prepared to determine: total polyphenols (calculated per chlorogenic acid) – through the colorimetric measurement of colorful substances formed due to the reaction between phenolic compounds and a Folin–Ciocalteau reagent (Sigma) (Poli-Swain and Hillis 1959) and to determine antioxidant activity based on the $ABTS^+$ free radical scavenging ability – by a colorimetric assessment of an amount of the $ABTS^+$ free radical solution, which had not been reduced by the antioxidant present in the products examined (Re *et al.* 1999).

The content of vitamin C was determined as the sum of ascorbic acid and dehydroascorbic acid using 2,6-dichlorophenoloindophenol. Oxalic acid solution was used for extraction of the ascorbic acid.

Determination of thiocyanate was based on extraction of the sample with trichloroacetic acid (TCA) and performing the reaction with ferric ions. Under acidic conditions created blood-red coloration due to the formation of complexes of $Fe(SCN)^{2+}$ to $Fe(SCN)_6^{3-}$.

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 and calculated as chlorogenic acid equivalents (CGA) (in terms of milligrams) per 100 g of fresh or dry weight, based on a standard curve.

The method involved colorimetric determination of the amount 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 test product. The absorbance was measured at a wavelength of 734 nm using a RayLeigh UV-1800 spectrophotometer. Values obtained for each sample were compared to the concentration–response curve of the standard Trolox solution and expressed as micromoles of Trolox equivalent per 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- and two-way analysis of variance has been employed to verify the significance of differences between the content of dry mass, vitamin C, polyphenols, thiocyanates and differences in the $ABTS^+$ free radical scavenging ability in the vegetables examined in dependence of the process used (chilled storage) and a type of the package used. The single-way analysis of variance has been 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 chilled-stored vegetable depending on the package type used and length of chilled storage. The Statistica 9.1. (StatSoft, Inc.) program was applied for all the calculations made. In order to evaluate the significance of differences at the critical significance level of $P \leq 0.05$, the Duncan's multiple range test has been used.

RESULTS

Dry Mass

Before packaging, red cabbage sauerkraut had a dry matter content of 11.3 g/100 g fresh vegetable mass (Table 1). After 1 month storage of sauerkraut in the PET met/PE bags under chilled conditions, a 2.7% significant increase ($P \leq 0.05$) in this parameter was observed for this product, while sauerkrauts analyzed after 3- and 4-month storage had, respectively, 3.5 and 4.4% less dry matter than the product before packaging and these results were statistically significant.

Storing the sauerkraut in PE-LD bags, resulted in significant reductions ($P \leq 0.05$) in dry matter content of 4.4, 3.5 and 5.3% after respectively 2, 3 and 4 month of storage, in comparison with the sauerkraut analyzed before packaging. Studies revealed that a type of the packaging used had no significant effect ($P > 0.05$) on dry matter content in the chilled stored sauerkraut (Table 1).

TABLE 1. THE CONTENT OF DRY MASS IN THE CHILLED STORED RED SAUERKRAUT (g/100 g)

The kind of processing	Dry mass	
Before storage	$11.3^{b} \pm 0.02$	
	The kind of packaging	
Cool storage	Zipper seal bags (PE-LD)	Bags (PET met/PE)
1 month	$11.3^{b} \pm 0.02$	$11.6^{a} \pm 0.02$
2 months	$10.8^{cd} \pm 0.16$	$11.1^{bc} \pm 0.08$
3 months	$10.9^{cd} \pm 0.04$	$10.9^{cd} \pm 0.08$
4 months	$10.7^{d} \pm 0.19$	$10.8^{cd} \pm 0.06$
Mean value for packaging	$11.0^{A} \pm 0.26$	$11.1^{A} \pm 0.28$

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

As the dry matter content in red sauerkraut depending on the process applied and the container used, all the results presented below along with conclusions have been reported and discussed basing on the results calculated per the dry matter unit. In consequence, only an effect of the process applied was shown.

Vitamin C

Before packaging, the vegetable contained 259.3 mg vitamin C per 100 g dry matter (Table 2). Losses in vitamin C in the vegetables which were chilled stored for successive 4 months were significant ($P \leq 0.05$) and were: 52.0; 58.1; 57.3; and 59.2% in the vegetables stored in polyethylene low-density (PE-LD) bags; and 68.9; 69.3; 68.1; and 69.7% in those kept

TABLE 2. THE CONTENT OF VITAMIN C IN THE CHILLED STORED RED SAUERKRAUT (mg/100 g d.m.)

The kind of processing	Vitamin C	
Before storage	$259.30^{a} \pm 11.9$	
	The kind of packaging	
Cool storage	Zipper seal bags (PE-LD)	Bags (PET met/PE)
1 month	$124.50^{b} \pm 14.1$	$80.70^{c} \pm 0.14$
2 months	$108.70^{b} \pm 1.56$	$79.60^{c} \pm 0.57$
3 months	$110.70^{b} \pm 0.36$	$82.80^{c} \pm 0.57$
4 months	$105.90^{b} \pm 1.88$	$78.60^{c} \pm 0.44$
Mean value for packaging	$141.80^{A} \pm 59.7$	$116.20^{A} \pm 71.7$

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

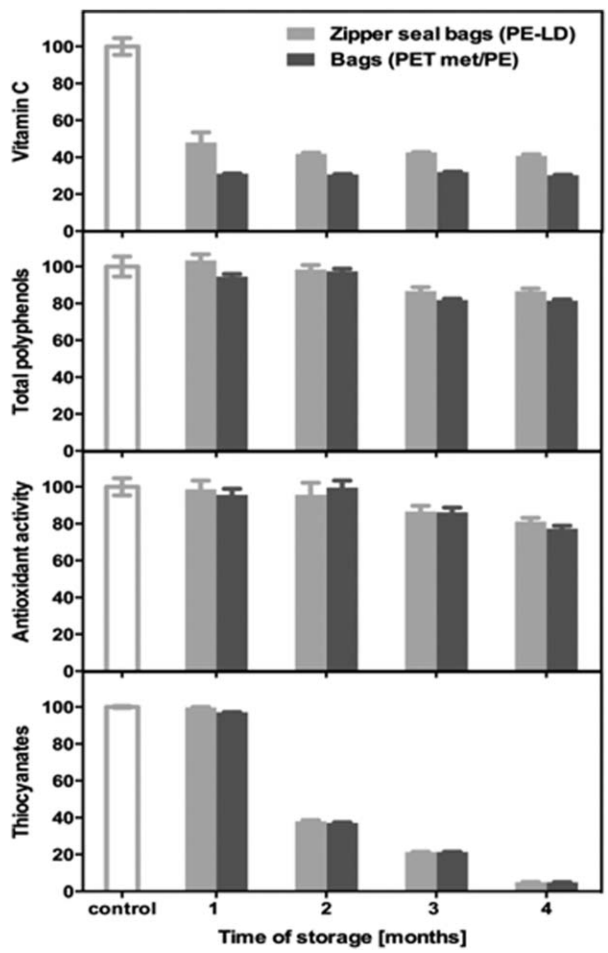

FIG. 1. THE CHANGES OF CONTENT OF VITAMIN C, TOTAL POLYPHENOLS, THIOCYANATES AND ANTIOXIDANT ACTIVITY IN RED SAUERKRAUT PACKED IN TWO DIFFERENT TYPES OF BAGS (PE-LD and PET met/PE) DURING 4 MONTHS OF CHILLED STORAGE
The values are given as % of control – assuming the results obtained for fresh sample as 100%.

in the PET met/PE bags, compared to the vegetable before packaging.

After each month of chilled storage, cabbage stored in PE-LD bags had significantly higher ($P \leq 0.05$) content of this component compared with the cabbage stored in PET met/PE bags (Table 2, Figure 1). However, when comparing mean values of this constituent, it can be stated that type of the package used had no statistically significant ($P > 0.05$) effect on the content of vitamin C in the chilled stored red sauerkraut.

Total Polyphenol

Total polyphenol content (calculated per chlorogenic acid) is shown in Table 2. After 3- and 4-month chilled storage of soured red cabbage, the level of total polyphenols felt significantly ($P \leq 0.05$) by 13.3 and 13.4%, respectively, in the case of PE-LD bags and by 18.1 and 18.6% in the PET met/PE bags, compared to the level determined in the vegetable prior to packaging (Table 3, Figure 1).

TABLE 3. THE CONTENT OF TOTAL POLYPHENOLS IN THE CHILLED STORED RED SAUERKRAUT (mg CGA/100 g d.m.)

The kind of processing	Total polyphenols	
Before storage	$4019^{ab} \pm 220.3$	
	The kind of packaging	
Cool storage	Zipper seal bags (PE-LD)	Bags (PET met/PE)
1 month	$4153^{a} \pm 134.5$	$3799^{b} \pm 55.4$
2 months	$3956^{ab} \pm 95.5$	$3914^{b} \pm 57.9$
3 months	$3485^{c} \pm 83.0$	$3292^{c} \pm 25.5$
4 months	$3480^{c} \pm 63.1$	$3272^{c} \pm 30.6$
Mean value for packaging	$3819^{A} \pm 311.0$	$3659^{A} \pm 333.3$

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

The package type was found to have no significant ($P > 0.05$) influence on total polyphenols in the chilled stored red sauerkraut (Table 3).

Thiocyanates

In subsequent months of chilled storage, significant ($P \leq 0.05$) reductions in thiocyanates were noted in red sauerkraut, compared with the sauerkraut before packaging (Table 3). The analyses done revealed that a decrease in the content of examined components in both types of the packages used was comparable and was ~62.0% after 2 months of chilled storage; and 79.0 and 95.0% after 3- and 4-month storage, respectively, compared to the red cabbage prior to packaging (Table 4, Figure 1).

TABLE 4. THE CONTENT OF THIOCYANATES IN THE CHILLED STORED RED SAUERKRAUT (μg/100 g d.m.)

The kind of processing	Thiocyanates	
Before storage	$574.90^{a} \pm 2.71$	
	The kind of packaging	
Cool storage	Zipper seal bags (PE-LD)	Bags (PET met/PE)
1 month	$574.00^{a} \pm 0.97$	$558.30^{b} \pm 0.96$
2 months	$218.80^{c} \pm 3.13$	$213.70^{c} \pm 1.54$
3 months	$123.00^{d} \pm 0.40$	$122.70^{d} \pm 0.84$
4 months	$28.80^{e} \pm 0.51$	$28.50^{e} \pm 0.16$
Mean value for packaging	$303.90^{A} \pm 228.9$	$299.20^{A} \pm 225.8$

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 5. ANTIOXIDANT ACTIVITY IN THE CHILLED STORED RED SAUERKRAUT (μm Trolox/1 g d.m.)

The kind of processing	Antioxidant activity	
Before storage	$181.1^{a} \pm 8.5$	
	The kind of packaging	
Cool storage	Zipper seal bags (PE-LD)	Bags (PET met/PE)
1 month	$178.70^{a} \pm 8.5$	$173.60^{a} \pm 5.8$
2 months	$173.40^{a} \pm 11.7$	$180.40^{a} \pm 6.9$
3 months	$156.90^{b} \pm 5.5$	$156.10^{b} \pm 4.5$
4 months	$147.00^{bc} \pm 3.6$	$140.00^{c} \pm 2.8$
Mean value for packaging	$167.40^{A} \pm 15.5$	$166.30^{A} \pm 17.0$

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

The analysis proved also that there were no significant ($P > 0.05$) differences in thiocyanate content in the chilled stored red sauerkraut depending on the package type (Table 4).

Antioxidant Activity

Antioxidant activity of red sauerkraut has been expressed as μmol Trolox per 1 g dry matter of the vegetable (Table 5). Similarly, as with the total polyphenols content discussed earlier, a significant ($P \leq 0.05$) reduction in antioxidant activity of red sauerkraut was observed only after a period of 3 and 4 months of chilled storage, the decline being respectively 13.4 and 18.8% in the cabbage stored in PE-LD bags; and 13.8 and 22.7% in the vegetables kept in PET met/PE bags, compared to the vegetable prior to packaging (Table 5, Figure 1).

Studies revealed that the type of package did not have a significant ($P \leq 0.05$) effect on antioxidant activity of the soured cabbage which was stored in it under chilled conditions (Table 5).

DISCUSSION

Dry Mass

The most important factor affecting the content of dry matter in the raw material is dry matter content in the fermented product, along with other factors like vegetable species, date of harvest, and consequently, length of a vegetation period, method of fertilization, and size of the cabbage head (Aires 2015). The results referring to the above parameter, which were obtained in this work for the sauerkrauts analyzed before packaging, correspond to the data reported by the literature (Wojciechowska *et al.* 2007).

In the literature available, there is no information on sauerkrauts stored in different packaging types; however, there are data referring to other vegetable species as well as types of plastic containers. Nath *et al.* (2011) observed smaller losses in mass (of 5.51%) in the broccoli chilled stored for 144 h in the polypropylene (PP) bags with micro perforation than those recorded for the vegetables stored in perforated plastic bags (of 27%). According to the findings of Wojciechowska and Rożek (2009), a fall in dry matter content in red cabbage heads, which were chilled stored for a long time, ranged in 5.5–8.9% too, depending on the nitrogen form used in fertilization. In tomatoes, there were no significant changes in this parameter during chilled storage (7C for 10 days) (Toor and Savage 2006). Olszówka and Perucka (2011) also observed the loss in dry matter content of 2% in the butterhead lettuce which was chilled stored in the PE-LD bags for 7 days, while after 14 days of chilled storage a slight increase in this parameter was noted; although, the changes were not statistically significant. No significant difference between a 40 μm film based on polylactic acid (PLA) and a 40 μm biaxially oriented polypropylene (BOPP) for dry matter content of swede was observed by Helland *et al.* (2016), after storage at −2 and 5C. González-Buesa *et al.* (2014) found, after cool storage at 7C, a larger weight loss for celery sticks stored in 44 μm thick unperforated film made of polylactic acid compared with celery sticks packed in a film made of polypropylene (PP) and low-density polyethylene (PE-LD).

Vitamin C

The content of vitamin C in red sauerkraut prior to packaging was 259.3 mg/100 g dry matter (29.2 mg/100 g fresh matter), while the value recorded about not fermented red cabbage by Kopec (1998) was almost two times greater (51.8 mg/100 g fresh matter). According to Jarczyk and Płocharski (2010), vitamin C content in the properly soured white cabbage ranges between 20 and 30 mg/100 g fresh mass. The value recorded by Peñas *et al.* (2015) was 20.1 mg/100 g. The level of vitamin C in sour cabbage depends on its amount in the raw material, sauerkraut acidity and storage conditions. In fresh vegetables, this parameter is affected, for example, by species, climatic and agrotechnical conditions and the time of harvest (Grajek 2007; Peñas *et al.* 2015). Czapski and Szwejda (2006) examined three white cabbage cultivars, which then underwent the process of souring and chilled storage of the product at 4C for successive 4, 12 and 24 weeks. In comparison with the raw material, this treatment led to an increase in vitamin C content in the range from 40 to 54% depending on the cultivar. After 4 weeks of chilled storage, the amount of this constituent in sauerkraut increased and fluctuated within the range of 50.8–64.4 mg/100 g fresh matter. Further, 8-week storage, resulted in a slight decrease of this component (4% on average), while after 12 subsequent weeks, a fall was about 23%, compared to the raw material. Peñas *et al.* (2015) reported 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) also observed that fermentation process of cabbage led to significant reductions of this compound. In this study, in comparison with the sauerkraut prior to packaging, the content of vitamin C decreased in both products: in the red cabbage stored in PE-LD bags: by 51.7 and 61.0% after 1- and 4-month storage; and in the cabbage kept in PET met/PE bags: by 67.8 and 70.9%, respectively. However, there is no data in the available literature that could confirm this observation.

The process of chilling caused also significant reductions in vitamin C content in other vegetables or fruits. Hounsome *et al.* (2009), who examined white cabbage, noticed a reduction in vitamin C content after 3 months of chilled storage at 1C of 80% and after 6 months of 50%, compared to the fresh vegetable. At the same time, the amount of dehydroascorbic acid did not change significantly. Santos *et al.* (2012) found larger losses in vitamin C in leafy vegetables stored at 3C for 10 days: 96% in wild rucola, 86% in spinach, or 77% in corn salad. On the other hand, Berger *et al.* (2007) reported lower losses in this component: 60% in green bean chilled stored for 14 days and 39% in green pea, compared to the fresh vegetable. According to others, however, the losses are even lower, ranging from 0 to 32% for (*Corchorus olitorius* L.) or broccoli stored in various package types (PE bags or PP bags with microperforation in chilled conditions (Tulio *et al.* 2002; Nath *et al.* 2011). Vina and Chaves (2006) proved a significant 38% increase in vitamin C content in portioned celery leaves which were chilled stored for 14 days in polystyrene bags with PVC (PS/PVC) layer. However finally, after 28 days of storage, the amount decreased to the initial value. Udomkun *et al.* (2016) also reported a significant decrease in ascorbic acid content during storage for up to 9 months of dried papaya in two packaging materials: aluminum laminated polyethylene (ALP) and polyamide/polyethylene (PA/PE). The packaging in aluminum laminated polyethylene pouches under ambient conditions was found to better preserve this compound after 7 months of storage.

In the examined red sauerkraut, shortly after a considerable fall observed in this constituent compared to the vegetable prior to packaging, its level stabilized after only 1-month chilled storage and remained unchanged until the end of this experiment. Toor and Savage (2006) observed similar tendency for tomatoes throughout their chilled storage at 7C. Peñas *et al.* (2015) stated that stability of vitamin C during chilled storage is affected, among other factors, by high acidity of products. This may explain our findings, since both tomatoes and red sauerkraut are characterized by high acidity.

Such a great diversity in the results reported by quoted authors may result from, for example, various parameters of cultivation, storage conditions after harvest or the fact that different varieties were subjected to analyses within the same species. Low storage temperature has a very positive influence on the retention of vitamin C in vegetables (Vina and Chaves 2006).

Kalt (2005) proved losses in vitamin C content in broccoli of 75–85% after 6 days of its storage in air. Reduced vitamin C content in plant material may also be affected, apart from oxygen activity, by high temperature, trace amounts of metals and enzymes, as well as a method of preparing the material for analysis (Nath *et al.* 2011). According to Wieczorek and Traczyk (1995), losses in vitamin C in chopped white cabbage were: 28% after 4 h and 39% after 24 h. The relative air humidity has also a significant impact on the losses of vitamin C. Low humidity, responsible for rapid vegetable wilting, as an increase in the concentration of ethylene in the storage chambers has an effect on the significant reduction in vitamin C content (Thompson 2015). In the literature available, there is no information on sauerkrauts stored in different packaging materials. Active, not passive packaging has been the focus of great number of studies in the last decades. In this study the authors focused on passive packages, which are generally used for shelf stable food products, simply serving and as physical barrier between the product and environment surrounding the package.

Total Polyphenols

The phenolic composition in vegetables is influenced by genetic and various argonomic and environmental factors, and may be further affected by postharvest conditions (Rybarczyk-Plonska *et al.* 2016). The content of total polyphenols in red cabbage varies according to different authors, ranging from 134.7 to 257.0 mg/100 g of the fresh vegetable. The value of total polyphenols recorded by Podsędek *et al.* (2006) in various varieties of red cabbage ranged from 134.7 to 171.4 mg/100 g fresh vegetable; however, this time were expressed as gallic acid equivalent. The results presented by remaining authors quoted beneath and calculated per gallic acid are: 254.0 (Wu *et al.* 2004); 158.0 (Proteggente *et al.* 2002); 221.2 (Leja *et al.* 2005); 185.9–196.5 mg/100 g fresh vegetable (Heo and Lee 2006).

Vegetables are primarily a source of polyphenolic compounds from the group of phenolic acids, since the proportion of flavonoids in the total polyphenol content ranges from 4% in white and Italian cabbage to 39% in red cabbage (Chun *et al.* 2004; Karadeniz *et al.* 2005). According to the literature data, the content of flavonoids other than flavonols and flavones' derivatives in vegetables is small. Anthocyanin pigments occurring in red cabbage (so far 23 have been identified) are acylated derivatives of cyanidin; their content in this vegetable is between 25 and 495 mg/100 g fresh vegetable. Of those, cyanidin-3,5-diglucoside; cyanidin-3-(p-coumaroyl) diglucoside-5-glucoside and cyanidin-3-(sinapoyl)-diglucoside-5-glucoside are dominant (Clifford 2000; Wiczkowski *et al.* 2015). Red cabbage contains the following amounts of flavonols and flavones: from 0.02 to 0.46 of quercetin; <0.01of kaempferol; from 1.1 to 1.3 of myricetin; from 0.2 to 0.4 of luteolin; and from 0.01 to 0.11 mg of apigenin per 100 g of fresh vegetable (Grajek 2007; Avato and Argentieri 2015).

As a result of the process of souring, the content of total polyphenols increases. This theory has been confirmed by the findings of Czapski and Szwejda (2006) as well as Ciska *et al.* (2005), who examined various varieties of white cabbage. Czapski and Szwejda (2006) reported a 39% rise in this constituent, while Ciska *et al.* (2005) an increase of 22%. Such an increase may be explained by the action of bacterial enzymes on cell walls; as a result, phenolic compounds are released from the ester and glycosidic linkages. Amanatidou *et al.* (2000) believe that an explanation for the elevated level of polyphenols is the response to infection and tissue damage.

The present study revealed also that 4-month chilled storage resulted in a decrease in total polyphenols in the red sauerkraut stored in PE-LD and PET met/PE bags of 17.4 and 21.5%, respectively. Czapski and Szwejda (2006) reported higher losses in these constituents. After 8-week chilled storage the losses were of 26%, while 5-month storage reduced losses by 15% compared to the fresh raw material. The falls in total polyphenols in chilled stored spinach observed by Bunea *et al.* (2008) were 7.6% (after 24 h) and 11.2% (after 72 h). Storage in different packages did not exert a significant ($P > 0.05$) effect on the content of total polyphenols in sauerkraut. On the other hand, there is no information in the literature on the influence of these package types on the selected health quality parameters of the food kept in them. In previous study of Kapusta-Duch *et al.* (2014) the authors observed that the frozen stored Brussels sprouts in zipper bags (low-density polyethylene) were characterized by significantly higher polyphenol content compared with vegetables stored in plastic boxes (oriented polystyrene) (the difference after the third month of storage is 17%). Vina and Chaves (2006) investigated an effect of chilled storage (0 and 4C) on the content of, among others, total polyphenols in the portioned celery leaves placed on polystyrene (PS) trays, which were sealed with PVC foil and stored for 0, 7, 14, 21 and 28 days. The authors found that the content of these constituents in the vegetable stored at 0C remained unchanged at the end of the experiment, while an insignificant 25% increase was in the vegetable kept in 4C. On the other hand, Amanatidou *et al.* (2000) reported an eightfold increase in total polyphenols in sliced carrots stored at 8C for 12 days, compared to the fresh vegetable. The results obtained in the present study along with literature data show a great diversity in the parameter analyzed. The content of polyphenolic compounds in vegetables, as in all other plant material, is determined by many factors like climatic conditions, agro-technical requirements, stage of maturity, the time of harvest, storage conditions as well as by genetic factors and varietal diversity. Other factors which significantly affect the level of these compounds are the time of chilled storage time, temperature and degree of damage to the vegetable tissue (Costa *et al.* 2016). Rybarczyk-Plonska *et al.* (2016) found that concentration of phenolic acids may increase or decrease during the process of maturation of *Brassica* vegetables, whereas their level reduces markedly during a period of storage. In the case of strongly diversified polyphenolic compounds (in terms of structure and properties), conditions of their extraction from the raw material and analytical methods used are equally important. Large discrepancies in the results referring to total polyphenols, which have been reported by the aforementioned authors, may result from different methods used for extraction of polyphenolic compounds from raw materials. They used 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 method of calculating the results, depending on the applied pattern. Chen *et al.* (2015) reported that the method of determining total polyphenols using FC reagent is vitiated by an error due to the fact that this substance may react not only with polyphenols but also with vitamin C, some alkaloids, proteins and other compounds, which are described in the literature. This method does not provide comprehensive information about quantity and quality of phenolic compounds in the extracts of the tested plants.

Thiocyanates

Glucosinolates (GLS) belong to the compounds which are relatively stable and resistant to high temperatures; however, they easily undergo nonenzymatic and enzymatic hydrolysis by the enzyme – myrosinase (thioglucoside glucohydrolase EC 3:2:3:1), which is in the *Brassicas* tissues and is released as a result of damage to the plant cell, their squashing or other technological processes. The process of GLS degradation runs in different ways depending on the medium pH; the products of hydrolysis are isothiocyanates, indoles, nitriles, oxazolidines and thiocyanates (Girgin and El 2015). The content of glucosinolates depend on many factors, such as plant variety, growing condition, climate, the tissue-specific distribution in a plant parts, and both storage conditions (type and duration) and technological processes (Fuentes *et al.* 2015).

According to Palani *et al.* (2016), fermentation results in extended shelf life of the products and produces several beneficial breakdown products. The content of thiocyanates in the examined nonstored red sauerkraut was 0.57 mg/100 g dry matter of the vegetable (0.06 mg/100 g fresh matter). According to literature data, the content of these compounds in raw red cabbage is much higher (approx. 2.1 mg/100 g fresh matter) (Wojciechowska *et al.* 2007). In this work, 4-month chilled storage of red cabbage sauerkraut reduced thiocyanate content, on average, by 95%, regardless of the type of packaging used. The study also showed that the effect of packaging used on the level of these substances in the product was insignificant ($P > 0.05$). There is no data in the available literature that could confirm this thesis. The study by Wojciechowska and Rożek (2009) revealed that long-term, chilled storage of the raw red cabbage heads elevated the content of thiocyanates by 10%, which is not consistent with our findings. Probably, the environment in cells or cell compounds of red cabbage can exert influence on the thermostability of GLS and their breakdown products. To specify of these compounds requires further research in this area.

Antioxidant Activity

Antioxidant activity in the examined red sauerkraut was 181.1 μmol Trolox eq./g dry matter (20.4 μmol Troloxu/g fresh matter), while the value recorded by Wiczkowski *et al.* (2015) was a little smaller (137.9 μmol Trolox eq./g dry matter). According to the literature, antioxidant activity of the crude red cabbage ranges broadly: from 5.6 to 40.0 μmol Trolox/g fresh vegetables. In this range there are also the values reported by the following authors: Podsędek *et al.* (2006) – 9.8-12.6; Wu *et al.* (2004) – 22.5; Leja *et al.* (2007) – 9.2–34.0; and Kusznierewicz *et al.* (2007) – 40 μmol Trolox eq./g fresh vegetables. Such a spread of the results referring to antioxidant capacity, which was obtained by several authors, demonstrates high variability of the parameter examined and may also indicate its dependency on the environmental conditions of cultivation. Differences in antioxidant capacity may also result from the use of different radicals (e.g., $ABTS^{+}$ and DPPH). A method used to determine the activity on the basis of the $ABTS^{+}$ free radical quenching (used in this paper) is applied to determine the activity of both lipolytic and hydrolytic antioxidants, whereas the method based on the $DPPH^{+}$ free radical scavenging for lipolytic only (Grajek 2007). Another reason for differences may be: a type and polarity of the solvent used for extraction; methods of isolation and purity of the active compounds; methods of determination; the substrates used; as well as the sampling method of the raw material; the number and mutual interactions between antioxidants in the raw material; species and variety; a type of the tissue; the stage of plant maturity; the temperature and time of storage; as well as heat treatment (Bhandari and Kwak 2015). All of these factors could be the reason for differences in the antioxidant capacity of *Brassica* vegetables with regard to both the species studied in this work and the results quoted in the literature. Studies on white cabbage by Kusznierewicz *et al.* (2008) showed that the process of fermentation increased the antioxidant activity of cabbage, which then stabilized after 10-day fermentation. According to the authors, soured cabbage has a higher antioxidant activity than raw, probably as a result of coupling of two effects: tissue damage which increases the total polyphenol content and the occurrence of chemical processes under the influence of lactic acid bacteria. Throughout this research, antioxidant activity in soured red cabbage kept in both types of packaging was decreasing after each month of chilled storage, an average by 24% at the end of the experiment. There is no literature data on the impact of these packages types on selected pro-healthy properties of the food, stored in them. Murcia *et al.* (2009) reported higher reductions in this parameter in broccoli (by 41.3%) and Brussels sprouts (by 30.3%) after 7 days of their chilled storage; slight losses were observed during storage of cauliflower (1.5%), celery (0.9%), green lettuce, pea or spinach (~0.6%). On the other hand, no significant changes of 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) have observed that 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. Frozen storage of vegetable is more beneficial to preserve higher antioxidant potential. After one month of frozen storage, the losses recorded were 1.6% (broccoli), 2.1% (Brussels sprouts) and only 0.6% (cauliflower) (Murcia *et al.* 2009). On the other hand, in the study of Kapusta-Duch *et al.* (2014) frozen storage of Brussels sprouts for three months resulted in significant reduction in antioxidant capacity of vegetables stored in zipper bags and plastic boxes, accounting to 10% and 16.8% after the first, and ~23 and ~23.9% after the second and third month of storage. In the conducted experiment, no statistically significant differences between the antioxidant activity of vegetables stored in zipper bags and plastic boxes was found. Large fluctuations in antioxidant capacity were observed during chilled storage of celery leaves under chilled conditions (0 and 4C) for 28 days. Initially, a decline in activity was observed that was followed by an increase until the value reached a maximum – after 14 days of frozen storage) (Vina and Chaves 2006). The statistical analysis proved that in this work the type of package had no significant effect on antioxidant activity of red sauerkraut; although, there is no data in the literature available, which could confirm the results obtained. On the other hand, Nath *et al.* (2011) showed no significant changes in antioxidant activity of broccoli after 144 h of its chilled storage in the bags of polypropylene film (PP) with microperforations; whereas, after this time, antioxidant activity in broccoli packed in perforated plastic bags decreased by 49.5%. Summarizing, it can be concluded that the number of publications on antioxidant activity is considerably smaller than the works discussing the content of antioxidants in raw materials. As has been shown, antioxidant activity of raw materials is proportional to the amount of antioxidants present in these vegetables (Kim *et al.* 2003).

CONCLUSIONS

The 4-month chilled storage of red cabbage sauerkraut led to the statistically significant reduction in the analyzed constituents as well as in antioxidant capacity, an average of 4.8% (dry mass), 64.4% (vitamin C), 16% (total polyphenols), 95% (thiocyanate) and 20.8% (antioxidant activity), regardless of the type of packaging used.

At the same time, our studies revealed no significant influence of the type of packaging used on the content of these components. Only in the case of vitamin C, after each month of chilled storage its content was found to be significantly higher in the cabbage stored in PE-LD than in PET met/PE bags. However, when comparing mean values of the constituent tested, it can be stated that the type of packaging used did not have a statistically significant effect on vitamin C content in pickled red cabbage, which was chilled stored.

Summarizing, the results obtained in this study do not allow us to determine the role of the packaging type in forming quality features of the chilled stored red sauerkraut.

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