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ORIGINAL ARTICLE

The yield and postharvest quality of Chinese cabbage, depending on weed management method

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Abstract

The studies were conducted from 2012 to 2015 at the National Institute of Horticultural Research in Skierniewice, Poland. The aim of the research was to determine the yield of Chinese cabbage, its storage ability and nutritional value, depending on weed management methods used during cultivation. In the field experiments the following methods were compared: mechanical treatments, mechanical treatments + growth stimulators, soil mulching with black polypropylene, black polyethylene and biodegradable foil and hand weeding. After harvest the Chinese cabbage was stored at 0–2°C for 125–126 days depending on the year and after storage marketable and rotten heads were sorted. The percent of yellowed, rotten leaves in the total mass of the stored heads was also determined, as well as the natural weight loss. The chemical composition of Chinese cabbage was analyzed after harvest and after storage. The analyses included: dry matter, total sugars, vitamin C and soluble phenol content. After harvest the highest yield of Chinese cabbage grown in black polyethylene mulch was obtained. After storage the highest yield of marketable heads from cabbage mechanically weeded with additional application of biostimulator AlfaMax during cultivation was obtained. Chemical analyses showed that after harvest the highest dry matter, total sugars and vitamin C content were found in Chinese cabbage mechanically weeded and soluble phenols were the highest in non-weeded Chinese cabbage. After storage the highest content of dry matter was recorded in non-weeded Chinese cabbage, while total sugars were the highest in cabbage mulched with black polyethylene and biodegradable foil. Vitamin C was the highest in mechanically weeded and soluble phenols were the highest in hand-weeded cabbage.

Keywords: Chinese cabbage, nutritional value, storage ability, weed control, yield

Introduction

Vegetables are significant in human nutrition. They contain many valuable nutrients and vitamins and have low energy value (Płocharski *et al.* 2017). Chinese cabbage (*Brassica rapa* L. subsp. *pekinensis*) is a valuable vegetable crop from the *Brasiccaceae* (Burnett) family (Krochmal-Marczak *et al.* 2017) and it is one of the most-bought vegetables from this group in Poland. It contains many valuable compounds, including glucosinolates, carotenoids, flavonoids, ketones, aldehydes, vitamin C and selenium (Jan *et al.* 2018). These compounds have anticancer and antioxidant properties and many authors report that eating brassica vegetables lowers the risk of contracting many diseases (Keck and Finley 2004; Jan *et al.* 2018).

The post-harvest ability of Chinese cabbage is determined by factors occurring during the growing season as well as conditions maintained during storage. The storage ability is influenced by factors such as variety, fertilization and irrigation, protection from diseases, pests and weeds, as well as the time and method of harvest (Adamicki and Czerko 2002; Domínguez--Perles *et al.* 2014).

One of the main treatments in vegetable cultivation, determining high yield and good quality is weed control (Bucki *et al.* 2018). These treatments not only reduce the weed population but also improve the conditions of growth and development of vegetable plants and affect the chemical composition of the yield. Weed infestation in Chinese cabbage can reduce the yield of heads. Moreover, the presence of weeds may limit access to light, which may cause unshaped heads, and lowering the soil temperature can delay the maturation of cabbage.

Chemical protection is an effective and widely used method of weed control. For many vegetable crops, classified as minor crops, a very limited choice or lack of herbicides for chemical weed control is a serious problem. Currently, plant protection methods friendly to the environment and human health are preferred. It forces researchers to look for other, non-chemical and effective solutions to make the cultivation of vegetables possible and profitable. In vegetable production, in addition to chemical protection, mechanical weeding is the most common method of weed control. Mechanical treatments can be performed both before sowing or planting plants and during the growing season (Dobrzański and Adamczewski 2013). For less weed-sensitive vegetable species, especially grown from seedlings, such as Chinese cabbage, mechanical treatment may be the only method of weed control or it can supplement other methods. Progress in the improvement of weeding machines and tools, with increasing efficiency and accuracy, makes it possible to control weeds which are close to or even in the rows of crops (Dziubański *et al.* 2013). The soil surface can also be mulched with various types of light-restricting materials. The most common materials for mulching are polyethylene or polyvinyl chloride film, non-woven polypropylene and agrotextile (Locher *et al.* 2005). Mulches, made from biodegradable materials, are also available, and can be ecological alternatives to conventional materials, especially useful on organic farms. In addition, these mulches reduce soil evaporation, raise soil temperature, protect against erosion, and improve plant growth conditions by changing the microclimate within plants and in the root zone (Locher *et al.* 2005).

This study was aimed to determine the effect of different weed control methods on the yield of Chinese cabbage and their impact on storage ability and nutritional value. It was assumed that effective weed control has a positive effect on the yield and quality of Chinese cabbage.

Materials and Methods

The studies were conducted from 2012 to 2015 on an experimental field of the National Institute of Horticultural Research in Skierniewice. Field experiments (2012–2014) and storage trials (2012–2015) were set up to determine yield and storage ability, and laboratory analyses were performed to determine the nutritional value of Chinese cabbage. The experiments were carried out on Luvisols (fawn) type soil, containing 1.2–1.5% of organic matter, with pH 6.3–6.5. The results from the plots were converted to a 100 m^2 area. Cabbage plants were planted at a row spacing of 45 cm and a distance of 30 cm between plants in the rows. Chinese cabbage, Bilko F1 variety, was planted on May 31, 2012, June 14, 2013 and June 10, 2014. The biostimulators Asahi SL (sodium ortho-nitrophenol + sodium para-nitrophenol + sodium 5-nitroguaiacol) and AlfaMax (plant extracts and seaweed extracts, containing L-amino acids, hormones, auxins, gibberellins, cytokinins) were applied three times, at the rates of 0.5 $l \cdot ha^{-1}$, at 2-week intervals after planting.

Mechanical treatments were performed 14 and 19–20 days after cabbage planting, depending on weed emergence, using an Ecopielnik EP-4 weeder. Since the weeder removed the weeds both in the inter-rows and in the rows of plants, supplementary hand weeding on these plots was not necessary. The weed-free plots were systematically weeded by hand, shortly after weed emergence on: June 19, 10, July 13 in 2012; July 1, 11, August 5 in 2013; and July 1, 14, 30, August 19 in 2014.

The leaf chlorophyll content (the light absorption by leaves) was measured during the growing season of Chinese cabbage, at 19–21, 26–28, 33–35, 41–42, 47–49, 54–56 and 60–63 days after planting. The efficacy of weed control was determined 21–30 days after cabbage planting. Fully shaped Chinese cabbage heads were harvested several times between 61 and 87 days after cabbage planting. The air temperature and precipitation were measured and recorded during the whole vegetation period. The measurements were obtained from the weather station located in the neighborhood of the experimental field.

The experiments with Chinese cabbage storage were set up immediately after harvesting, in four replicates. The outer, damaged and yellowed leaves of the heads of Chinese cabbage were removed and put into boxes lined with polyethylene film. Six heads of cabbage were placed in each box and stored in cold storage, at 0–2°C, for 125–126 days. After this period the Chinese cabbage storage ability was determined by comparing the percentage of each fraction with the total weight when taken into storage. The marketable cabbage included healthy heads, cleaned of outer leaves. On the other hand, losses consisted of rotten heads, outer rotten and over-rotten leaves and weight loss.

The nutritional value of Chinese cabbage heads was determined immediately after harvest and after storage. The dry matter content was determined using the dryer-weight method (drying at up to 104°C for 24 h), total sugars, using the Luff-Schoorl method (according to PN-A-75101-07 : 1990), and vitamin C, using the Tillman's titration method, according to Pijanowski *et al.* (1964) and soluble phenols, using the Folin-Ciocalteu reagent method according to Lee *et al.* (1995) and Vinson *et al.* (1998).

The results were statistically analyzed by analysis of variance using Statistica Program v. 13.0 (Statsoft Inc.). The Newman-Keuls test ($p = 0.05$) was used to compare the significance of the means.

Results and Discussion

The Skierniewice area is characterized by climatic conditions typical of the entire lowland area of Poland. Temperatures are influenced by continental as well as oceanic air masses. The prevailing winds are westerly and southwesterly. Skierniewice is located in the lowest precipitation zone of Poland. Chinese cabbage prefers moderate air temperatures during the growing season. The temperatures recorded during the field experiments were favorable for the growth and development of both the crop and weeds (Fig. 1). The lowest monthly temperatures were noted in May and September of 2013 but they did not have any negative impact on cabbage growth. Chinese cabbage develops a weak root system, mainly in the soil layer of 20–30 cm, therefore it has high water requirements. The monthly precipitation during the years of the experiments was low and varied, with the lowest being in July, 2013 and May, 2012. Water shortage in periods of low rainfall and a high demand for water were supplemented by sprinkling irrigation, especially in July and August, when heads are formed.

The use of various methods of weed control either reduced the occurrence of weeds or totally eliminated them, thus improving the growth conditions of Chinese cabbage. However, these methods differed in their effectiveness and influence on cabbage yield.

In the experiments with Chinese cabbage, the chlorophyll content in the leaves (greenness index) in the first half of the growing season was similar in all plants, regardless of the method of weed control (Fig. 2). At 41–42 days after planting, the chlorophyll content in cabbage leaves became varied, depending on the method of weeding the plants. Before harvest, there was an increase in the content of this pigment in the leaves of mechanically weeded cabbage and mulched with the tested materials. The chlorophyll content in the leaves of cabbage weeded by hand was similar to the control.

Hand weeding and mulching the soil with black materials effectively prevented weed emergence (Fig. 2). The high effectiveness of soil mulching has been reported by many authors (Wierzbicka *et al.* 2001; Dobrzański and Anyszka 2006). The experiments in Skierniewice also showed a strong reduction of weed infestation by mechanical treatments. According to Anyszka and Dobrzanski (2010), in properly prepared soil, cabbage can be cultivated without herbicides,

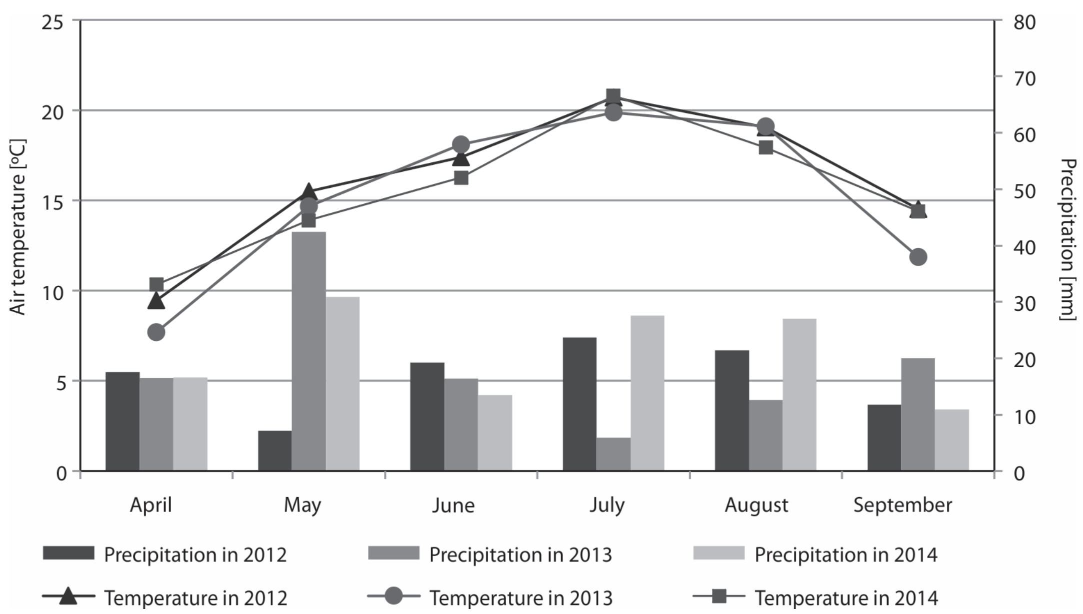

Fig. 1. Weather conditions, 2012–2014, during Chinese cabbage cultivation

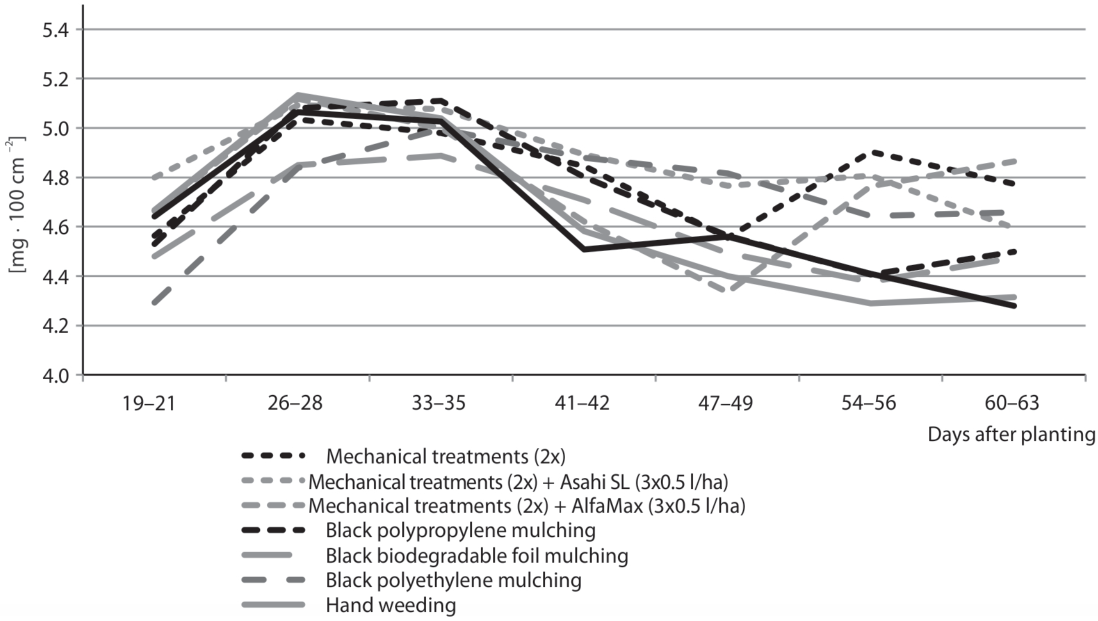

Fig. 2. Chlorophyll content in Chinese cabbage leaves, depending on the weed management methods

based on mechanical treatments and hand weeding, but weeds occurring in the early stages of cultivation can cause a yield reduction. Furthermore, Chinese cabbage is usually planted from early May to mid-June and for the fall harvest even until mid-August, so there is a lot of time to perform the cultivation treatments that will reduce potential weed infestation before planting.

Regardless of the method of weed control, weeding had a positive effect on the yield of Chinese cabbage (Tab. 1). The highest yields of cabbage heads, both total and marketable, were obtained from plants mulched with black polyethylene film, biodegradable film and black non-woven polypropylene fabric. The total yield from the plots mulched with these materials was higher by 35.3; 28.1 and 26.0%, respectively, than the control. The highest share of marketable yield in the total yield in these objects was also recorded. The beneficial effect of using black mulches on the yield of vegetable crops has also been confirmed by Braun *et al.* (2019), Bucki *et al.* (2018), Haapala *et al.* (2015), Franczuk *et al.* (2015), Belel (2012), Kosson *et al.* (2012), and Dobrzański and Anyszka (2006).

The positive effect of mulching the soil with light-impermeable materials on the plants may be caused by microclimatic changes around the plants, increasing the temperature and maintaining humidity, which

Table 1. The influence of weed management method on the yield of Chinese cabbage (means for 2012–2014)

Weed management method	Weed control in %	Total yield		Marketable yield		
		kg · 100 m^{-2}	%	kg · 100 m^{-2}	%	% of total yield
Mechanical treatments	95.7 c*	866.4 b	109.7	752.3 b	115.5	86.8
Mechanical treatments + Asahi SL – 3 × 0.5 l · ha^{-1}	96.0 c	853.8 b	108.1	728.9 b	111.9	85.4
Mechanical treatments + AlfaMax – 3 × 0.5 l · ha^{-1}	94.7 c	854.2 b	108.1	698.8 b	107.3	81.8
Black polypropylene mulching	100 a	995.5 a	126.0	901.1 a	138.4	90.5
Black biodegradable mulching	100 a	1011.7 a	128.1	892.6 a	137.1	88.2
Black polyethylene mulching	100 a	1068.8 a	135.3	946.7 a	145.4	88.6
Hand weeding	100 a	864.7 b	109.5	724.7 b	111.3	83.8
Check	0 d	789.9 c	100	651.2 c	100	82.4
Weeds number in check (no. · m^{-2})	103.4	–	–	–	–	–

*values in columns, followed by the same letter are not significantly different at 5% level, according to Newman-Keuls multiple range test contributes to improving the growth conditions (Decoteau *et al.* 1990; Haapala *et al.* 2015). In addition, the black color of these materials accelerates the heating of the soil and raises its temperature compared to unmulched soil (Locher *et al.* 2005), protects against temperature fluctuations and maintains the soil moisture.

In our study, the yield obtained from the plots weeded by hand and mechanically was lower than from mulched plots but higher than from the control, while additional spraying of cabbage plants with biostimulants did not affect yield.

A positive effect of soil loosening on the growth and yield of cabbage heads was obtained by Anyszka and Dobrzański (2010), who reported an increase in the yield after performing one mechanical weeding in the inter-rows (and hand weeding in the rows), as well as two mechanical treatments.

The impact of weed management methods on nutritional value and quality of vegetable yield is not described well in the literature, and there are not many reports on this subject especially for vegetable crops. On the other hand, one can find comparisons of the quality of yields produced by conventional, integrated or organic systems, but the results are often not unequivocal. Many authors suggest that vegetables grown in an organic system have better nutritional value and health properties than those produced by other systems (Duthie *et al.* 2000; McNaughton and Marks 2003; Bavec *et al.* 2010; Jakopic *et al.* 2013). However, other authors express the opinion that the health value is similar, regardless of the cultivation method (Seljåsen *et al.* 2013; Brandt *et al.* 2011; Dangour *et al.* 2010).

In our study, the dry matter content in fresh heads of Chinese cabbage, immediately after harvest, varied from 4.2 to 5.8% and after storage from 4.6 to 5.4%. The highest dry matter content was found in fresh cabbage mechanically weeded during cultivation, and after storage in cabbage mulched with black biodegradable film (Tab. 2). The lowest dry matter content, both post-harvest and after storage, was seen in cabbage mulched with black polypropylene. Similar results in

Table 2. The nutrition value of Chinese cabbage after harvest and after the storage, dependng on weed management method (means for 2012–2014)

Weed management method	Dry matter [% FM]	Total sugars [% FM]	Vitamin C [mg · 100 g^{-1} of FM]	Soluble phenol [mg · 100 g^{-1} FM]
	after harvest			
Mechanical treatments	5.8 a*	2.2 a	21.3 a	32.5 a
Mechanical treatments + Asahi SL – 3 × 0.5 l · ha^{-1}	4.9 a	1.7 b	16.0 b	28.4 b
Mechanical treatments + AlfaMax – 3 × 0.5 l · ha^{-1}	4.6 a	1.6 b	16.3 b	36.6 a
Black polypropylene mulching	4.2 a	1.4 b	15.8 b	28.9 b
Black biodegradable mulching	4.8 a	1.4 b	16.8 b	26.2 b
Black polyethylene mulching	4.8 a	1.5 b	17.1 b	28.7 b
Hand weeding	5.5 a	2.0 a	16.9 b	29.2 b
Check	5.0 a	1.6 b	20.9 a	34.5 a
	after the storage**			
Mechanical treatments	5.1 a	1.7 a	21.5 a	30.5 b
Mechanical treatments + Asahi SL – 3 × 0.5 l · ha^{-1}	4.6 a	1.6 a	18.9 a	30.3 b
Mechanical treatments + AlfaMax – 3 × 0.5 l · ha^{-1}	4.9 a	1.4 a	21.4 a	36.8 a
Black polypropylene mulching	4.7 a	1.7 a	19.1 a	35.8 a
Black biodegradable mulching	5.3 a	1.8 a	19.1 a	36.4 a
Black polyethylene mulching	5.2 a	1.8 a	18.0 a	30.2 b
Hand weeding	5.2 a	1.6 a	19.8 a	38.2 a
Check	5.4 a	1.7 a	18.3 a	36.5 a

*values in columns for the analysis terms, followed by the same letter are not significantly different at the 5% level, according to Newman-Keuls multiple range test

**Chinese cabbage was stored through 125–126 days, at the temperature of 0–2°C other crops have also been obtained by some other researchers. Franczuk *et al.* (2015) obtained a significantly lower dry matter content in pepper fruits mulched with black polypropylene and black polyethylene foil as did Adamczewska-Sowińska and Kołota (2010) in eggplant mulched with black polyethylene film.

However, many authors consider that mulching the soil with black polypropylene does not affect the dry matter content of some vegetable crops, e.g., peppers (Adamczewska-Sowińska and Kołota 2010), ground cucumbers (Spiżewski *et al.* 2010) eggplants (Adamczewska-Sowińska and Kolota 2010), and carrots (Anyszka and Elkner 2007).

Immediately after harvest, the content of total sugars in Chinese cabbage ranged from 1.4 to 2.2% of fresh weight (FW), and after storage from 1.4 to 1.8%. The lowest post-harvest total sugar content was obtained in cabbage mulched with black polypropylene and black biodegradable film (1.4% FW), while it was the lowest after storage in cabbage mechanically weeded with additional application of biostimulant AlfaMax. After harvest mechanically weeded cabbage had the highest sugar content.

The vitamin C content in vegetables depends on many factors, mainly the crop species. However, the method of cultivation, climatic conditions, maturity at harvest and harvest time, as well as storage conditions and storage period can also have an impact (Noichinda *et al.* 2007; Ignat *et al.* 2012). Lee and Kader (2000) reported that the vitamin C content in plant tissues depends on the intensity of light during the growing season and the higher intensity of light is correlated with higher vitamin C content. Light is not necessary for the synthesis of vitamin C in plants but it does affect the amount of sugars (formed by photosynthesis), which have a direct effect on the synthesis of this vitamin (Oke *et al.* 2013).

In our study the vitamin C content in fresh and post-storage cabbage ranged between 16.0 and 21.5 mg · 100 g^{-1} of fresh matter (FM) and on both dates the highest content of this compound in mechanically weeded cabbage was found. In Chinese cabbage mulched with black materials a slightly lower vitamin C content than in control plots was noted. Some researchers report no observed effect of mulching with black polyethylene foil and black polypropylene on vitamin C content, in comparison to crops without mulching, in such vegetables as eggplant fruits (Adamczewska-Sowińska and Kolota 2010) or tomato fruits mulched with black polypropylene (Majkowska-Gadomska and Arcichowska 2010). Franczuk *et al.* (2015) indicated the beneficial effect of mulching, especially with black polypropylene on vitamin C content in sweet pepper fruits. Klieber and Franklin (2000), analyzing changes in vitamin C content during Chinese cabbage storage at 5°C, noted a reduction of vitamin C content in the leaves at an average of 13%, while in outer, greener leaves of cabbage the vitamin C content was higher and in the leaves inside the cabbage heads it was lower. Higher losses of vitamin C during storage of Chinese cabbage are favored by temperatures above 4°C, as well as temperature changes during storage (Adisa 1986).

The highest soluble phenol content, immediately after harvest was obtained in the heads of cabbage weeded mechanically with additional spraying of biostimulant AlfaMax (36.6 mg · 100 g^{-1} of FM) and after storage in cabbage weeded by hand (38.2 mg · 100 g^{-1} of FM). There are many reports that the cultivation method may have an impact on phenolic compounds in vegetables. In organically grown vegetables the content is higher than in those from conventional cultivation. Similar results were obtained in onion (Duthie *et al.* 2000) and tomato (McNaughton and Marks 2003). Isabelle *et al.* (2010) reported that total phenolic content was highly correlated with the antioxidant activity of vegetables (correlation coefficient was 0.8136). Seong *et al.* (2016), studying the polyphenol content of Chinese cabbage leaves, speculated that prolonged exposure of plants to sunlight leads to a higher content of these compounds in the leaves.

After storage, the soluble phenol content in Chinese cabbage was higher, regardless of the method of weed control. Similar results in leaf and root vegetables, after short-term storage under the conditions commonly used in practice, were obtained by Leja *et al.* (1998). These authors indicated a significant increase in phenolic compound content in early cabbage, greenhouse lettuce and carrot roots. With increasing phenolic compound content, a rapid increase of enzyme activity responsible for their oxidation was observed (Leja *et al.* 1995). They also concluded that the synthesis of phenolic compounds, shortly after the beginning of leafy vegetable storage, could signal plant aging processes, even before their visual symptoms. Other reports confirm that the synthesis of phenolic compounds, followed by their oxidation and polymerization, can lead to changes in tissues, causing their darkening and, in the next stage, lignification and necrosis (Ke and Saltveit 1989).

In our study, after using biostimulants, changes in some yield quality parameters were observed. Dry matter content tended to be reduced. In studies conducted by Łyszkowska *et al.* (2008) on lettuce, the results were different. Leaf lettuce, grown outside, sprayed twice with biostimulant Aminoplant (15% Sargassum seaweed extract + 10% alpha-amino acids) had a higher dry matter content, as well as lettuce grown in a greenhouse on rockwool, treated with Aminoplant or Asahi SL.

Adamicki and Czerko (2002) reported that the storage value of vegetables is mainly determined by their storage ability, including a complex of genetically

Table 3. The percentage share of Chinese cabbage fraction, after the storage (means for 2013–2015)

Weed management method	Heads		Leaves		The weight loss	Losses
	marketable	rotten	yellow, wilted	rotten		
Mechanical treatments	66 bc*	16 a	10 b	3 ab	4 ab	34 b
Mechanical treatments + Asahi SL – 3 × 0.5 l · ha^{-1}	71 a–c	14 a	11 ab	2 ab	3 ab	29 b
Mechanical treatments + AlfaMax – 3 × 0.5 l · ha^{-1}	76 a	9 a	9 b	2 ab	3 ab	24 b
Black polypropylene mulching	48 c	28 a	14 ab	4 a	3 ab	52 a
Black biodegradable mulching	68 bc	9 a	11 ab	4 a	5 a	32 b
Black polyethylene mulching	65 bc	15 a	12 ab	3 ab	4 ab	35 b
Hand weeding	74 a–c	10 a	12 ab	1 b	4 ab	26 b
Check	70 a–c	9 a	14 ab	4 a	4 ab	30 b

Chinese cabbage was stored through 125–126 days, at the temperature of 0–2°C
*values in columns for the analisys terms, followed by the same letter are not significantly different at the 5% level, according to Newman-Keuls multiple range test

determined features. The storage life of vegetables is also affected by other factors, such as climatic or agrotechnical. In our studies Chinese cabbage showed good storage ability (Tab. 3). Mechanically weeded cabbage and additionally sprayed with biostimulants and cabbage weeded by hand stored the best. After storage, the highest percent of marketable heads (70.7 to 75.9%), the lowest proportion of rotten and over-rotten leaves (0.6 to 2.2%) and the lowest total losses (24.1 to 29.4%) was obtained in these objects. Cabbage grown in soil mulched with black polypropylene was characterized by a lower storage ability.

Chinese cabbage grown in soil mulched with black polypropylene was characterized by lower storage stability. The percent of marketable heads in the total mass of stored cabbage amounted to 47.9% and the percent of rotten heads and withered leaves increased. Chinese cabbage mulched with black polyethylene foil and biodegradable foil had good storage ability. The percent of commercial heads after storage was clearly higher than after mulching with black polypropylene but there were higher weight losses during storage.

Conclusions

The weed management methods fully eliminated or very highly reduced the weed infestation and all methods can be useful in Chinese cabbage production.

The highest total and marketable yields of Chinese cabbage grown in mulches with black polyethylene foil, black biodegradable foil and black polypropylene were obtained.

Immediately after harvest, the highest contents of dry matter, total sugars and vitamin C were found in mechanically weeded Chinese cabbage and soluble phenols in mechanically weeded with additional application of biostimulant AlfaMax.

After harvest the lowest dry matter, total sugars and vitamin C contents in Chinese cabbage grown in mulch with black polypropylene and the soluble phenols in biodegradable foil were obtained.

After storage the reduction of dry matter and total sugars in Chinese cabbage weeded mechanically (with and without biostimulant Asahi SL) and total sugars with AlfaMax and weeded by hand, were reported.

The content of soluble phenols in cabbage weeded mechanically was reduced during storage, while increased in all other objects.

Chinese cabbage weeded mechanically with the additional application of biostimulant AlfaMax and weeded by hand showed the best storage ability.

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