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INTRODUCTION

The potato plantation area in Poland is getting limited every year (in 2002 the plantation area was 803 thousand ha, in 2003 – 766 thousand ha, in 2004 – 713 thousand ha and 2012 – 373 thousand ha) and it was 8,2% smaller than last. In comparison to the average of the 2001-2005 period it decreased by over 54% – the source: the Main Statistical Office (GUS), Dzwonkowski and Chotkowski [2012], which is mostly due to a decreasing interest in potato as fodder, which is replaced with corn. Over the last few years potato yields in Poland have been growing. Unfortunately still their level is one of the lowest in the EU countries, mostly due to traditional, labor--consuming and money-saving cultivation technologies. Still very low is the level of mineral fertilization used, the use of protection agents, certified seed potatoes are used on a small scale. Only on large-scale farms, where the total potato plantation area accounts for about 25%, modern production technologies are used, the yield ranges from 250 to 350 $dt \cdot ha^{-1}$, and in the potato production for chips and french fries even up to about 400 $dt \cdot ha^{-1}$ [Dzwonkowski and Chotkowski 2005, 2012].

One of the most important reasons of high, even 70%, potato yield losses is a high weed infestation, and weed control only with mechanical means, without herbicides, is unsatisfactory [Rola 1991, Rola and Rola 1997, Zarzecka and Gugała 2008]. The use of herbicides significantly limits the secondary weed infestation, however there is a risk of a phytotoxic reaction of potato plants conditioned by morphological, physiological and biochemical variation of respective cultivars [Banaszkiewicz 1993, Sawicka and Skalski 1993]. It is affected by the dose, kind of the agent used, application date, plant sensitivity, soil and climatic conditions, mainly soil moisture content. The effectiveness of weed control treatments applied on potato plantations is well covered in literature [Beres 1993, Zarzecka 1997, Gruczek and Pastusiak 1999, Klikocka 2000, Rola and Rola 2001, Golinowska and Pytlarz-Kozicka 2002, Urbanowicz 2005, Ciuberkis 2007], the effect of weed-killing agents on the chemical composition and the values of organoleptic characters of potato tubers is not defined in the same way by the researchers. In fact there are no reports on the effect of chemical weed control during the plant vegetation period on the tuber storage life.

According Dzwonkowski and Chotkowski [2012], potato harvests in Poland recorded over the last few ears (about 9 m tons) are mostly used for consumption purposes (2,3%) and processing purposes (170 thousand tons for french fries, over 67 thousand tons for chips and about 120 thousand tons for dried material). Processing as well as consumption of potato tubers take place throughout the year. It is therefore necessary to perform research on the effect of the use of agents protecting from weeds in a form of herbicides on the change in the size and structure of the tuber yield as well as on those qualitative characters which condition their functional applicability throughout their usage period.

The main aim of the present research was to define the effect of selected herbicides on the qualitative qualities and the storage life of potato tubers. To obtain the effects resulting from the main concept of research, itemized aims were defined:

- to what extent, as a result of the weed control treatments used, the size and the structure of the total tuber yield will change;
- whether the herbicides used modify the chemical composition of potato tubers which plays an important role in evaluating their applicability for consumption and processing;

- whether the nutritive value in potato tubers depend on the weed-killing agents used during the vegetation period;
- determining the degree of qualitative changes defining the functional value of potato tubers during storage;
- analyzing to what extent the treatments applied during the vegetation period can change the tuber storage life conditioned genetically.

LITERATURE REVIEW

The greatest challenge for agriculture of the 21st century is an increase in production and enhanced quality of foodstuffs without increasing the agricultural acreage. In the world foodstuffs production the protection of plants from diseases, pests and weeds is important [Dobrzański and Adamczewski 2001]. It is estimated that on average globally about 10% of yield losses are generated by the occurrence of weeds. Without chemical weed-killing agents the losses would be much higher, even up to 70% [Domańska *et al.* 1988, Adamczewski 2000, Praczyk and Skrzypczak 2004, Urbanowicz 2004a]. When making a selection of the method of eliminating segetal vegetation, from mechanical, mechanical-and-chemical and chemical control, the following factors are essential: status of weed infestation, species composition, especially dominant taxa, the economic potential of the farm and intended final effect of the production – economic justification whether the yield obtained will balance the costs born [Urbanowicz 2004]. According to Zarzecka [1997], mechanical treatments, especially over years of high rainfall and in the fields heavily weed-infested are insufficient. As reported by other authors [Beres 1993, Klikocka 2000, Rola and Rola 2001, Golinowska *et al.* 2002, Urbanowicz 2005], the advantage of chemical and mechanical-and-chemical weed control is high effectiveness and low costs as compared with the mechanical weed control method. Experiments conducted in Germany in potato growing the effectiveness of field bedstraw control after the use of the herbicide was over two-fold higher as compared with the effects recorded for the mechanical method [Börner 1995].

A skilful use of herbicides makes it possible to eliminate the competitive effect of weeds towards crops as early as at the beginning of the existence of the plantation as well as to limit later weed emergence [Gruczek and Pastusiak 1999]. An important advantage of the chemical weed control is also a possibility of performing the treatment on a large area over a short time. The use of herbicides makes it possible to limit, or even give up, agricultural practices, especially plowing. A few-time drives with the tractor on the plantation can carry viral and bacterial diseases and pressing of interrows [Choroszewski 1994b], and after emergence – potato plant damage. On bigger acreage a large number of drives are connected also with an increase in production costs [Urbanowicz 2004a]. Limiting mechanical control also decreases water losses from soil as a result of evaporation, which is very important for the regions with rainfall deficit and threatened with soil erosion [Praczyk and Skrzypczak 2004]. Chemical weed control, however, is questioned due to the toxicity of herbicides. Heavy toxicity of modern herbicides is in many cases lower, as compared with commonly used chemical agents, e.g. aspirin, table salt, gasoline. Using them compliant with the principles of good practice of plant protection (DPOR), as part of good agricultural practice [Pruszyński and Wolny 2001] ensures complete safety of foodstuffs to consumers. The remains of chemical pesticides used at adequate doses and on adequate dates in potato yield are inconsiderable. Most modern pesticides are practically water-insoluble, and they solve in fats. Potato contains very low amounts of these compounds (about 0.1%), and over 90% of lipids is found in the skin, and so potato accumulates much less pesticides than other crops [Leszczyński 2000].

The effectiveness of herbicides depends heavily on the development phase of weeds as well as on weather conditions, mostly soil moisture. A low soil moisture increases the concentration of herbicides and can lead to their crystallizing. In such a case herbicides cannot get activated and become inaccessible for weed roots [Urbanowicz 1999]. If soil is wet, the amount of spray liquid can be limited; over drought it is necessary to increase it almost two-fold [Gabriel and Świeżyński 1977]. Foliar herbicides must be used under conditions facilitating weed sprouting and growth. Taking up active substance by weeds is enhanced by high temperature which can, at the same time, result in drying of drops of active substance, which limits the absorption of the herbicide. The activity of herbicides is usually higher at higher temperature, however at the temperature which is too high the sensitivity of crops can increase, especially to herbicides used after their emergence [Dobrzańska and Dobrzański 1979]. The temperature most optimal for the use of herbicides is 10-25°C.

A high amount of herbicides registered for weed control in potato to be used both before emergence and after emergence [Guidelines of the Institute of Plant Protection, Monitor Polski, Praczyk and Skrzypczak 2004], makes their adequate selection possible, depending on the occurrence of dominant weed species, on equipping the farm with applicable machinery and on its organizational efficiency [Choroszewski 1994a, Nowacki 2006]. An inadequate use of herbicides as well as no rotation can result in the compensation of weeds or selection in the population of weeds of biotypes resistant to a given group of weed-killing agents [Praczyk and Skrzypczak 2004]. Selecting herbicides to potato weed control, one shall consider not only the spectrum of the weeds controlled but also the toxic character of the preparations for the crop [Choroszewski 1994b, Radke *et al.* 2000]. The use of herbicides after emergence can result in a phytotoxic reaction of the crop, depending on the sensitivity of the cultivar [Urbanowicz 2004a]. The phytotoxicity effect is of special importance when growing cultivars of the shortest vegetation period which can react in a decrease in the yield and in smaller tubers – due to an excessively short time for chlorophyll reconstruction [Urbanowicz 2004b]. Special triazine preparations decrease the amount of chlorophyll [Divis and Kuncl 1993], which can result in a decrease in yield, as reported by Sawicka and Skalski [1993], after an agent containing metribuzin used after potato emergence. Many authors, including Urbanowicz [2004b], Choroszewski [1994a], found differences in the susceptibility of cultivars by testing the same preparations. A negative reaction of cultivars to the cultivars used, expressed in yield decreases was also reported by many authors, including Adamiak [1985], Pawłowski and Pomykalska [1987a], Ceglarek and Księżak [1992]. The phytotoxic effect of herbicides increases under rainfall deficit and over years which are cold and with high rainfall [Palikowa and Grabowska 1986].

The harmful effect of weeds in potato growing involves limiting the availability of water, light and nutrients for plants, which, in turn, leads to a decreased number of tubers under the plant, deteriorated yield structure, and thus decreased yielding [Krężel and Kołbus 1988, Pawłowski and Pomykalska 1988, Zarzecka 2000, Kraska and Pałys 2002, Klikocka *et al.* 2010]. A low competitiveness of potato towards weeds, especially at the beginning of the vegetation period, due to slow initial rate of plant development, limits its yielding potential [Gruczek 2001, Zarzecka and Gąsiorowska 2002b]. A negative dependence of yielding on weed infestation of potato was also reported by Renner [1992], Rola and Rola [1996], Osowski and Erlichowski [2001]. According to Zarzecka and Baranowska [2004], most weed species which occur on potato plantations, dominated by white goose-foot, barnyardgrass, common chickweed, curltop knotgrass and black knotgrass, contain 2-3 – fold more macroelements than potato tubers. Additionally weeds create a favorable microclimate for the development of diseases and pests [Gruczek 2001, Zarzecka and Baranowska 2004], making harvest difficult and increasing mechanical damage of tubers, which, in turn, results in further yield losses during storage [Gruczek 2003, Urbanowicz 2004a]. A high weed infestation also results in smaller tubers and decreased number under the plant [Pawłowski and Pomykalska 1988, Pałys 1991, Sawicka 1991, Jabłoński 2000].

The amount of active substance of pesticides, penetrating into the plant tissue, undergoes, as a result of biochemical transformations, a gradual decrease in size [Edwards and Owen 1989]. However their presence even in inconsiderable amounts changes the activity of a number of enzymes [Habiba *et al.* 1992, Pireaux *et al.* 1992] disturbing the pattern of many metabolic processes, and as a result, changing the chemical composition of tubers [Baker 1991, Lisińska and Leszczyński 1989]. The toxicity of triazine and carbamide herbicides involves their inhibition of photosynthesis [Domańska 1991, Różański 1998, Praczyk and Skrzypczak 2004], sulphone-carbamide herbicides disturb the synthesis of proteins. The effect of this interaction can be not only a plant destruction, favorable in the case of weeds, but also the modification of the chemical composition of crops [Ashton and Crafts 1981]. The influence of herbicides can also depending on the kind and dose of the preparation, date and method of application, susceptibility of the protected plant, soil and climatic conditions during agent application [Mężykowska and Mazurczyk 1979, Banaszkiewicz 1993, Sawicka and Skalski 1993].

A growing interest of consumers in potato for direct consumption and in a form of potato products makes producers improve growing and storage conditions as well as the selection of such potato cultivars which would meet specific requirements of a given direction, also over a period distant from harvest. According to general criteria, common for all the directions of use, potato tubers should demonstrate, e.g. shape regularity, tuber size, no quality defects, such as: getting green, discoloration, surface cracking, tuber injuries, no empty cavities inside, infection with pathogens and should be applicable for long-term storage [Leszczyński 1994a, Leszczyński 2000, Lisińska 2006].

Detailed requirements cover mostly internal characters, e.g. (Table 1): an adequate content of dry matter, starch, total and reducing sugars, possibly the lowest tendency to the appearance of black spot, possibly the lowest flesh blackening of raw tubers and after cooking, an adequate functional and consumption type, a good tastefulness [edited by Głuska and Zgórska 2004]. Potato processing is an industry which defines top requirements concerning the raw material processed (Table 1). Besides the characters mentioned, the potato to be processed into chips should demonstrate the capacity for long-term storage since the processing period in chips production plants takes all year. Tubers for chips production should also have a limited capacity for producing reducing sugars in tubers stored at low temperatures (about +4°C). The potato cultivar considered least unreliable, applicable for processing after a long-term storage, is 'Saturna' [Lisińska 2006]. Strict requirements concerning the raw material for french fries production, despite those given in Table 1, concern also the tuber size (the bigger the tubers, the greater the share of chips in the raw material processed). A very important character is also an even distribution of sugars in tubers as the so-called effect 'sugar end' (brown chip ends) can be seen only after the second degree of frying.

Table 1. Quality character requirements of potato tubers for direct consumption and foodstuffs processing

Quality characters	Direct consumption			Products					
	cooked or steamed tubers			dry material from tubers		fried		frozen	tinned
	from water (as a whole)	sieved (puree)	sliced (salads)	raw	cooked	french fries	chips		
Tuber shape	regular with shallow buds			round to oval		elongated to oval	round to round-and-oval		
Transverse diameter, mm	40-60	>40	>40	>30	>30	>55	40-65	40-65	to 35
Content of starch, %	12-16	>14	≤14	15-19	about 16	14-17	16-20	12-14	12-14
Content of dry matter, %	18-22	>20	<20	21-25	21-22	20-22	21-25	18-20	18-20
Content of reducing sugars in the fresh weight, %: – desired – boundary	- ≤0.5	- ≤0.5	<0.25 ≤0.5	<0.25 ≤0.5	<0.25 ≤0.5	<0.25 ≤0.5	≤0.15 ≤0.3	≤0.5	≤0.5
Content of the total sugars in the fresh weight, %	≤1.0	≤1.0	≤1.0	≤1.0	≤1.0	≤1.0	≤1.0	≤1.0	≤1.0
Tendency to black spot	possibly lowest								
Flesh blackening after cooking	very small >8 and small >7.5			less important character	very small >8 small >7.5	small >7.5	less important character	small >7.5	very small >8 small >7.5
Raw flesh blackening	>6.5			very small >8 small >6.5	>6.5	>6.5		very small >8 small >6.5	very small >8 small >6.5
Culinary type	AB-BC	B-C	A-AB	BC-C	B-BC	B-BC	BC-C	A-AB	A-AB
Tastefulness	very good >7 and good >6			good >6		very good >7 good >6	good >6	very good >7 good >6	

Source: Characteristics of registered potato cultivars, 2004, IHAR, Jadwisin [in Polish]

The nutritive value of tubers is determined by the content of starch, vitamin C, protein of a high biological value, content of mineral compounds (e.g. potassium) and others [Kolasa 1993, Niederhauser 1993, Leszczyński 2000]. What is undesired is an increased content of harmful substances, mainly glycoalkaloids and nitrates. According to the Decree of Minister of Health and Social Welfare (Dz.U. 2003 No 37 item 306), potato tubers should not contain more than 200 mg $NaNO_3 \cdot kg^{-1}$ of fresh weight. Culinary treatment (peeling, washing, cooking, frying) enhances the level of nitrates in tubers, decreasing their content [Mozolewski *et al.* 2004, Wichrowska and Wojdyła 2011]. Cooking, however, should not be too long to prevent most vitamins and minerals from being transported to the stock together with harmful compounds. In the research reported by many authors, including e.g. Wichrowska [2007], the content of nitrates in tubers after 6-month storage also decreased, even to 59%, which is favorable from the point of view of healthiness of raw material.

Most morphological characters (shape, tuber size, bud depth, skin type – smooth, rough) are determined mainly by the genotype, however they can be modified by soil--and-climatic as well as agrotechnical conditions [Nowacki 2002]. Moist years, unlike the years of low rainfall and high solar radiation, have a positive effect on the shape of tubers increasing their weight and decrease the bud depth [Bombik *et al.* 1998]. According to Lisińska and Leszczyński [1989], also herbicides, mostly carbamide herbicides, increase the amount of big tubers in the yield, and thus the average weight of a single tuber is higher.

For the consumer and the processing plant, the nutritive value, organoleptic characters and technological properties, which depend on the content of respective components in the tuber, are essential [Głuska 2000, Nowakowska and Skalski 2000, Leszczyński 1994b, Rogozińska 1987]. The chemical composition depends on the genotype characters, soil-and-climatic conditions and agrotechnical treatments, including weed control over the vegetation period [Hak 1990, Mazurczyk 1994, Roztropowicz 1989, Głuska 2000, Zarzecka *et al.* 2000] and storage [Rogozińska 1987, Zgórska and Frydecka-Mazurczyk 2000].

The content of dry matter in tubers considerably determines the culinary value, which guarantees high production capacity and the right density of products obtained from potatoes. Many reports [Trinnette Van Merle *et al.* 1997, Thybo and Martens 1999, Van Dijk *et al.* 2002, Weber and Hasse 2005] point to highly significant relationships between the culinary type (compactness of the flesh after cooking), and the content of dry matter in tubers. Tubers of a lower content of dry matter most often represent the compact (salad) type, and of a higher content of this component – average--compact to floury type. Besides, the level of dry matter determines the texture of fried products and a fat absorption by the product [Pritchard and Scanlon 1997, Lisińska 2006]. An excessively low or high content of dry substance (also starch) makes the density of french fries not crispy enough (or too hard) on the surface, and the inner part of french fries is cracked and gunky. A similar importance of the level of dry matter and starch in tubers is in the case of chips and an excessively low content of dry matter and starch also lowers the capacity, increases the oil consumption, resulting in oily character of the product. The content of dry matter in tubers depends mostly on the cultivar factor and is modified by pluviometric conditions during the vegetation period as well as habitat conditions. Many researchers [Kołpak *et al.* 1987, Ceglarek *et al.* 1990, Mazurczyk and Lis 1999, Leszczyński 2002] report on potato tubers, in the dry years, of high solar radiation and high temperatures, accumulating more dry matter than in wet years. The changes in the content of dry matter in tubers are also affected by herbicides used during the vegetation period of the plants [Mężykowska and Mazurczyk 1979, Pawłowski and Pomykalska 1987a]. A number of preparations out of triazine herbicides can decrease the content of the character discussed [Leszczyński and Lisińska 1985]. A significant decrease in dry matter in tubers from the plots with the use of chemical weed control was also reported by Zarzecka *et al.* [2000], while Ceglarek *et al.* [1990] reports on significantly less dry matter in potato tubers collected from the plots as a result of herbicide mixtures applied during the vegetation period, as compared with tubers from the plots where the mechanical control was used. Other researchers [Lisińska 1981, Kołpak *et al.* 1987] did not note significant differences in the percentage content of dry matter in tubers as affected by herbicides. Kołpak *et al.* [1987] recorded only the tendencies for its decreasing content in tubers treated with herbicides.

The main component of dry matter is starch. It is one of the essential characters defining the applicability of cultivars for processing. The value of that character is affected by similar factors as in the case of dry matter. A high humidity and low temperature during the vegetation period decrease the content of starch in tubers [Zgórska and Frydecka-Mazurczyk 1985]. Late cultivars show the highest content of the component, which is connected with the length and intensity of photosynthesis. As reported by many authors [Ceglarek *et al.* 1990, Zarzecka and Gąsiorowska 2000], Lisińska 1981, Kołpak *et al.* [1987], besides the cultivar and climatic-and-soil conditions, the content of starch in tubers is also affected by the herbicides used, which made its content lower.

The nutritious qualities of potato are affected mostly by the presence of protein. Nitrogen compounds occur in tubers accounting for about 2% expressed in protein (N × 6.25), as the so-called total protein, 35-65% of which is true protein. It has a high biological value, comparable with protein in soybean and slightly lower that the protein of hen egg considered to be the model of the amino acid composition as it contains exogenous amino acids [Leszczyński 2000, Zgórska 2002], e.g. leucine, lysine, phenylalanine and methionine [Woda-Leśniewska 1993, Wroniak 2006]. The content of protein considerably depends on the climatic conditions over the vegetation period. Dry years enhance the growth of the content of total protein in tubers [Roztropowicz 1989, Pytlarz-Kozicka 2002]. Results of many research [Kłosińska-Rycerska and Mężykowska 1975, 1979, Kołpak *et al.* 1987, Ceglarek *et al.* 1990, Zarzecka and Gąsiorowska 2000] show that most herbicides influence the level of nitrogen and its transformations in plants, increasing the protein synthesis and its scale depends also on the cultivar grown [Woda-Leśniewska 1993].

An important indicator of the tuber quality of table potato and foodstuffs processing potato is the level of reducing sugars (glucose + fructose) and the sum of sugars (reducing sugars + saccharose). An increased content of the sum of sugars up to about $1 g \cdot 100 g^{-1}$ in fresh weight makes tubers taste sweet [Zgórska and Frydecka-Mazurczyk 1999]. Reducing sugars, when heated, especially when fried, undergo non-enzymatic browning as a result of the Maillard reaction, deteriorating the flavor and aroma and production of harmful heterocyclic aromatic amines [Pritchard and Adam 1994, Leszczyński 2000]. Over the last few years the requirements concerning the admissible level of reducing sugars in tubers have become stricter after the publications of the research results of Swedish scientists on the production of acrylamides as a result of that reaction [Moltram *et al.* 2002, Putz 2004]. Acrylamides have been classified by the World Health Organization (WHO) as substances carcinogenic for humans and animals [Kejbets 2006]. When exposed to fatty acids (frying) in the reaction environment the capacity of acrylamides production increases [Sikorski 2000]. Besides a high content of reducing sugars decreases the flavor properties and flesh blackening [Leszczyński 1994b]. The level of sugars depends mostly on the cultivar and climatic conditions over the vegetation period (it decreases with tuber ripening). Besides, big tubers contain less reducing sugars and more saccharose [Lisińska and Leszczyński 1989]. The herbicides used on potato plantations, according to Zarzecka and Gąsiorowska [2000], Lisińska [1981], slightly increase the content of sugars in tubers.

Potatoes are one of the main sources of vitamin C as the amounts of potatoes consumed are high [Borek-Wojciechowska 2000, Leszczyński 2000]. Vitamin C plays an important role as an antioxidant, preventing raw flesh blackening [Pawelzik and Delgado 1999], as well as decreases the tendency to tuber blackening after cooking [Rogozińska 1991, Delgado *et al.* 2001a, b]. Its content in the tuber ranges from 100 to 300 $mg \cdot kg^{-1}$ and depends mostly on the cultivar but also considerably on the climatic conditions during the vegetation period [Zgórska and Frydecka-Mazurczyk 1985]. According to many authors [Kołpak *et al.* 1987, Ceglarek *et al.* 1990, Woda-Leśniewska 1993, Zarzecka *et al.* 1997], herbicides have a positive effect on the content of vitamin C in tubers. Different results are reported by Laaniste *et al.* [1999] after the use of triazine group herbicides.

Phenolic compounds (caffeic acid and chlorogenic acid) from the physiological point of view are acids important for the plant, playing a protective role, as natural antibacterial compounds [Ghanekar *et al.* 1984]. They are created as a result of stress caused by excessive moisture or drought over the plant vegetation period, mechanical damage over harvest, transport and storage technology actions [Pawelzik and Delgado 1999, Laerke *et al.* 2002]. They also contribute to increased intensity of tuber blackening. Besides the content of phenols is positively correlated with unfavorable bitterness and tartness of potato tubers [Horubała 1988]. The content of phenolic compounds in total in tubers depends on the cultivar, the vegetation period, location and the cultivation method [Leszczyński 2000].

Irrespective of the direction of use, one of the most important characters of potato quality is tuber susceptibility to external and internal mechanical damage (post-damage black spot). Potato tuber resistance or susceptibility to damage is mostly connected with individual characters of the cultivar and the effect of weather conditions is secondary [Zgórska 1989].

As reported by Zgórska and Frydecka-Mazurczyk [1997], potato tubers for direct consumption and processing to obtain enriched products should demonstrate adequate external characteristics and an adequate concentration of biochemical components, limiting the tendency to flesh blackening of raw tubers and tubers after cooking. According to Rogozińska [2002] and Müller [1988], blackening is a defect which can disqualify the raw material for consumption and processing. The reason for raw flesh blackening is the effect of the enzyme of polyphenol oxidase which, when exposed to oxygen, oxidizes phenol compounds contained in the tuber, mainly aromatic amino acid tyrosine and phenolic acids: chlorogenic, caffeic and others which undergo further reactions as a result of which they form colorful melanin compounds [Komorowska-Jędrys 1997]. The intensity of enzymatic blackening, being to a large extent, a genetic character [Zgórska 1989, Ceglarek *et al.* 1990, Bill and Jackowiak 1992, Dean *et al.* 1993, Wulkow 2009], is conditioned by the content of phenolic compounds and the activity of polyphenol oxidase enzyme [Bill and Jackowiak 1992, Kaaber *et al.* 2002], which increases at the end of the vegetation period [Corsini *et al.* 1999]. The enzyme can get inactivated at higher temperature by blanching. Enzymatic blackening can be made weaker by the use of NaCl or SO_2 and in the presence of ascorbic acid. Blackening occurs only when the entire amount of ascorbic acid gets oxidized. The dark pigment produced is absorbed by starch, which, instead of becoming shiny, becomes grey and matt [edited by Chotkowski 2002]. The process of blackening of cooked tubers involves iron ions forming bonds with chlorogenic acid. Free ion Fe^{2+} as affected by the air, gets oxidized to Fe^{3+}, which reacts with chlorogenic acid released during cooking and produces dark color of the flesh [Komorowska-Jędrys 1997]. The process gets inhibited in the presence of compounds chelating iron, including phosphates, and mainly citric acid [Gabriel 1985, Grzesiuk and Górecki 1994, Rogozińska 2002], forming with it colorless complexes [Lisińska and Leszczyński 1989]. The organoleptic evaluation conducted by many authors demonstrated that tubers from the plots sprayed with weed-killing agents showed tendencies to increased blackening [Gruczek 1980, Ceglarek *et al.* 1990, Sawicka and Dialo 1997, Zarzecka *et al.* 1997]. According to Kołpak R. *et al.* [1987], differences in that character over years demonstrate the effect of meteorological conditions during plant vegetation. Over dry and sunny years there was recorded a decreasing tendency to blackening of raw tubers and tubers after cooking [Kłosińska-Rycerska 1971].

The consumption value of potato tubers incorporates, besides flesh blackening, such characters as: the flesh color, functional and consumption type as well as tastefulness.

The flesh color is cultivar-specific and it is only slightly modified by habitat conditions [Teodorczyk 1982, Leszczyński 1994b, Ciećko *et al.* 2005]. Most frequently it is white, cream, yellow in color or intermediate colors, sometimes slightly pink. The yellow color of flesh is affected by carotenoids, mostly zeaxantine and lutein, while the pink color is due to the presence of anthocyanins, mainly glycosides pelargonidin, petunidin and malvidin [Leszczyński 2000]. The tendency to enzymatic blackening has an unfavorable effect on the color of flesh, changing it into grey.

The texture of flesh is the basic indicator for qualifying potatoes to a given functional and consumption type: A – salad, B – general functional, C – floury, D – very floury (in practice mixed types occur). Consumer requirements in that matter differ. To define the texture of cooked potatoes, the EAPR (European Association for Potato Research) differentiated four characters: the density, floury character (tendency to spilling), moisture (viscosity of the flesh and slippery flesh) as well as the flesh structure. In Poland the functional type is defined based on five characters, besides the ones listed, also the overcooking character (tendency to cracking and spreading out of the tuber surface). The basic substances which define the texture of cooked potatoes are starch, pectin substances and cellulose [Hoff 1972, Nanoka 1980]. The characters given defining the properties of cooked potatoes are affected by the environmental factors very considerably [Van Marle *et al.* 1997]. Over the dry and hot years cooked potatoes are more floury and get overcooked more heavily than over the cool and rainy years [Komorowska-Jędrys 1997]. The most important factor is, however, the potato cultivar and the degree of tuber maturity. During ripening the chemical composition of tubers changes, there are changes in the structure and composition of cell walls [Lisińska and Leszczyński 1989, Kolbe 1995,]. As reported by Gugała and Zarzecka [2007], Zarzecka [1997], Ceglarek *et al.* [1990], Kołpak *et al.* [1987], Kłosińska-Rycerska [1971], the effect of herbicides on the texture of flesh is inconsiderable.

Tastefulness as a group of flavor and aroma sensations is the most subjective character defined for table potato and, at the same time, one of the top characters defining the culinary quality. According to Komorowska-Jędrys [1997], tastefulness undergoes environmental variation to an average degree. It is foremost the character conditioned genetically dependent on the chemical composition of tubers. Free amino acids and nucleotides as well as vitamin C enhance the tastefulness of tubers, unlike the access of sugar and ash. Similarly an unfavorable effect on that character is reported for a high content of glycoalkaloids making the tubers burning and bitter tasting [Leszczyński 1994b, Lachman *et al.* 2001]. There are reasons for which herbicides are not a neutral factor as, to some extent, they have a negative effect on the tuber tastefulness [Kołpak *et al.* 1987, Ceglarek *et al.* 1990].

Defining the effect of herbicides on changes in the chemical composition and organoleptic characters is difficult as the development of these characters depends considerably on environmental factors which can overlap or act divergently [Leszczyński and Lisińska 1985].

In Poland table potatoes and potatoes for processing are in 95% stored October through June [Gąsiorowska 2000, Czerko 2001, Sowa-Niedziałkowska 2004a]. As for long-term storage, however, only cultivars of a long period of dormancy are applicable, sprouting possibly late, collected at full maturity, undamaged, non-infected by pathogens [Leszczyńki 2000, Sowa-Niedziałkowski 2000]. It is important to maintain optimal conditions in the storage room to minimize qualitative and quantitative losses, which are a result of life processes [Leszczyński 1994b, Sowa-Niedziałkowska 2000, 2001]. The amount of losses during storage depends on the storage life of the cultivar and temperature and the relative air humidity in the warehouse [Rogozińska 1987, Gąsiorowska 2000, Sowa-Niedziałkowska 2004a]. Biochemical and physiological processes in tubers are least intensive at the temperature of +2 to +4°C; under these conditions the loss of dry matter is limited, however, there is an accumulation of reducing sugars and saccharose. A higher storage temperature (+8 to +10°C), on the other hand, limits the level of these compounds in tubers, however already after 4-5 months of storage there is observed a deterioration of the qualitative characters of tubers, which is mostly connected with sprouting and turgor loss, as well as starch losses [Cheong *et al.* 1999, Frydecka-Mazurczyk and Zgórska 2000a, Zgórska and Frydecka-Mazurczyk 2000]. The storage life of tubers is much affected by the cultivar, soil and climatic as well as growing conditions during growth. Wet and cold years contribute to losses during storage [Gąsiorowska 2000]. An adequately adjusted temperature and relative air humidity in the storage room prevent losses resulting from transpiration and respiration [Leszczyński 2000, Sowa-Niedziałkowska 2004a, b].

Most table cultivars stored at the temperature of +6ºC and the relative humidity of the air over 90% show low losses of dry matter and starch (calculated from the balance) as compared to the content after harvest [Frydecka-Mazurczyk and Zgórska 2001]. During storage, especially at higher temperatures, seemingly the content of dry matter increases. It is connected with water loss in the process of transpiration, as a result of which the density of tubers changes after cooking [Kaaber *et al.* 2001]. Changes in the content of dry matter and starch in tubers also affect the organoleptic properties of french fries and chips.

The lower the storage temperature, the higher the level of reducing sugars and the $\longleftrightarrow$ sum of sugars, which is due to a displacement of the equilibrium: starchsugars in the direction of sugar formation [Zgórska and Frydecka-Mazurczyk

1985, Lisińska and Leszczyński 1989, Hertog *et al.* 1997]. A high content of sugars in tubers stored at low temperatures (+4ºC) can be lowered as a result of the reconditioning treatment (tuber storage for about 2 weeks at the temperature of +18ºC). Besides the level of reducing sugars can be lowered by blanching during french fries and chips production. However a longer treatment of the raw material with hot water increases the consumption of oil during frying and the product is oily of the texture which is little crispy and gunky [Lisińska 2000]. Fo·r that reason it is important to maintain the optimal temperature which, for most cultivars, is from +6 to +8ºC, to maintain the right level of sugars in potato tubers for processing [Hyde and Morrison 1964, Frydecka--Mazurczyk and Zgórska 2001].

Most authors, drawing on multi-year research, claim that the content of vitamin C as a result of storage decreases regularly (even to 60%), as a result of oxidation of ascorbic acid [Gąsiorowska 2000, Rogozińska 2000]. During storage losses of vitamin C occur very fast, especially in the first 20-30 days [Amberger and Schaller 1975, Rogozińska 1989]. After 7 months of storage the losses account for about 50%, however there are cultivars in which losses of vitamin C account for even up to 70%. As reported by Frydecka-Mazurczyk and Zgórska [2001], most cultivars demonstrate lower losses after storage at the temperature of +6ºC. At the final period of storage there can occur a fast increase in vitamin C, and the phenomenon is connected with, according to Amberger and Schaller [1975], the initiation of tuber sprouting.

During storage there is observed an increase in blackening of raw tubers and tubers after cooking. It is seen mostly in spring and it is a result of the process of potato sprouting. A lower tendency to flesh blackening is noted after tuber storage at the temperature of +4 to +6°C [Frydecka-Mazurczyk and Zgórska 2001]. Long-term storage of tubers at higher temperatures without the use of growth inhibitors of sprouts can lead to the appearance of dark physiological spots in the entire flesh of tubers, which is connected with an excessive loss of water. According to Dean *et al.* [1993], the storage time reduces the susceptibility to blackening. A bigger group of researchers, on the other hand, including Müller [1988], Kolbe and Hasse [1997], Rogozińska *et al.* [1986], claim that the susceptibility to blackening of tubers increases with storage, which is connected with a decrease in vitamin C.

An increase in raw tuber blackening to the value below 6.5 in the 9-degree opposite Danish scale disqualifies them as raw materials from french fries and chips production. Blackening of cooked tubers cannot exceed the value of 7.5 for potatoes for direct consumption and for french fries production as during storage of frozen french fries the product can get grey. In the case of potato tubers used for chips production, the degree of cooked tuber blackening is less important.

The susceptibility of tubers to raw and cooked flesh blackening, especially at the initial storage period, is also connected with an increased content of phenolic compounds (chlorogenic acid) in the raw material [Rogozińska *et al.* 1986, Zgórska 1989]. These compounds are formed especially in the parts of tubers which are damaged during the harvest, transport and actions connected with the storage technology [Rogozińska *et al.* 1986, Pawelzik and Delgado 1999, Laerke *et al.* 2002].

After 4 and 6-month storage period, the content of citric acid in tubers increases as compared with the content after harvest [Rogozińska 1987]. According to Amberger and Schaller [1975], the effect of storage temperature on the level of this compound in tubers is lower than the genetic conditions of the cultivar.

With time of storage, the flavor of table potato deteriorates [Komorowska-Jędrys 1997]. According to Nowacki [2000], the lowest changes in flavor occur in tubers stored at the temperature of +6°C, which is connected with low fluctuations in the chemical composition of tubers, mostly sugars.

To guarantee limiting potato losses during long-term storage is to select the tubers which are healthy, ripe and without mechanical damage. It depends on most treatments in the adequate technology of potato cultivation [Sowa-Niedziałkowska 1999, 2000]. To limit losses of tuber weight inflicted as a result of storage, it is a good idea to increase processing of raw material of potato into long-life products, already in autumn and the beginning of winter, which decreases the storage costs of tubers to be used for enriched products.

3. MATERIAL AND METHODS

3.1. RESEARCH MATERIAL AND METHODS

The research material was made up of potato tubers from field experiments carried out over 2002-2004 at the Experiment Station of the Faculty of Agriculture of the University of Technology and Agriculture at Mochełek, set up following the split-plot method in three reps.

The split-plots of the first order were the herbicides used (Table 2):

H-0 – plots without the use of herbicide – mechanical weed control before and after potato emergence (control object),

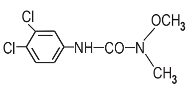
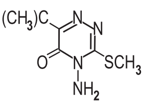
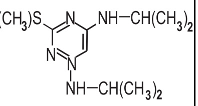
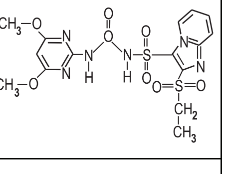
H-1 – mechanical weed control until emergence, and right before emergence the use of herbicide Afalon 50 WP (linuron) 2 kg·ha^{-1},

H-2 – mechanical weed control until emergence, and after emergence herbicide Sencor 70 WG (metribuzin) 0.5 kg·ha^{-1} + adjuvant Olbras 88 EC 1.5 dm^3·ha^{-1},

H-3 – mechanical weed control until emergence, and after emergence spraying with herbicide Apyros 75 WG (sulphosulphuron) 26.5 g·ha^{-1} + adjuvant Atpolan 80 EC 1.5 dm^3·ha^{-1},

H-4 – mechanical weed control until emergence and a few days before emergence herbicide Azogard 50 WP (prometrin) 3 kg·ha^{-1}.

Table 2. Characteristics of the herbicides used

Trade name of the herbicide	Afalon 50 WP	Sencor 70 WG	Azogard 50 WP	Apyros 75 WG
Active substance	linuron 	metribuzin 	prometrin 	sulphosulphuron 
How it works	systemic			
	– enters through roots, partially through leaves, – inhibits the process of photosynthesis (electron transport inhibitor)	– enters through roots, slightly through leaves, – inhibits the process of photosynthesis (electron transport inhibitor) and other physiological processes	– enters through leaves, herbaceous stems and roots – inhibits the process of photosynthesis (electron transport inhibitor)	– enters through roots, also through leaves – holds the synthesis of amino acids (inhibits cell divisions in stem apexes of overground parts and roots)

Source: Czerniakowski and Czerniakowski 1993, Praczyk and Skrzypczak 2004.

Split-plots II of the second order were two mid-late potato cultivars (Fig. 1):

'Rywal' is a cultivar of consumption and versatile functional culinary type, very susceptible to mechanical damage of yellow flesh color, blackening little [Chotkowski 1999], of a red skin color and leaf-and-stem habit.

'Saturna' is a starch cultivar, of versatile functional culinary type to floury, mostly for chips production, light yellow to yellow flesh color, representing average-blackening cultivars (Bundessortenamt 2002), of stem-and-leaf habit.

Fig. 1. Tuber shape and plant habit

The size of the experimental plot was 28.125 m^2, and the plot for harvest – 22.5 m^2. In the vegetation period observations of more essential development stages of potatoes were made (Table 5), necrotic pathological changes, more essential events were noted, e.g. the appearance of diseases and pests in considerable numbers. To evaluate the effectiveness of herbicides, there was evaluated the number and flora composition of weeds at two dates: prior to potato row closing and right before tuber harvest on three randomly selected plots defined by the frame 31.25×160 cm in size (0.5 m^2).

Potato tubers were sampled, according to the applicable standard, at the amount of 50 kg from each plot and packed into net bags 10 kg each to make analyses and evaluation after harvest and storage in storage chambers at +4ºC and +8ºC and the relative air humidity of 95% for a period of 3 and 6 months. In every storage season in the storage room there were 120 samples, namely 2 cultivars × 5 weed control methods × 2 measurement dates during storage × 2 storage temperatures × 3 reps.

The evaluation of the yields involved:

- the yield size,
- tuber shape and size, separating the following fractions: <40 mm, 41-55 mm, >55 mm.

After harvest and after 6 months of storage the following were evaluated:

- consumption value according to the current requirements approved by E.A.P.R. (European Association for Potato Research), Wageningen, which considers the following characters:

– flesh color was evaluated by the use of numerical quality evaluation, where: 1 – white flesh, 2 – white with a shade of grey, 3 – cream, 4 – light yellow, 5 – yellow, 6 – dark yellow;
– tastefulness, namely flavor and aroma qualities, performed with the 9-degree scale, 9 stands for very good, 1 – very bad;
– culinary and functional type, based on the evaluation of five characters (tendency to overcooking, density, floury character, moisture, flesh structure), using the 4-degree scale, applying numerical denotations: 1 – salad type (A), 2 – general functional type (B), 3 – floury type (C), 4 – very floury type (D);
– degree of blackening after cooking – the evaluation was made after 10 minutes and 24 hours after cooking on the longitudinal section of 10 tubers with Danish tables with the use of a 9-degree scale, where 9 – stands for non-blackening flesh, 1 – black flesh (Fig. 2);

Fig. 2. Tuber blackening after cooking determined according to color tables

- Technological value – quality of the enriched products produced under laboratory conditions – french fries, chips according the methods includes in [Rogozińska 1997].

The quality of french fries was evaluated with the 5-degree scale with instructions of the Department of Quality Testing Technologies of the Central Laboratory of Refrigeration in Łódź, which covered the following characters:
– color after the first frying – coefficient of importance – 0.2,
– color after the second frying – coefficient of importance – 0.1,
– density after the second frying – coefficient of importance – 0.4,
– flavor and aroma after the second frying – coefficient of importance – 0.3.

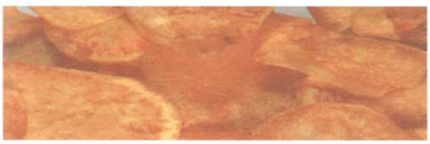
The quality of chips was evaluated using the 5-degree scale, considering the color, flavor, aroma and density, color of chips according to the color charts IBVL using the 9-degree scale recommended by EAPR Wageningen – Fig. 3.

Evaluation using the 9-degree scale: 1

Evaluation using the 9-degree scale: 2

Evaluation using the 9-degree scale: 3

Evaluation using the 9-degree scale: 4

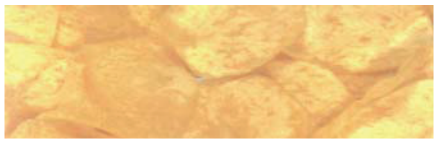


Evaluation using the 9-degree scale: 5

Evaluation using the 9-degree scale: 6

Evaluation using the 9-degree scale: 7

Evaluation using the 9-degree scale: 8



Evaluation using the 9-degree scale: 9

Fig. 3. Chips color

The sensory analysis of the consumption and technological value of potato tubers was performed by a 5-person team, tested for their sensory qualities according to PN-ISO 6658:98.

After harvest, as well as after 3 and 6 months of storage, potato tubers were researched for:

The oxidative potential of tubers (degree of blackening) determined at the Department of Plant Product Quality of the Department of Functional Plants Sciences, at the George August University in Goettingen using the homogenisation procedure as described by Dean *et al.*, 1993. A 25 g sample was obtained from six tubers and weighet in a beaker; 50 ml 0.05 M phosphate buffer (Scharlau, Germany) at pH 6.5 was then immediately added. The sample was homogenized with the homogenizer (Ultra Turrax, IKA T 18 B, Germany). This mixture was allowed to oxidize at room temperature for 24 hours. Then filtering using filter paper no. 615 ¼ Ø 150 mm (Macherey-Nagel, Germany), followed by centrifugation at 12,000 rpm for 10 minutes (Du Pont Instruments, Sorvall RC-5B, Germany). Absorbance was measured at 475 nm with a Spectrophotometer (Hewlett Packard 8453, Germany) and presented as absorbance units [AU_{475} nm] (Table 3).

Table 3. Categories of susceptibility to raw potato tuber blackening

Categories of susceptibility	[$AU_{475\ nm}$]
Resistant to blackening (non-blackening)	0.0-0.2
Moderately resistant to blackening	0.21-0.4
Moderately susceptible to blackening	0.41-0.6
Susceptible to blackening	0.61-0.8
Very susceptible to blackening (black)	>0.8

- Content of components
  - in fresh raw material:
    - dry matter content of the potatoes determined according the EAPR (1974). Six tubers were washed, dried and cut into cubes. The cubes were homogenized in laboratory mixer until a homogenous pulp was obtained. About ten grams of the pulp was poured into a petri dish and then heated at the temperature of 60°C for 15 hours. Afterwards the oven temperature was raised to 105°C. After four hours at 105ºC, the petri dish with the dry potato was cooled to room temperature in the desiccators and weighed. The total dry matter content of potatoes was calculated according to formula:

$$DM = \frac{D}{W} x100$$

DM – dry matter (%)
W – weight of wet sample (g)
D – weigt of dry sample (g)

    - starch – polarimetrically with the Ewers method,
    - vitamin C – with the volumetric method following PN-A-04019, 1998 by tritation with solution 2,6 – dichlorophenolindophenol (DIP) accordind Tillmans,
    - total sugars, after acidic hydrolysis and reducing sugars – with the colorimetric method [Talburt and Smith 1987],
  - in the material dried in the process of sublimation (freeze-drying were conducted at the Department of Plant Product Quality of the Department of Functional Plants Sciences, at the George August University in Goettingen for 48 hours):
    - chlorogenic acid – with the colorimetric method [Griffiths *et al.* 1992]. Freeze – dried potato flour (100 mg) was suspended in 2 mL solution

Germany). After adding 1 mL distilled water, the suspension was shaken for 15 s. After shaking, 1 mL 0.014 natrium nitrite (Merck) was added and mixed well. After two minutes of reaction, 1 mL 0.5 natriumhydroxid (Roth, Germany) was added to the suspention. The suspention was then centrifuged at 2250 gravities in the centrifuge (Eppendorf 5416, Germany) for ten minutes. The absorbance at the clear solution measured at 510 nm with a Hewlett Packard 8453 uv-Spectrophotometer (Germany). The concentration was calculated from the standard curve produced by measuring 50-400 ppm chlorogenic acid (Sigma),

- total protein – calculated from the content of total nitrogen using the multiplier 6.25, with the Kjeldahl method.

The results of component determination in the dry matter of tubers were converted into fresh matter.

After storage natural potato tuber losses were expressed in weight percentage. The losses were considered while calculating the content of components in fresh weight of potato tubers (dry matter, starch, vitamin C, total and reducing sugars).

The research results were verified statistically using the analysis of variance for 2- and 3-factor experiments. There was also made a multi-year results synthesis, applying the mixed model [Trętowski and Wójcik 1988, edited by Rudnicki 1991]. The statistical analysis was made with the use of software *Statistica Pl v.5.1, 6.0,* by Stat Soft. To evaluate the difference in the object means of respective factors the Tukey test was used, determining the significance of differences at the significance level of $\alpha = 0.05$. Similarly, coefficients of simple and multiple correlation as well as multiple regression equations were calculated.

3.2. SOIL, CLIMATIC AND AGROTECHNICAL CONDITIONS

In each research year potato was cultivated on lessive soil, formed from moraine clay qualified as good rye complex, class IV b. The soil demonstrated average content of available phosphorus and potassium and a low content of available magnesium. The content of organic substance in the arable layer was low and the soil reaction was slightly acidic (Table 4), which is adequate for an adequate potato growth.

Table 4. Content of basic nutrients and soil pH

Research years	Content of available forms ($mg \cdot kg^{-1}$)			Content of organic substance ($mg \cdot kg^{-1}$)	pH in 1M KCl
	P_2O_5	K_2O	Mg		
2002	62.0	130.0	20.8	8520.0	6.0
2003	60.0	160.0	22.1	8500.0	6.0
2004	102.0	169.0	20.2	8600.0	6.2

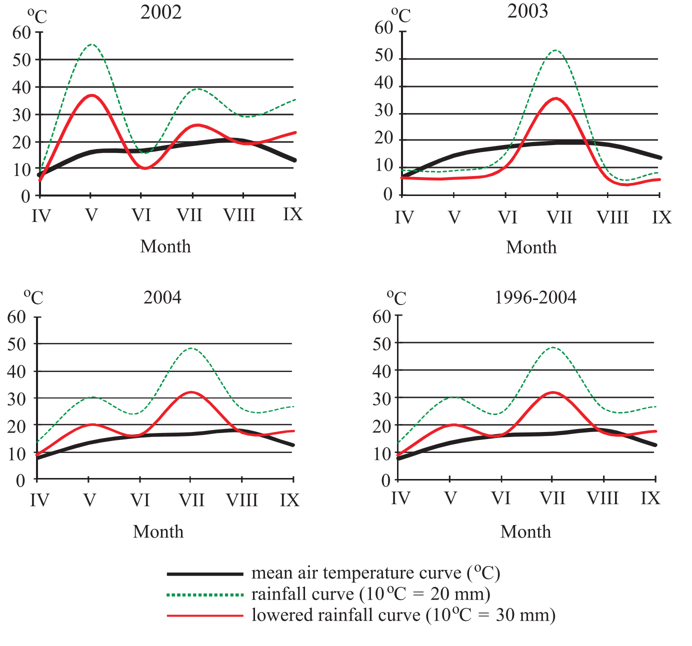
The thermal and moisture conditions over the research years differed and the rainfall and temperature distribution over the plant vegetation period were uneven. The year 2002 demonstrated the highest of all those researched and multi-year mean total rainfall and high air temperature over the plant vegetation period (Figs. 4, 5). Only in June, namely over plant flowering and the beginning of tuber formation did semi-drought occur (according to Walter, 1976), and in the third decade of August there was no rainfall at all. The other months were warm (temperature May through June ranged from 15.7 to 19.9ºC) and recorded quite high rainfall which, although distributed unevenly, enhanced the plant growth, development and yielding. In the year 2003 rainfall deficit occurred from planting to the beginning of flowering as well as at the end of the plant vegetation period. Only July recorded a higher total rainfall and mean air temperature than multi-year mean, while the year 2004 was moist and cool. June and July was semi-dry, whereas August was warm and recorded high rainfall, which enhanced the yield accumulation.

Cereals constituted the potato forecrop. In autumn manure was applied at the dose of 25 t·ha^{-1}. All the mineral fertilizers were applied in spring before potato planting at the amount considering the soil resources and nutrient requirements of plants:

Nitrogen – 120 kg N·ha^{-1} in a form of ammonium nitrate (34%),
Phosphorus – 110 kg P_2O_5·ha^{-1} in a form of triple superphosphate (46%),
Potassium – 120 kg K_2O·ha^{-1} in a form of potassium sulphate (50%).

Agrotechnical practices were performed compliant with agrotechnical requirements for potato growing and plant protection from diseases and pests followed the requirements of optimal agrotechnical practices and the recommendations of the Institute of Plant Protection as well as control needs depending on the pattern of weather conditions. Mechanical weed control included harrowing and hilling.

About 14 days prior to potato harvest desiccation was performed by applying Reglone 200 SL at the amount of 4 dm^3·ha^{-1}.



Area defined by the rainfall curve below the temperature curve = dry period
Area defined by lowered rainfall curve below the temperature curve = semi-dry period

Fig. 4. Curves of air temperature and rainfall over the potato plant vegetation period according to Walter 1976

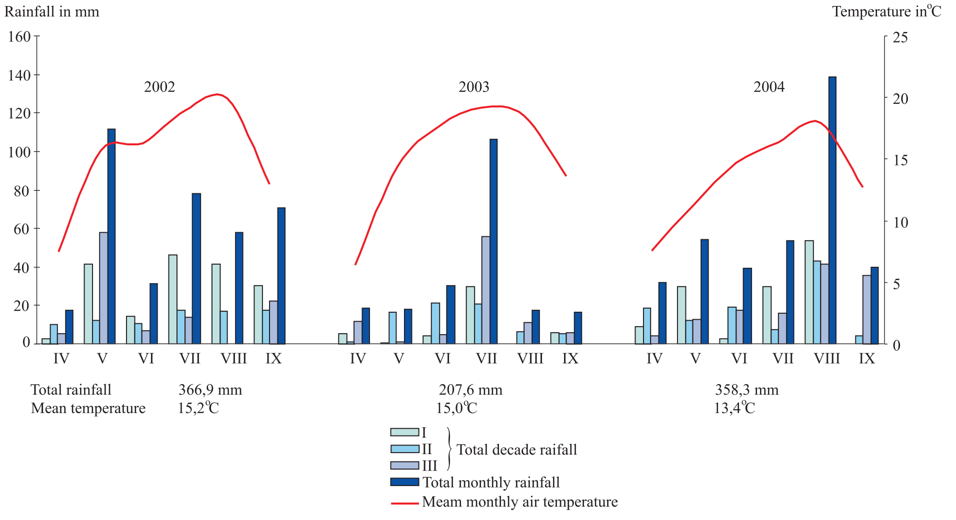


Fig. 5. Rainfall and air temperature distribution over the research years according to the Meteorological Station at Mochełek

3.3. MORE ESSENTIAL DEVELOPMENT STAGES OF POTATO PLANTS

The potato planting dates over the research years were as follows: 2002 – 24.04, 2003 – 25.04, 2004 – 22.04. The beginning of emergence was recorded after 28-31 days (Table 5), and depended on thermal and rainfall conditions. The most favorable conditions to plant emergence and growth were recorded in the year 2002 with high rainfall and a favorable air temperature distribution. Plant flowering over that period started earliest and lasted longest and tops wilting started later than in the other research years. The longest period from the end of flowering to the beginning of tops wilting was recorded in 2004 when at the end of the vegetation period high total rainfall was recorded. The shortest vegetation period of plants was noted in 2003, showing low total rainfall at the beginning and at the end of the vegetation period.

The length of respective development stages for the two cultivars differed. ‘Saturna’ showed a shorter vegetation period than ’Rywal’. The differences were on average 4 days.

Table 5. Pattern of development stages

Phenological periods	Research years	Number of days for cultivars	
		Rywal	Saturna
Planting – beginning of emergence	2002 2003 2004	28 30 31	29 31 33
Beginning of emergence – end of emergence	2002 2003 2004	13 15 14	15 16 15
End of emergence – beginning of flowering	2002 2003 2004	22 20 18	20 18 17
Beginning of flowering – end of flowering	2002 2003 2004	25 21 21	21 19 18
End of flowering – beginning of potato tops wilting	2002 2003 2004	21 20 25	20 20 23
Beginning of potato tops wilting – complete tops wilting, harvest	2002 2003 2004	26 25 23	24 23 22
Vegetation period length	2002 2003 2004	135 131 132	130 127 129

4. RESULTS

4.1. INTERACTION BETWEEN THE DEGREE OF WEED INFESTATION OF POTATO PLANTATION AND THE YIELD SIZE

4.1.1. Effect of herbicides on the weed infestation of potato plantation

4.1.1.1. Number and species composition of weeds prior to potato row closing

The number of weeds determined on the potato plantation prior to row closing differed significantly depending on the factors researched (Table 6). The number of weeds in the field was also affected by pluviometric conditions in respective research years. The herbicides used significantly limited the weed infestation as compared with the control objects (with mechanical weed control before and after potato emergence). 'Rywal' was significantly less weed-infested; the period from planting to the end of emergence was shorter than in 'Saturna'. The competitiveness towards weeds was also affected by the leaf-and-stem habit of the plant. There was demonstrated a significant effect of the interaction between both factors on the weed infestation in the years researched, which comes from the fact of a strict interaction between the herbicides and the environment as well as the individual reaction of cultivars to the agents. Weather conditions in the research years also affected the weed infestation prior to row closing. The year 2003 at the beginning of the vegetation period of the plants was dry and cold, which delayed emergence and growth of potato, and weeds developed quite strongly.

Table 6. Weed infestation of potato plantation prior to row closing (number of weeds per 1m^2) over 2002-2004

Herbicides used	Year			Cultivar		Mean
	2002	2003	2004	Rywal	Saturna	
Without herbicide (control)	19.2	27.5	23.7	13.3	33.3	23.3
Afalon 50 WP	3.7	5.2	5.2	1.7	7.3	4.5
Sencor 70 WG + adjuvant Olbras 88 EC	0.0	11.5	9.0	5.0	8.7	6.8
Apyros 75 WG + adjuvant Atpolan 80 EC	0.0	13.5	11.5	5.7	11.0	8.3
Azogard 50 WP	12.3	10.5	10.7	7.3	14.0	10.7
Mean	7.0	13.6	12.0	6.6	14.9	–
$LSD_{p = 0.05}$ between: herbicides used – 1.1; cultivars – 3.6; in the interaction: herbicides used × cultivars – 11.4						

In the total number of weeds which occurred in all the experimental plots before potato row closing, 91% were dicotyledonous taxa (Table 8), among which the following dominated: *Chenopodium album* L., *Galium aparine* L., *Polygonum convolvulus* L. The monocotyledonous flora was made up by: *Agropyron repens* L. and *Echinochloa crus galli* L. Of all the herbicides used, the most effective one in weed control was Afalon 50 WP, limiting the abundance of the community by 80.3%, especially dicotyledonous weed individuals.

4.1.1.2. Number and species composition of weeds prior to potato tuber harvest

The herbicides used and the cultivars had a significant effect on the number of weeds identified prior to potato harvest (Table 7). In all the variants with the use of herbicides the number of weeds was lower as compared with the control object. Azogard 50 WP was least effective in the control of weeds applied prior to potato plant emergence. Of all the cultivars researched, similarly as before row closing, 'Rywal' was least infested. The number of weeds was codependent on the herbicides used and rainfall and temperature distribution over the plant vegetation period. In 2003, when in the initial period weeds developed quite strongly, due to a lack of competition from the crop, at the end of the potato vegetation period their number decreased. Due to drought during the application of herbicides, the amount of the spray liquid was doubled, and quite a high temperature during the use of the agent, especially after potato emergence, facilitated the activity of the active substance of herbicides, increasing their effectiveness.

The species composition and the weed infestation structure on experimental plots prior to potato tuber harvest were similar to the one before row closing (Tables 8, 9). Dicotyledonous taxa accounting for 89% of the total number of weeds prevailed, of which *Viola arvensis* Murr., *Chenopodium album* L., *Polygonum convolvulus* L. dominated. Least effective in dicotyledonous weed control was Azogard 50 WP. Monocotyledonous species occurred in low numbers and were eliminated in over 50% by all the herbicides used.

Table 7. Weed infestation prior to potato tuber harvest (number of weeds per 1 m^2), 2002-2004 mean

Herbicides used	Year			Cultivar		Mean
	2002	2003	2004	Rywal	Saturna	
Without herbicide (control)	21.3	28.7	25.7	16.7	33.7	25.2
Afalon 50 WP	6.7	3.3	8.0	0.3	11.7	6.0
Sencor 70 WG + adjuvant Olbras 88 EC	10.3	1.7	8.0	3.3	10.0	6.7
Apyros 75 WG + adjuvant Atpolan 80 EC	12.0	3.8	8.3	4.7	11.3	8.0
Azogard 50 WP	20.3	10.7	10.7	8.7	19.0	13.8
Mean	14.1	9.4	12.1	6.7	17.1	–

$LSD_{p = 0.05}$ between: herbicides used – 1.3
cultivars – 3.2
in the interaction: herbicides used × cultivars – 10.2

Table 8. Species composition and the number of weeds per 1 m^2 prior to potato plant row closing, 2002-2004 mean

Weed species	Herbicides used					Mean
	Without herbicide (control)	Afalon 50 WP	Sencor 70 WG + adjuvant Olbras 88 EC	Apyros 75 WG + adjuvant Atpolan 80 EC	Azogard 50 WP	
I Monocotyledonous – in total	1.5	0.4	0.2	0.7	2.0	0.96
1. Quack grass *Agropyron repens* L.	1.2	0.2	0.2	0.2	1.5	0.66
2. Barnyard grass *Echinochloa crus galli* L.	0.3	0.2	0.0	0.5	0.5	0.30
II Dicotyledonous – in total	21.9	4.2	6.5	7.6	8.6	9.76
3. White goose-foot *Chenopodium album* L.	4.7	0.2	0.0	2.3	0.8	1.60
4. Field bedstraw *Galium aparine* L.	3.3	0.5	1.3	1.3	2.0	1.68
5. Black knotgrass *Polygonum convolvulus* L.	3.3	0.3	0.5	0.3	0.0	0.88
6. Field violet *Viola arvensis* Murr.	1.0	1.0	1.5	0.5	0.2	0.84
7. Purple deadnettle *Lamium purpureum*L.	1.7	0.5	0.2	1.0	0.8	0.84
8. Lady's purse *Capsella bursa-pastoris* L Med.	2.5	0.0	0.2	0.0	0.3	0.60
9. Field pennycress *Thlaspi arvense* L.	1.0	0.0	0.8	0.3	0.3	0.48
10. Common stork's bill *Erodium cicutarium* (L.) L.Herit.	0.3	0.2	0.3	0.3	1.3	0.48
11. Field mayweed *Anthemis arvensis* L.	1.2	0.2	0.3	0.0	0.7	0.48
12. Common wormwood *Artemisia vulgaris* L.	0.5	0.3	0.3	0.3	0.8	0.44
13. Smallflower galinsoga *Galinsoga parviflora* Cav.	0.2	0.7	0.2	0.2	0.2	0.30
14. Creeping crowfoot *Ranunculus regens* L.	0.3	0.3	0.2	0.2	0.2	0.24
15. Scentless mayweed *Multicaria indora* L.	0.5	0.0	0.2	0.0	0.3	0.20
16. Common dandelion *Teraxacum officinale Web.*	0.2	0.0	0.3	0.2	0.3	0.20
Other species 17-20	1.2	0.0	0.2	0.7	0.3	0.48
Total species number	23.4	4.6	6.7	8.3	10.6	–

Table 9. Species composition and the number of weeds per 1 m^2 prior to potato harvest, 2002-2004 mean

Weed species	Herbicides used					Mean
	Without herbicide (control)	Afalon 50 WP	Sencor 70 WG + adjuvant Olbras 88 EC	Apyros 75 WG + adjuvant Atpolan 80 EC	Azogard 50 WP	
I Monocotyledonous – in total	2.5	1.5	1.2	1.3	1.2	1.54
1. Quack grass *Agropyron repens* L.	0.8	0.7	0.5	0.0	0.0	0.4
2. Barnyard grass *Echinochloa crus galli* L.	1.7	0.8	0.7	1.3	1.2	1.14
II Dicotyledonous – in total	22.7	4.5	5.5	6.8	12.7	10.44
3. White goose foot *Chenopodium album* L.	4.2	0.7	0.8	2.3	1.5	1.90
4. Field bedstraw *Galium aparine* L.	1.8	0.0	0.2	0.5	1.3	0.76
5. Black knotgrass *Polygonum convolvulus* L.	3.2	0.8	0.8	0.8	0.7	1.26
6. Field violet *Viola arvensis* Murr.	5.0	1.2	0.8	1.0	4.5	2.50
7. Purple deadnettle *Lamium purpureum*L.	1.0	0.0	0.0	0.2	0.0	0.24
8.Lady's purse *Capsella bursa-pastoris* L Med.	0.8	0.0	0.2	0.0	0.2	0.24
9. Field pennycress *Thlaspi arvense* L.	1.2	0.0	0.0	0.0	0.0	0.24
10. Common stork's bill *Erodium cicutarium* (L.) L.Herit.	0.3	0.3	0.2	0.8	0.8	0.48
11. Field mayweed *Anthemis arvensis* L.	1.2	0.5	1.0	0.0	0.7	0.68
12. Common wormwood *Artemisia vulgaris* L.	0.5	0.2	0.0	0.3	0.0	0.20
13. Smallflower galinsoga *Galinsoga parviflora* Cav.	0.3	0.3	0.8	0.2	0.8	0.48
14. Creeping crowfoot *Ranunculus regens* L.	0.2	0.0	0.0	0.0	0.0	0.04
15. Scentless mayweed *Multicaria indora* L.	0.5	0.2	0.0	0.2	0.2	0.22
16. Common dandelion *Teraxacum officinale Web.*	1.0	0.0	0.2	0.0	0.5	0.34
Other species 17-20	1.5	0.3	0.5	0.5	1.5	0.86
Total number of species	25.2	6.0	6.7	8.1	13.9	–

4.1.2. Effect of weed control with the use of herbicides on the yield and structure of potato tubers

4.1.2.1. Total tuber yield

To characterize the material for research the yield size was defined depending on the weed control methods during the plant vegetation period. The herbicides used on the potato plantation, limiting the competitive effect of weeds, significantly increased the total tuber yield in all the research years (Table 10). This increase, as compared with the control object, with mechanical weed control only was on average from 5.3 to 8.1 t per ha (15.0-22.9%). The highest yield was obtained from plots with mechanical-and--chemical weed control with the use of herbicide Afalon 50 WP, which demonstrated the lowest weed infestation. The yield size was also conditioned by genetics of the cultivar. 'Rywal' yielded significantly higher (an average of 46.8 $t \cdot ha^{-1}$), by 12.2 t per ha (25.9%), as compared with 'Saturna'. Potato yielding also depended on the weather conditions over the research years. The lowest potato tuber yield was recorded in 2003 showing low total rainfall during the plant vegetation period (mean for objects 33.8 $t \cdot ha^{-1}$).

Table 10. Total yield of 'Rywal' and 'Saturna' potato tubers as affected by the herbicides used ($t \cdot ha^{-1}$)

Herbicides used (I)	Cultivars (II)	Research years			
		2002	2003	2004	Mean
Without herbicide (control)	Rywal Saturna	45.6 34.4	30.1 22.6	48.4 31.3	41.4 29.4
	Mean	40.0	26.4	39.9	35.4
Afalon 50 WP	Rywal Saturna	50.3 42.4	38.2 34.2	60.5 35.0	49.7 37.2
	Mean	46.4	36.2	47.8	43.5
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	46.9 36.3	38.9 30.6	57.4 33.8	47.7 33.6
	Mean	41.6	34.8	45.6	40.7
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	47.8 43.7	36.8 29.8	52.9 34.0	45.8 35.8
	Mean	45.8	33.3	43.5	40.8
Azogard 50 WP	Rywal Saturna	48.7 41.6	38.9 37.3	60.5 32.6	49.4 37.2
	Mean	45.2	38.1	46.6	43.3
Mean	Rywal Saturna	47.9 39.7	36.6 30.9	55.9 33.3	46.8 34.6
	Mean	43.8	33.8	44.7	40.7
$LSD_{p = 0.05}$	I II I × II	1.0 0.3 1.0	4.3 2.0 6.8	3.9 1.6 5.3	2.9 4.0 ns

ns – non-significant

4.1.2.2. Potato tuber yield structure

One of the characters conditioning the applicability of cultivars to different directions of use is the tuber size (Table 1). The share of the number of tubers in the fraction >55mm in the total yield was significantly differentiated by the herbicides used (Table 11). The greatest number of tubers over 55 mm in diameter was collected from the object least weed-infested after the use of Afalon 50 WP. 'Rywal' demonstrated significantly higher percentage share of tubers >55 mm, than 'Saturna'. It is noteworthy that the smallest tubers were obtained from the objects sprayed with herbicide Apyros 75 WG + adjuvant Atpolan 80 EC, where the weed infestation was significantly lower than on the control objects (without herbicide – Tables 6, 7). It can suggest a reaction of the plants to the herbicide used, which is significantly confirmed by the results of the interaction.

Table 11. Percentage* share of tubers of respective fractions in the total yield (2002-2004 mean)

Herbicides used (I)	Cultivars (II)	Tuber size		
		<40 mm	40-55 mm	>55 mm
Without herbicide (control)	Rywal Saturna	23.7 37.3	40.2 38.3	36.1 24.4
	Mean	30.5	39.2	30.3
Afalon 50 WP	Rywal Saturna	9.0 15.1	22.1 30.0	68.9 54.9
	Mean	12.1	26.0	61.9
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	19.4 32.2	26.8 23.2	53.8 44.5
	Mean	25.8	25.0	49.2
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	25.6 42.2	34.4 39.9	40.0 17.9
	Mean	33.9	37.1	29.0
Azogard 50 WP	Rywal Saturna	21.6 32.6	34.4 37.2	44.0 30.2
	Mean	27.1	35.8	37.1
Rywal Saturna		19.9 31.9	31.6 33.7	48.6 34.4
Mean		25.9	32.6	41.5
$LSD_{p=0.05}$	I II I × II	4.8 1.7 5.5	ns ns 18.7	9.7 5.5 18.1

Explanations: *100% = total number of tubers of all the fractions per sample

4.1.2.3. Dependence of yielding on weed infestation

The effect of the herbicides used on the number of weeds, yield and yield structure made it necessary to analyze the relationship between weed infestation and the yield of potato. To determine these relationships, coefficients of correlation and regression equations were calculated. The data obtained (Table 12) show a significant negative effect of an increase in weed infestation of the field on the tuber yield. An increase in weed infestation determined prior to row closing on the plots with 'Rywal' in 2003, 2004 by a single weed plant per 1 m^2 decreased the yield by about 0.5 t and over 0.6 t per ha, and an increase by the same value of the weed density throughout the vegetation period increased the yield loss up to over 0.5 t per ha in 2003 and almost 0.8 t per ha in the successive year. The coefficient of correlation between the degree of weed infestation and the yield collected from potato plantation with 'Saturna' was significant prior to row closing in 2002 (increase by a single plant in the weed density decreased the yield by almost 0.2 t per ha), while in 2003 there was a significant decrease in the tuber yield per ha together with an increase in weed infestation per 1 m^2, both prior to row closing and prior to harvest, respectively by almost 0.4 and over 0.4 t per ha.

Table 12. Dependence between the total tuber yield in t per ha on the number of weeds per 1 m^2

Research year	Rywal		Saturna	
	before row closing	prior to harvest	before row closing	prior to harvest
2002	R = -0.17 (ns) y = 48.144 – 0.082x	R = -0.382 (ns) y = 48.657 – 0.076x	R = -0.54* y = 41.433 – 0.174x	R = -0.29 (ns) y = 41.946 – 0.101x
2003	R = -0.69** y = 40.837 – 0.476x	R = -0.86** y = 39.217 – 0.519x	R = -0.69** y = 36.948 – 0.365x	R = -0.80** y = 35.791 – 0.437x
2004	R = -0.64** y = 60.079 – 0.641x	R = -0.80** y = 59.554 – 0.765x	R = -0.51 (ns) y = 35.672 – 0.136x	R = -0.44 (ns) y = 35.126 – 0.104x

Explanations:
* significant correlation at $\alpha = 0.05$
** significant correlation at $\alpha = 0.01$
ns – non-significant correlation
x – number of weeds per 1 m^2
y – tuber yield in $t \cdot ha^{-1}$

4.2. EFFECT OF HERBICIDES ON QUALITATIVE CHARACTERS OF THE POTATO TUBERS RESEARCHED AFTER HARVEST

4.2.1. Chemical composition of potato tubers

4.2.1.1. Content of dry matter

The analysis of variance showed a significant effect of the research factors on the content of dry matter in potato tubers (Table 13). The herbicides used significantly decreased the level of dry matter as compared with the control object; its lowest content was found for tubers harvested from the plots with the use of herbicide Afalon 50 WP. There were also significant differences across cultivars. 'Saturna' contained more dry matter than 'Rywal'. It was also observed that the level of dry matter in potato tubers depended on meteorological conditions over the vegetation period. The year 2003 recorded low rainfall, the tubers of the potato cultivars researched accumulated more dry matter than in the moist years of uneven rainfall distribution. In the same year, 2003, the cultivars did not differ significantly as far as that character was concerned.

Table 13. Content of dry matter in the fresh weight of tubers (%) of the potato cultivars researched depending on the herbicides used

Herbicides used (I)	Cultivar (II)	Research years			
		2002	2003	2004	Mean
Without herbicide (control)	Rywal Saturna	22.6 23.2	24.7 24.9	21.9 23.5	23.1 23.9
	Mean	22.9	24.8	22.7	23.5
Afalon 50 WP	Rywal Saturna	20.9 21.6	23.6 23.7	20.3 21.7	21.6 22.3
	Mean	21.3	23.7	21.0	22.0
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	22.3 22.6	24.5 24.1	21.8 23.2	22.9 23.3
	Mean	22.5	24.3	22.5	23.1
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	21.9 22.4	23.7 24.2	21.8 22.6	22.5 23.1
	Mean	22.2	24.0	22.2	22.8
Azogard 50 WP	Rywal Saturna	21.5 22.5	23.6 24.0	21.4 23.1	22.2 23.2
	Mean	22.0	23.8	22.3	22.7
Mean	Rywal Saturna	21.8 22.5	24.0 24.2	21.4 22.8	22.4 23.2
	Mean	22.2	24.1	22.1	22.8
$LSD_{p = 0.05}$	I II I × II	0.6 0.2 ns	0.5 ns 0.6	0.4 0.2 0.6	0.4 0.3 ns

4.2.1.2. Starch content

The content of starch, similarly as the content of dry matter, in the tubers of the cultivars researched depended significantly on the herbicides used during the vegetation period, which decreased it, mostly in tubers from the object with the use of Afalon 50 WP (Table 14). ‘Saturna’ accumulated more starch than ‘Rywal’. The most favorable year for the accumulation of that compound in tubers was the dry year of 2003 in which there were found no significant differences across cultivars. However, there were shown significant interactions between the research factors, which suggests a different reaction of cultivars to the herbicides used.

Table 14. Content of starch in the fresh weight of tubers (%) of the potato cultivars researched depending on the herbicides used

Herbicides used (I)	Cultivar (II)	Research year			
		2002	2003	2004	Mean
Without herbicide (control)	Rywal Saturna	16.1 16.7	18.2 18.4	15.4 17.0	16.6 17.3
	Mean	16.4	18.3	16.2	17.0
Afalon 50 WP	Rywal Saturna	14.2 15.1	17.1 17.2	13.8 15.2	15.0 15.8
	Mean	14.7	17.1	14.5	15.4
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	15.8 16.2	18.0 17.6	15.3 16.7	16.4 16.8
	Mean	16.0	17.8	16.0	16.6
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	15.4 16.0	17.2 17.7	15.3 16.1	16.0 16.6
	Mean	15.7	17.4	15.7	16.3
Azogard 50 WP	Rywal Saturna	15.0 16.0	17.1 17.5	14.9 16.6	15.7 16.7
	Mean	15.5	17.3	15.8	16.2
Mean	Rywal Saturna	15.3 16.0	17.5 17.7	14.9 16.3	15.9 16.7
	Mean	15.6	17.6	15.6	16.3
$LSD_{p = 0.05}$	I II I × II	0.6 0.2 ns	0.5 ns 0.5	0.4 0.2 0.6	0.4 0.3 0.9

4.2.1.3. Content of total protein

Based on the results given in Table 15, one can state that the content of total protein in tubers depended significantly on the weed control methods and the cultivars. The tubers collected from the objects sprayed with herbicides contained significantly more total protein than from the objects with the use of mechanical weed control only. ‘Saturna’ showed a higher content of that compound than ‘Rywal’. Similarly the research years differentiated the content of protein in tubers. In the dry year 2003 the accumulation of total protein was higher than in the other seasons.

Table 15. Content of total protein in the fresh weight of tubers (%) of the potato cultivars researched depending on the herbicides used

Herbicides used (I)	Cultivar (II)	Research year			
		2002	2003	2004	Mean
Without herbicide (control)	Rywal Saturna	1.90 2.50	2.69 3.02	1.74 2.24	2.11 2.59
	Mean	2.20	2.86	1.99	2.35
Afalon 50 WP	Rywal Saturna	2.02 2.62	2.74 3.10	1.86 2.31	2.21 2.68
	Mean	2.32	2.92	2.08	2.44
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	2.02 2.60	2.76 3.10	1.88 2.33	2.22 2.68
	Mean	2.31	2.93	2.11	2.45
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	2.02 2.60	2.74 3.07	1.83 2.29	2.20 2.65
	Mean	2.31	2.90	2.06	2.42
Azogard 50 WP	Rywal Saturna	2.02 2.64	2.74 3.10	1.83 2.29	2.20 2.68
	Mean	2.33	2.92	2.06	2.44
Mean	Rywal Saturna	2.00 2.60	2.74 3.07	1.83 2.29	2.19 2.65
	Mean	2.30	2.90	2.06	2.42
$LSD_{p = 0.05}$	I II I × II	0.05 0.02 ns	0.05 0.02 ns	0.07 0.02 ns	0.05 0.02 ns

4.2.1.4. Content of total and reducing sugars

The analysis of variance of the results of the content of reducing sugars (glucose + fructose) and total sugars (reducing sugars + saccharose) confirmed a significant effect of the research factors (Tables 16, 17).

Table 16. Content of reducing sugars in the fresh weight of tubers (%) of the potato cultivars researched depending on the herbicides used

Herbicides used (I)	Cultivar (II)	Research year			
		2002	2003	2004	Mean
Without herbicide (control)	Rywal Saturna	0.10 0.07	0.12 0.02	0.20 0.03	0.14 0.04
	Mean	0.09	0.07	0.11	0.09
Afalon 50 WP	Rywal Saturna	0.14 0.06	0.15 0.01	0.20 0.03	0.16 0.04
	Mean	0.10	0.08	0.12	0.10
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	0.15 0.09	0.11 0.01	0.26 0.04	0.18 0.05
	Mean	0.12	0.06	0.15	0.11
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	0.13 0.06	0.12 0.02	0.22 0.03	0.16 0.04
	Mean	0.09	0.07	0.13	0.10
Azogard 50 WP	Rywal Saturna	0.15 0.06	0.11 0.02	0.21 0.03	0.16 0.04
	Mean	0.11	0.06	0.12	0.10
Mean	Rywal Saturna	0.14 0.07	0.12 0.02	0.22 0.03	0.16 0.04
	Mean	0.10	0.07	0.13	0.10
$LSD_{p = 0.05}$	I II I × II	0.02 0.01 ns	0.01 0.04 0.01	0.03 0.01 0.03	ns 0.02 ns

The herbicides used during the vegetation period modified the content of total sugars, increasing their content. The compound which differentiated the level of total sugars in tubers from the plots sprayed with herbicides was saccharose because the level of reducing sugars did not differ significantly as a result of the factor researched. ‘Rywal’ accumulated more total and reducing sugars than ‘Saturna’. Besides, the multi--year results synthesis made demonstrated the effect of the interaction between the weed control methods and the cultivars, as a result of an individual reaction of cultivars to weed-killing agents, on the accumulation of saccharose. Weather factors also differentiated the level of sugars in potato tubers. The highest amount of reducing sugars and the lowest amount of saccharose were recorded in the more moist year, with uneven rainfall distribution (2004).

Table 17. Content of total sugars in the fresh weight of tubers (%) of the potato cultivars researched depending on the herbicides used

Herbicides used (I)	Cultivar (II)	Research year			
		2002	2003	2004	Mean
Without herbicide (control)	Rywal Saturna	0.35 0.23	0.32 0.20	0.29 0.13	0.32 0.19
	Mean	0.29	0.26	0.21	0.25
Afalon 50 WP	Rywal Saturna	0.38 0.27	0.35 0.23	0.34 0.15	0.36 0.21
	Mean	0.32	0.29	0.24	0.29
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	0.37 0.21	0.35 0.24	0.35 0.14	0.36 0.19
	Mean	0.29	0.29	0.25	0.28
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	0.38 0.25	0.36 0.21	0.36 0.15	0.37 0.20
	Mean	0.32	0.28	0.25	0.28
Azogard 50 WP	Rywal Saturna	0.40 0.25	0.36 0.21	0.37 0.14	0.38 0.20
	Mean	0.33	0.28	0.26	0.29
Mean	Rywal Saturna	0.38 0.24	0.35 0.22	0.34 0.14	0.36 0.20
	Mean	0.31	0.28	0.24	0.28
$LSD_{p = 0.05}$	I II I × II	0.03 0.01 ns	0.03 0.01 ns	0.02 0.01 ns	0.02 0.02 0.05

4.2.1.5. Content of vitamin C and chlorogenic acid

The herbicides used in potato weed control significantly increased the content of vitamin C and chlorogenic acid in tubers (Tables 18, 19). The highest positive effect on the content of vitamin C in tubers was found for weed-killing agent Azogard 50 WP where, as compared with the control, the increase was 8.8%. The herbicides used during the plant vegetation period also increased the content of unwanted chlorogenic acid in tubers, Afalon 50 WP most considerably, by 20.5%, as compared with the level of that compound in tubers from the control object.

Table 18. Content of vitamin C in the fresh weight of tubers (mg· kg^{-1}) of the potato cultivars researched depending on the herbicides used

Herbicides used (I)	Cultivar (II)	Research year			
		2002	2003	2004	Mean
Without herbicide (control)	Rywal Saturna	200.7 202.7	220.7 231.3	209.4 211.9	210.3 215.3
	Mean	201.7	226.0	210.7	212.8
Afalon 50 WP	Rywal Saturna	205.9 218.3	231.3 251.0	219.0 224.2	218.7 231.2
	Mean	212.1	241.2	221.6	225.0
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	199.7 210.0	225.0 238.3	218.4 218.7	214.4 222.3
	Mean	204.9	231.7	218.6	218.4
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	208.0 214.7	235.0 257.7	218.7 219.7	220.6 230.7
	Mean	211.4	246.4	219.2	225.6
Azogard 50 WP	Rywal Saturna	211.7 215.3	239.3 266.7	226.3 229.7	225.8 237.2
	Mean	213.5	253.0	228.0	231.5
Mean	Rywal Saturna	205.2 212.2	230.3 249.0	218.4 220.8	217.9 227.4
	Mean	208.7	239.6	219.6	222.6
$LSD_{p = 0.05}$	I II I × II	3.4 2.8 ns	3.2 1.8 6.0	2.4 1.7 ns	2.6 4.2 13.4

The cultivars grown differed significantly in their content of vitamin C, and chlorogenic acid. ‘Saturna’ demonstrated a higher content of the compounds discussed in tubers than ‘Rywal’. The interactions of the weed control methods with cultivars regarding the effect on the content of vitamin C and chlorogenic acid show a different susceptibility of the cultivars to the herbicides used during the vegetation period. Similarly the accumulation of the compounds researched was also affected by meteorological conditions in respective research years. In the dry year of 2003 potato tubers contained most vitamin C and the lowest content of chlorogenic acid as compared with the tubers analyzed in the other research years.

Table 19. Content of chlorogenic acid in the fresh weight of tubers ($mg \cdot kg^{-1}$) of the potato cultivars researched depending on the herbicides used

Herbicides used (I)	Cultivar (II)	Research year			
		2002	2003	2004	Mean
Without herbicide (control)	Rywal Saturna	167.0 262.0	136.3 215.0	164.7 222.7	156.0 233.2
	Mean	214.5	175.7	193.7	194.6
Afalon 50 WP	Rywal Saturna	249.7 294.3	157.0 236.3	214.3 254.7	207.0 261.8
	Mean	272.0	196.7	234.5	234.4
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	233.3 267.3	140.7 224.0	185.7 238.7	186.6 243.3
	Mean	250.3	182.3	212.2	214.9
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	233.7 273.3	143.7 224.7	187.7 234.7	188.3 244.2
	Mean	253.5	184.2	211.2	216.3
Azogard 50 WP	Rywal Saturna	189.0 265.0	139.0 221.3	179.3 229.3	169.1 238.6
	Mean	227.0	180.2	204.3	203.8
Mean	Rywal Saturna	214.5 272.4	143.3 224.3	186.3 236.0	181.4 244.2
	Mean	243.5	183.8	211.2	212.8
$LSD_{p = 0.05}$	I II I × II	4.8 1.6 5.4	4.1 1.4 ns	3.5 1.6 5.3	3.5 13.6 4.7

4.2.2. Effect of herbicides on the consumption value of potato tubers

4.2.2.1. Tastefulness

The tastefulness, which is a group of flavor and aroma sensations of cooked potato tubers, depends on the content of many components (e.g. organic acids, sugars, solanine, volatile compounds) and their quantitative ratios changing during culinary treatment. The herbicides used on the potato plantation slightly deteriorated the flavor and aroma qualities of tubers, especially post-emergence agents (Sencor 70 WG, Apyros 75 WG). Tubers of both cultivars showed a similar tastefulness (Table 20).

Table 20. Organoleptic evaluation of cooked potato tubers after harvest (2002-2004 mean)

Herbicides used	Cultivar	Tastefulness[1]	Tuber flesh color[2]	Culinary and functional type[3]	Flesh blackening[4]	
					After 10 min.	After 24 hours
Without herbicide (control)	Rywal	6.8	4.8	2.0	9.0	8.7
	Saturna	6.9	4.4	2.2	8.7	8.4
	Mean	6.9	4.6	2.1	8.9	8.6
Afalon 50 WP	Rywal	6.1	4.4	1.8	9.0	8.1
	Saturna	6.4	4.1	1.7	8.5	7.7
	Mean	6.3	4.3	1.8	8.3	7.9
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal	6.0	4.6	1.9	9.0	8.6
	Saturna	6.3	4.2	1.9	8.6	8.3
	Mean	6.2	4.4	1.9	8.8	8.5
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal	6.0	4.7	2.2	8.5	7.7
	Saturna	6.3	4.4	2.0	8.0	7.7
	Mean	6.2	4.6	2.1	8.3	7.7
Azogard 50 WP	Rywal	6.6	4.7	2.3	9.0	8.6
	Saturna	6.6	4.5	2.1	8.6	8.5
	Mean	6.6	4.6	2.2	8.8	8.6
Mean	Rywal	6.3	4.6	2.0	8.9	8.3
	Saturna	6.5	4.3	2.0	8.6	8.1
Mean		6.4	4.5	2.0	8.7	8.2

1 grade scale: 9 – very good, 1 – very bad
2 grade scale: 1 – white flesh, 2 – white with shade of grey, 3 – cream, 4 – light yellow, 5 – yellow, 6 – dark yellow
3 grade scale: 1 – salad type (A), 2 – general functional type (B), 3 – floury type (C), 4 – very floury type (D)
4 grade scale: 9 – non-blackening flesh, 1 – black flesh

4.2.2.2. Tuber flesh color

The results given in Table 20 show a high stability of the cooked tuber flesh color of the cultivars researched collected from the objects sprayed with herbicides as compared with those from the control. The flesh color is a cultivar-specific property. The cultivars selected for the research differed slightly as far as that character was concerned. 'Rywal' tuber flesh was more yellow than that of 'Saturna'.

4.2.2.3. Culinary and functional type

Qualifying the potato tubers researched to a given functional and consumption type was based on the properties of cooked tubers, including: the degree of overcooking, density (compactness), floury character, flesh structure (granulation), moisture. According to the data given in Table 20, the herbicides used did not affect a change in the functional and consumption type of potato tubers. The cultivars researched did not differ from each other in their characters qualifying them to a given type, either. Both cultivars demonstrated quite a compact density, were slightly floury, moist, of delicate structure, which qualifies them as type B, even though 'Saturna', according to the qualification assumed by the Potato Institute, was considered as representing culinary intermediate – versatile functional to floury (BC).

4.2.2.4. Flesh blackening of raw and cooked tubers

Table 21. Enzymatic blackening of tubers of the potato cultivars researched depending on the herbicides [AU $_{475\ nm}$] used – for explanations, see Table 3

Herbicides used (I)	Cultivar (II)	Research year			
		2002	2003	2004	Mean
Without herbicide (control)	Rywal Saturna	0.23 0.51	0.18 0.32	0.24 0.34	0.22 0.39
	Mean	0.37	0.25	0.29	0.31
Afalon 50 WP	Rywal Saturna	0.37 0.59	0.22 0.36	0.31 0.45	0.30 0.47
	Mean	0.48	0.29	0.38	0.38
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	0.34 0.54	0.19 0.34	0.27 0.38	0.26 0.42
	Mean	0.44	0.26	0.32	0.34
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	0.34 0.57	0.19 0.34	0.28 0.36	0.27 0.42
	Mean	0.46	0.27	0.32	0.35
Azogard 50 WP	Rywal Saturna	0.29 0.52	0.18 0.33	0.26 0.35	0.24 0.40
	Mean	0.40	0.26	0.31	0.32
Mean	Rywal Saturna	0.31 0.55	0.19 0.34	0.27 0.38	0.26 0.42
	Mean	0.43	0.27	0.33	0.34
$NIR_{p = 0.05}$	I II I × II	0.03 0.02 ns	0.03 0.01 ns	0.02 0.02 ns	0.02 0.02 ns

Blackening of raw flesh (Table 21) evaluated with instrumental methods was significantly dependent on the herbicides researched and the cultivar. The weed-killing agents used during the plant vegetation period increased the tendency to enzymatic blackening, especially significantly – Afalon 50 WP, Sencor 70 WG, Apyros 75 WG. The differences, despite being significant, were inconsiderable, qualifying potato tubers as moderately resistant to blackening (according to Table 3). The cultivars researched also differed significantly from each other; 'Rywal' was blackening less considerably than 'Saturna' which was moderately susceptible to blackening.

Cooked tubers of 'Saturna' from the plots sprayed with herbicides, evaluated both after 10 minutes, as well as after 24 hours, blackened more than those which were collected from the control plots, from 0.1 to 0.8 degree using the 9-degree scale (Table 21). There were also observed slight, from 0.2 to 0.3, differences in cooked tuber blackening of both cultivars. Tendencies to flesh blackening after cooking were greater in 'Saturna'.

4.2.3. Effect of herbicides on the enriched products quality

4.2.3.1. Quality of french fries

Table 22. Score of the quality of french fries obtained from tubers of the potato cultivars researched after harvest depending on the herbicides used

Herbicides used	Cultivar	Research year			
		2002	2003	2004	Mean
Without herbicide (control)	Rywal Saturna	3.8 3.9	3.4 3.5	3.6 3.8	3.6 3.7
	Mean	3.9	3.5	3.7	3.7
Afalon 50 WP	Rywal Saturna	4.1 4.2	3.5 3.6	3.7 4.3	3.8 4.0
	Mean	4.2	3.6	4.0	3.9
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	3.7 3.8	3.4 3.5	3.4 4.1	3.5 3.7
	Mean	3.8	3.5	3.7	3.6
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	3.9 4.0	3.5 3.6	3.6 3.9	3.7 3.7
	Mean	4.0	3.6	3.8	3.7
Azogard 50 WP	Rywal Saturna	3.9 3.9	3.5 3.6	3.6 3.9	3.7 3.7
	Mean	3.9	3.6	3.8	3.7
Mean	Rywal Saturna	3.9 3.9	3.5 3.6	3.6 4.0	3.6 3.8
	Mean	3.9	3.6	3.8	3.7

5-degree scale: 5 – very good, 1 – unsatisfactory

The quality of french fries includes such characters as: color, density, flavor and aroma. The score of the quality of french fries obtained from tubers from the plots with chemical weed control and without the use of herbicides was comparable (Table 22). The tubers of the cultivars researched did not differ considerably in the quality of the enriched products obtained from them – french fries, either (the differences were on average 0.2 degree using the 5-degree scale). As for mean for objects for two cultivars, there was obtained quite a good score which, using the scale assumed, was on average 3.7. The best french fries were obtained from tubers grown in the moist year of 2002.

4.2.3.2. Chips quality

Table 23. Degree of the quality of chips obtained from tubers of the potato cultivars researched after harvest depending on the herbicides used

Herbicides used	Cultivar	Research year							
		2002		2003		2004		Mean	
		1*	2*	1*	2*	1*	2*	1*	2*
Without herbicide (control)	Rywal Saturna	8.3 8.7	4.4 4.5	8.2 8.8	4.5 4.6	7.2 8.7	3.8 4.3	7.9 8.7	4.2 4.4
	Mean	8.5	4.5	8.5	4.6	8.0	4.1	8.3	4.4
Afalon 50 WP	Rywal Saturna	7.5 8.7	4.0 4.4	7.3 8.7	4.3 4.5	6.8 8.5	3.6 3.9	7.2 8.6	4.0 4.3
	Mean	8.1	4.2	8.0	4.4	7.7	3.8	7.9	4.1
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	7.2 8.3	4.3 4.4	8.0 8.7	4.5 4.5	5.8 8.6	3.7 4.1	7.0 8.6	4.2 4.3
	Mean	7.8	4.4	8.4	4.5	7.3	3.9	7.8	4.3
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	7.7 8.5	3.8 4.0	8.3 8.5	4.3 4.4	7.0 8.6	3.6 4.0	7.7 8.5	3.9 4.1
	Mean	8.1	3.9	8.4	4.4	7.9	3.8	8.2	4.0
Azogard 50 WP	Rywal Saturna	7.0 8.5	3.9 4.3	8.2 8.5	4.3 4.4	6.8 8.5	3.6 4.0	7.3 8.5	3.9 4.1
	Mean	7.8	4.1	8.4	4.4	7.7	3.8	7.9	4.1
Mean	Rywal Saturna	7.5 8.5	4.1 4.3	8.0 8.7	4.4 4.5	6.7 8.6	3.7 4.0	7.4 8.6	4.1 4.3
	Mean	8.0	4.2	8.4	4.4	7.7	3.8	8.0	4.2

1* color according to 9-degree scale – Fig. 2 (9 – evenly light, 4-1 – disqualifying score)
2* chips quality according to the 5-degree scale (5 – very good, 1 – unsatisfactory)

The chips quality is determined mostly by the color but also aroma and density, therefore the results of the color evaluation performed according to color tables approved by E.A.P.R. are presented separately. Based on all the characters presented, an evaluation was made using a 5-degree scale. The herbicides used had a negative effect on potato tubers from which chips were produced (Table 23). The color of chips got deteriorated as well as the other parameters affecting their general evaluation. The color of chips obtained from 'Saturna' tubers was evenly light and the total score was higher than in the case of chips produced from 'Rywal' tubers. The highest chips quality, evenly light in color, was obtained from the tubers grown in the dry year of 2003.

4.3. EFFECT OF THE STORAGE TIME ON THE QUALITATIVE CHANGES OF TUBERS CONDITIONING THEIR FUNCTIONAL VALUE

4.3.1. Fresh weight losses of potato tubers

Table 24 presents fresh weight losses of tubers (natural losses) which occur during storage and resulting from processes of transpiration and respiration as well as sprouting. After 3 months of tuber storage the differences in the size of fresh weight losses depended mostly on the storage temperature. Mean for the objects and years, the losses of fresh weight of tubers stored at the temperature of +8°C accounted for 2% and in the chambers with the temperature of +4°C – 1.1%. The size of losses also differed depending on the storage time and on the degree of the storage life of the cultivars. The highest losses (mean from objects of 8.9%) were noted after 6 months of storage for ‘Rywal’ stored in the chambers with the temperature of +8°C (Table 24). After 6 months of storage, there were observed tendencies to lower losses of fresh weight of tubers from the plots sprayed with herbicides, of a lower degree of weed infestation (Tables 6, 7). Potato tubers collected from weed-infested plots are more susceptible to mechanical damage which can increase the intensity of life processes which occur during storage, and thus increase natural losses.

In respective research years, the size of fresh weight losses also differed. The year 2004 was a cold and quite moist year, at the end of potato vegetation period rainfall was inconsiderable, and during storage it was warm and sunny, which enhanced tuber ripening, decreasing the susceptibility to mechanical damage, which resulted in the lowest losses of fresh weight of tubers during storage in the storage period of 2004/2005.

Natural losses are also affected by sprouting. The most intensive growth of sprouts in both cultivars was recorded after 6 months of storage at the temperature of +8°C, especially in potato tubers for which the vegetation period coincided with warm and dry year of 2003.

Table 24. Losses of fresh weight of tubers of the cultivars researched after storage depending on the herbicides used during the vegetation period (% of storage sample weight losses)

Herbicides used	Cultivar	Storage season												Mean			
		2002/2003				2003/2004				2004/2005							
		1*	2*	3*	4*	1*	2*	3*	4*	1*	2*	3*	4*	1*	2*	3*	4*
Without herbicide	Rywal	1.9	0.6	9.8	8.3	3.5	1.7	11.2	8.1	1.3	0.8	8.4	4.1	2.2	1.0	9.8	6.8
	Saturna	2.3	1.2	6.3	2.4	2.0	1.2	8.1	4.0	2.2	1.3	4.4	3.4	2.2	1.2	6.3	3.3
	Mean	2.1	0.9	8.1	5.3	2.8	1.4	9.6	6.1	1.8	1.1	6.4	3.7	2.2	1.1	8.0	5.0
Afalon 50 WP	Rywal	2.7	1.3	9.0	7.8	1.8	1.7	10.4	8.0	2.0	1.0	7.6	4.3	2.2	1.3	9.0	6.7
	Saturna	2.0	1.4	5.7	2.8	1.9	1.6	7.7	3.9	0.9	0.7	3.2	1.5	1.6	1.2	5.5	2.8
	Mean	2.3	1.3	7.4	5.3	1.8	1.7	9.0	6.0	1.5	0.8	5.4	2.9	1.9	1.3	7.3	4.7
Sencor 70 WG	Rywal	2.0	1.3	8.9	4.6	1.8	1.0	8.9	6.1	0.9	0.6	7.9	2.9	1.5	1.0	8.6	4.6
	Saturna	1.9	0.7	3.3	1.7	1.1	1.2	6.5	2.6	1.5	0.7	3.4	1.4	1.5	0.9	4.4	1.9
	Mean	1.9	1.0	6.1	3.2	1.5	1.1	7.7	4.4	1.2	0.7	5.7	2.2	1.5	0.9	6.5	3.2
Apyros 75 WG	Rywal	1.7	1.0	9.1	3.3	2.4	1.2	9.6	5.5	2.5	1.4	7.5	3.5	2.2	1.2	8.7	4.1
	Saturna	3.6	0.9	7.0	3.0	1.3	0.9	5.9	2.8	1.0	0.6	3.5	1.8	1.9	0.8	5.5	2.5
	Mean	2.6	1.0	8.1	3.2	1.9	1.0	7.8	4.1	1.7	1.0	5.5	2.7	2.1	1.0	7.1	3.3
Azogard 50 WP	Rywal	1.9	0.9	9.1	5.3	2.0	1.6	8.8	5.8	1.8	0.7	7.8	4.1	1.9	1.1	8.6	5.1
	Saturna	4.3	1.4	7.8	3.4	2.7	1.6	8.1	4.7	2.0	0.8	4.8	2.4	3.0	1.2	6.9	3.5
	Mean	3.1	1.1	8.5	4.4	2.3	1.6	8.5	5.2	1.9	0.7	6.3	3.3	2.5	1.2	7.7	4.3
Mean	Rywal	2.0	1.0	9.2	5.9	2.3	1.4	9.8	6.7	1.7	0.9	7.8	3.8	2.0	1.1	8.9	5.5
	Saturna	2.8	1.1	6.0	2.7	1.8	1.3	7.3	3.6	1.5	0.8	3.9	2.1	2.0	1.1	5.7	2.8
	Mean	2.4	1.1	7.6	4.3	2.0	1.4	8.5	5.1	1.6	0.9	5.9	2.9	2.0	1.1	7.3	4.1

1* after 3 months of storage in chambers with the temperature of +8°C
2* after 3 months of storage in chambers with the temperature of +4°C
3* after 6 months of storage in chambers with the temperature of +8°C
4* after 6 months of storage in chambers with the temperature of +4°C

4.3.2. Chemical composition of potato tubers after storage

4.3.2.1. Content of dry matter and starch

The content of dry matter and starch in tubers stored at the temperature of +8°C depended on the cultivar and the storage time (Tables 25, 26). The content of dry matter in tubers was also a result of the interaction between the herbicides used during the vegetation period and the storage time (Table 25). ‘Saturna’ showed significantly higher content of dry matter and starch after storage, similarly as after harvest, than ‘Rywal’. The longer the storage, the significantly lower the content of dry matter and starch in tubers of the cultivars researched.

The research factors considered in the storage experiment had a significant effect on the content of dry matter and starch in tubers stored at the temperature of +4°C (Table 25). Contents of these compounds in tubers after 3 and 6 months of storage significantly decreased with the date of determination and depended on the herbicides used over the vegetation period as well as the cultivar, similarly as after harvest (Tables 12, 13).

During storage the main factors resulting in changes in the content of dry matter and starch are the processes which occur in tubers, including transpiration and respiration, as well as sprouting. A higher storage temperature (+8°C) resulted in dry matter losses in tubers, average for objects, 1.8% and starch 2.5% after 3 months and almost 4% of dry matter and 5.5% of starch after 6 months. Changes in the content of dry matter and starch in tubers stored at the temperature of +4°C were inconsiderable and accounted for 0.9% (dry matter losses), 1.2% (starch losses) after 3 months and respectively, 2.2% and 3.1% after 6 months. A comparison of the pattern of changes in the content of these components in tubers (Figs 6, 7) during storage suggests that the direction of these changes is similar in all the objects, with an exception of a higher decrease in dry matter and starch after 6 months of storage at the temperature of +8°C in ‘Rywal’ tubers from the control object where the weed infestation of the field was highest (Tables 6, 7). Besides ‘Rywal’ tubers were more susceptible to mechanical damage during harvest due to a greater size of tubers than ‘Saturna’ tubers (a considerable part – almost 50% were tubers >55mm in size, Table 11), which resulted in higher losses of fresh weight during storage (Table 25). Having considered natural losses, dry matter and starch losses were also higher in ‘Rywal’ than in ‘Saturna’.

Table 25. Content of dry matter in the fresh weight of tubers (%) of the potato cultivars researched depending on the herbicides used and the storage time at the temperature of +8ºC and +4ºC

Cultivar	Herbicides used	After harvest	Storage time					
			at the temperature of +8ºC			at the temperature of +4ºC		
			3 months	6 months	mean (3,4,5)	3 months	6 months	mean (3,7,8)
1	2	3	4	5	6	7	8	9
Rywal	H-0	23.1	22.7	21.8	22.5	22.8	22.4	22.8
	H-1	21.6	21.2	20.7	21.2	21.3	21.1	21.4
	H-2	22.9	22.6	22.2	22.5	22.7	22.5	22.7
	H-3	22.5	22.0	21.8	22.1	22.3	22.1	22.3
	H-4	22.2	21.8	21.4	21.8	22.0	21.6	21.9
Mean		22,4	22.1	21.6	22.0	22.2	21.9	22.2
Saturna	H-0	23.8	23.4	22.9	23.4	23.6	23.4	23.6
	H-1	22.3	22.0	21.6	22.0	22.1	21.9	22.1
	H-2	23.3	23.0	22.5	22.9	23.1	22.9	23.1
	H-3	23.0	22.7	22.2	22.6	22.9	22.6	22.8
	H-4	23.2	22.7	22.2	22.7	23.0	22.6	23.0
Mean		23,2	22.8	22.7	22.7	22.9	22.7	22.9
Mean for cultivars	H-0	23.5	23.1	22.3	22.9	23.2	22.9	23.2
	H-1	22.0	21.6	21.1	21.6	21.7	21.5	21.7
	H-2	23.1	22.8	22.3	22.7	22.9	22.7	22.9
	H-3	22.8	22.3	22.0	22.3	22.6	22.4	22.5
	H-4	22.7	22.3	21.8	22.2	22.5	22.1	22.4
Mean		22.8	22.4	21.9	22.4	22.6	22.3	22.6

$LSD_{p = 0.05}$ for the storage temperature:	+8ºC	+4ºC
Cultivars	0.3	0.6
Herbicides used	ns	0.4
Storage time	0.3	0.1
Herbicides used × cultivars	ns	ns
Cultivars × herbicides used	ns	ns
Storage time × cultivars	ns	ns
Cultivars × storage time	ns	ns
Storage time × herbicides used	0.1	ns
Herbicides used × storage time	0.2	ns
Cultivars × herbicides used × storage time	ns	ns

H-0 – plots without the use of herbicide
H-1 – herbicide Afalon 50 WP used
H-2 – herbicide, Sencor 70 WG used
H-3 – herbicide Apyros 75 WG used
H-4 – herbicide Azogard 50 WP used

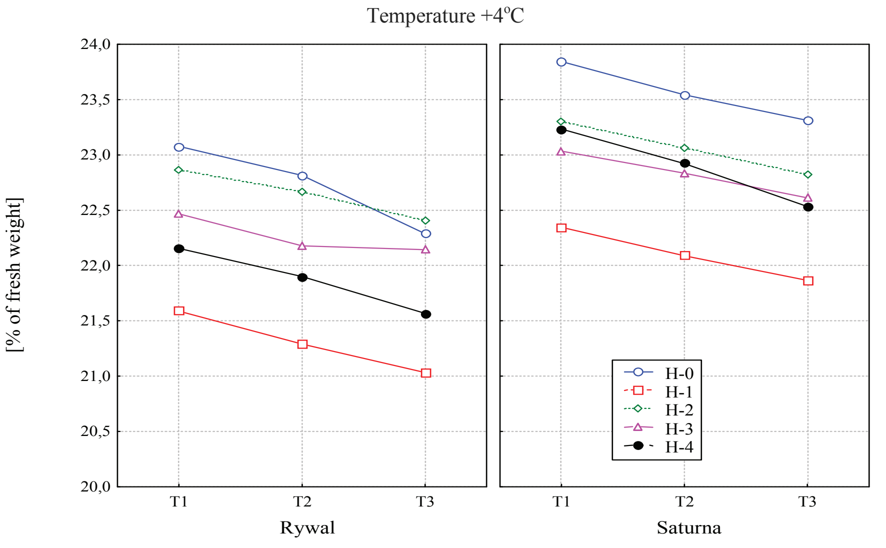
Table 26. Content of starch in the fresh weight of tubers (%) of the potato cultivars researched depending on the herbicides used and the storage time at the temperature of +8ºC and +4ºC

Cultivar	Herbicides used	After harvest	Storage time					
			at the temperature of +8ºC			at the temperature of +4ºC		
			3 months	6 months	mean (3,4,5)	3 months	6 months	mean (3,7,8)
1	2	3	4	5	6	7	8	9
Rywal	H-0	16.6	16.1	15.3	16.0	16.3	15.9	16.3
	H-1	15.0	14.7	14.2	14.7	14.8	14.6	14.8
	H-2	16.4	16.1	15.7	16.0	16.2	16.0	16.2
	H-3	16.0	15.6	15.3	15.6	15.8	15.6	15.8
	H-4	15.7	15.3	14.9	15.3	15.5	15.1	15.4
Mean		15,9	15.6	15.1	15.5	15.7	15.4	15.7
Saturna	H-0	17.3	16.9	16.4	16.9	17.1	16.9	17.1
	H-1	15.8	15.5	15.1	15.5	15.6	15.4	15.6
	H-2	16.8	16.5	16.0	16.5	16.7	16.4	16.6
	H-3	16.6	16.2	15.7	16.2	16.4	16.1	16.4
	H-4	16.7	16.2	15.7	16.2	16.5	16.1	16.5
Mean		16,7	16.3	15.8	16.2	16.4	16.2	16.4
Mean for cultivars	H-0	17.0	16.5	15.8	16.4	16.7	16.4	16.7
	H-1	15.4	15.1	14.6	15.1	15.2	15.0	15.2
	H-2	16.6	16.3	15.8	16.3	16.4	16.2	16.4
	H-3	16.3	15.9	15.5	15.9	16.1	15.9	16.1
	H-4	16.2	15.8	15.3	15.8	16.0	15.6	15.9
Mean		16.3	15.9	15.4	15.9	16.1	15.8	16.1

$LSD_{p=0.05}$ for the storage temperature:	+8ºC	+4ºC
Cultivars	0.3	0.4
Herbicides used	ns	0.6
Storage time	0.1	0.1
Herbicides used × cultivars	ns	ns
Cultivars × herbicides used	ns	ns
Storage time × cultivars	ns	ns
Cultivars × storage time	ns	ns
Storage time × herbicides used	ns	ns
Herbicides used × storage time	ns	ns
Cultivars × herbicides used × storage time	ns	ns

H-0, H-1, H-2, H-3, H-4, see Table 25

a)



b)

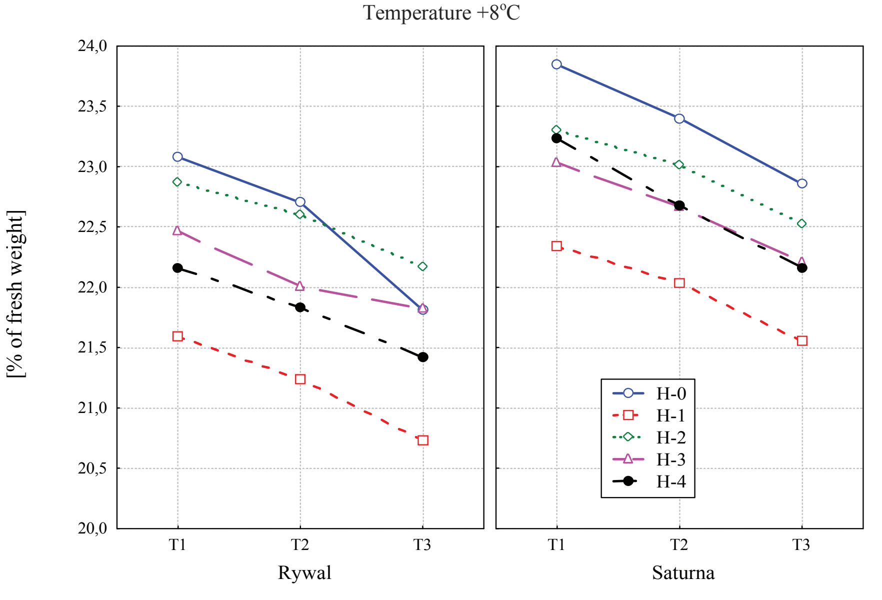


Fig. 6. Dependence of the content of dry matter in tubers of the potato cultivars researched on the herbicides used, storage temperature and measurement date: T1 – measurement after harvest, T2 – measurement after 3 months of storage, T3 – measurement after 6 months of storage; symbols of the herbicides used, see Table 25

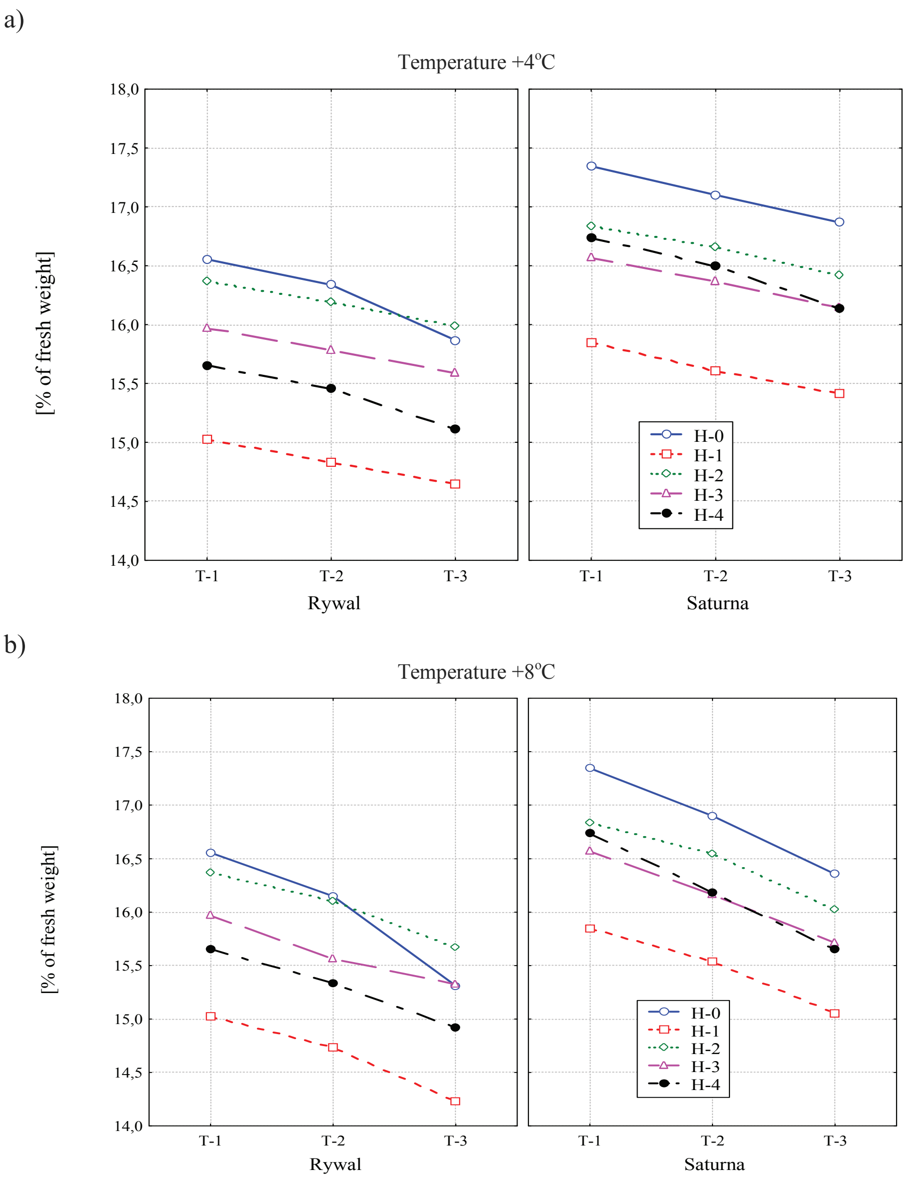


Fig. 7. Dependence of the content of starch in tubers of the potato cultivars researched on the herbicides used, storage temperature and measurement date: T1 – measurement after harvest, T2 – measurement after 3 months of storage, T3 – measurement after 6 months of storage; symbols of the herbicides used, see Table 25

4.3.2.2. Content of total protein

The content of total protein in tubers stored in the chambers with the temperature of +4 and +8°C differed significantly depending on the cultivar and storage time (Table 27). Similarly as after harvest, 'Saturna' accumulated more of that component than

'Rywal'. Both after 3 and after 6 months of storage in the chambers with the temperature of +8°C in tubers of both cultivars, mean from objects, the content of total protein decreased significantly, while in the tubers stored in the chambers with the temperature of +4°C the level of the component discussed decreased significantly only after 6 months.

Table 27. Content of total protein in the fresh weight of tubers (g· $100g^{-1}$) of the potato cultivars researched depending on the herbicides used and storage time at the temperature of +8ºC and +4ºC

Cultivar	Herbicides used	After harvest	Storage time					
			at the temperature of +8ºC			at the temperature of +4ºC		
			3 months	6 months	mean (3,4,5)	3 months	6 months	mean (3,7,8)
1	2	3	4	5	6	7	8	9
Rywal	H-0	2.11	2.05	2.00	2.05	2.07	2.05	2.08
	H-1	2.21	2.17	2.10	2.16	2.19	2.14	2.18
	H-2	2.22	2.17	2.10	2.16	2.19	2.14	2.18
	H-3	2.20	2.17	2.10	2.16	2.19	2.14	2.18
	H-4	2.20	2.14	2.10	2.15	2.17	2.14	2.17
Mean		2,19	2.14	2.07	2.13	2.17	2.12	2.16
Saturna	H-0	2.59	2.50	2.43	2.51	2.55	2.50	2.55
	H-1	2.68	2.60	2.55	2.61	2.64	2.62	2.65
	H-2	2.68	2.62	2.60	2.63	2.64	2.62	2.65
	H-3	2.65	2.60	2.57	2.61	2.62	2.60	2.62
	H-4	2.68	2.62	2.57	2.62	2.67	2.62	2.66
Mean		2,42	2.60	2.55	2.52	2.62	2.60	2.55
Mean for cultivars	H-0	2.35	2.29	2.21	2.28	2.31	2.26	2.31
	H-1	2.45	2.38	2.33	2.39	2.43	2.38	2.42
	H-2	2.45	2.38	2.36	2.40	2.43	2.38	2.42
	H-3	2.43	2.38	2.33	2.38	2.40	2.36	2.40
	H-4	2.44	2.38	2.33	2.38	2.43	2.38	2.42
Mean		2.42	2.36	2.31	2.36	2.40	2.36	2.39

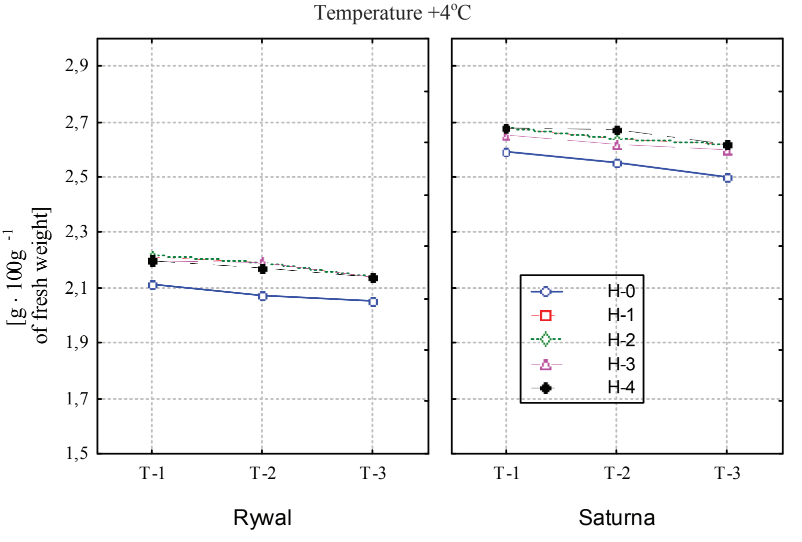
$LSD_{p = 0.05}$ for the storage temperature:	+8ºC	+4ºC
Cultivars	0.02	0.02
Herbicides used	ns	ns
Storage time	0.02	0.05
Herbicides used × cultivars	ns	ns
Cultivars x herbicides used	ns	ns
Storage time × cultivars	ns	ns
Cultivars × storage time	ns	ns
Storage time × herbicides used	ns	ns
Herbicides used × storage time	ns	ns
Cultivars × herbicides used × storage time	ns	ns

H-0, H-1, H-2, H-3, H-4, see Table 25

A decrease in the content of total protein after storage had a similar pattern in the tubers of both cultivars from all the experimental objects (Fig. 8). These losses were, respectively, after 3 and 6 months of storage in the chambers with the temperature of

+8°C at the level of 2.5% and 4.5% as well as 0.8% and 2.5% in tubers stored at the temperature of +4°C.

a)



b)

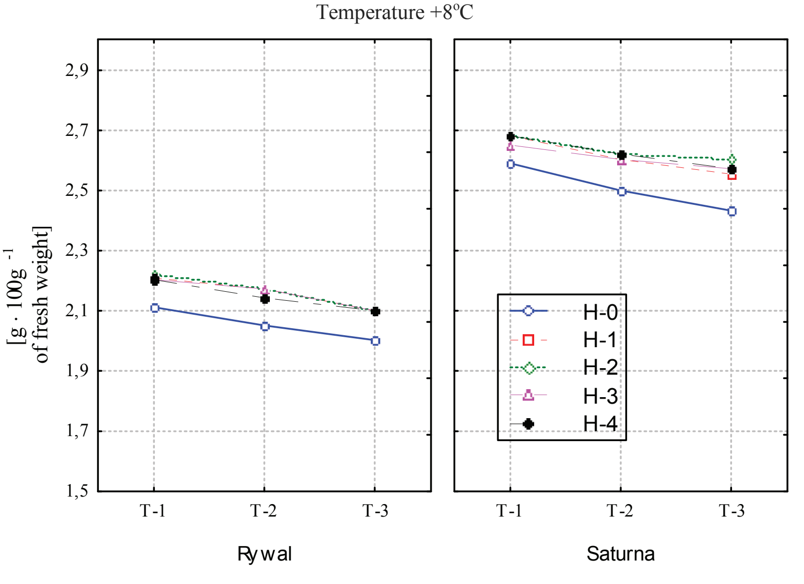


Fig. 8. Dependence of the content of total protein in tubers of the potato cultivars researched on the herbicides used, storage temperature and measurement date: T1 – measurement after harvest, T2 – measurement after 3 months of storage, T3 – measurement after 6 months of storage; symbols of the herbicides used, see Table 25

4.3.2.3. Content of total and reducing sugars

After storage of potato tubers at +8 and +4°C there was recorded a significant increase in the content of soluble sugars – total and reducing (Tables 28, 29, Figs. 9, 10). The level of these compounds was significantly higher in 'Rywal' tubers. The weed-killing agents used during the plant vegetation period did not modify the pattern of results concerning the content of monosaccharides and total sugars in tubers of both cultivars after storage at the temperature of +8 and +4°C. In potato tubers stored in the chambers with the temperature of +4°C the content of soluble sugars was affected by the interaction between the storage period length and the properties of cultivars to produce them.

Table 28. Content of total sugars in the fresh weight of tubers (%) of the potato cultivars researched depending on the herbicides used and the storage time at the temperature of +8ºC and +4ºC

Cultivar	Herbicides used	After harvest	Storage time					
			at the temperature of +8ºC			at the temperature of +4ºC		
			3 months	6 months	Mean (3,4,5)	3 months	6 months	Mean (3,7,8)
1	2	3	4	5	6	7	8	9
Rywal	H-0	0.32	0.48	0.65	0.48	0.66	0.89	0.63
	H-1	0.36	0.50	0.69	0.51	0.69	0.93	0.66
	H-2	0.36	0.51	0.70	0.52	0.69	0.95	0.67
	H-3	0.37	0.50	0.69	0.52	0.68	0.96	0.67
	H-4	0.38	0.51	0.72	0.53	0.70	0.96	0.68
Mean		0,36	0.50	0.69	0.51	0.69	0.94	0.66
Saturna	H-0	0.19	0.31	0.43	0.31	0.42	0.60	0.42
	H-1	0.21	0.33	0.45	0.33	0.45	0.61	0.43
	H-2	0.19	0.34	0.46	0.33	0.46	0.63	0.42
	H-3	0.20	0.34	0.47	0.34	0.45	0.63	0.43
	H-4	0.20	0.32	0.46	0.33	0.46	0.62	0.42
Mean		0,20	0.33	0.45	0.33	0.45	0.62	0.42
Mean for cultivars	H-0	0.25	0.39	0.54	0.40	0.54	0.75	0.52
	H-1	0.29	0.42	0.57	0.42	0.57	0.77	0.54
	H-2	0.28	0.42	0.58	0.43	0.58	0.79	0.55
	H-3	0.28	0.42	0.58	0.43	0.56	0.79	0.55
	H-4	0.29	0.41	0.59	0.43	0.58	0.79	0.55
Mean		0.28	0.41	0.57	0.42	0.57	0.78	0.54

$LSD_{p = 0.05}$ for the storage temperature	+8ºC	+4ºC
Cultivars	0.01	0.01
Herbicides used	ns	ns
Storage time	0.04	0.04
Herbicides used × cultivars	ns	ns
Cultivars × herbicides used	ns	ns
Storage time × cultivars	ns	0.05
Cultivars × storage time	ns	0.04
Storage time × herbicides used	ns	ns
Herbicides used × storage time	ns	ns
Cultivars × herbicides used × storage time	ns	ns

H-0, H-1, H-2, H-3, H-4, see Table 25

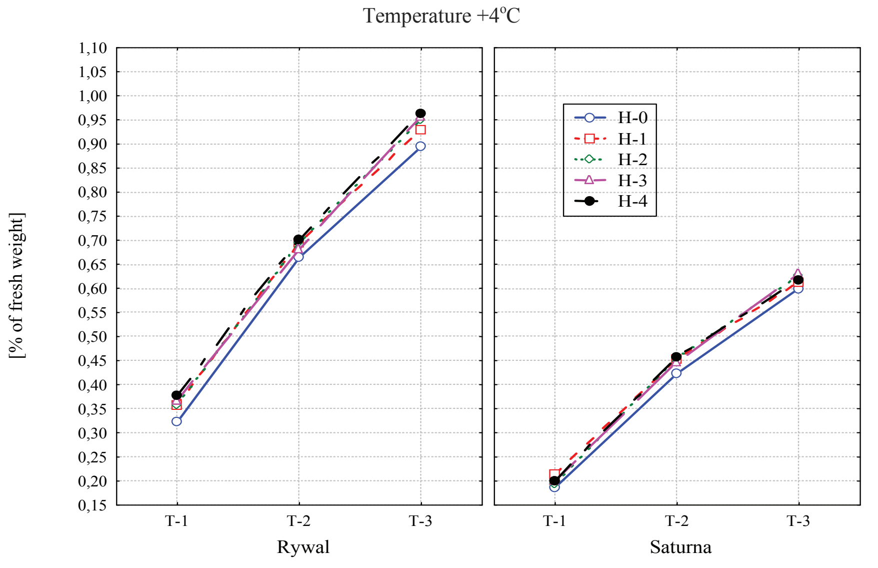
Table 29. Content of reducing sugars in the fresh weight of tubers (%) of the potato cultivars researched depending on the herbicides used and the storage time at the temperature of +8ºC and +4ºC

Cultivar	Herbicides used	After harvest	Storage time					
			at the temperature of +8ºC			at the temperature of +4ºC		
			3 months	6 months	mean (3, 4, 5)	3 months	6 months	mean (3,7,8)
1	2	3	4	5	6	7	8	9
Rywal	H-0	0.14	0.14	0.29	0.19	0.44	0.59	0.39
	H-1	0.16	0.16	0.27	0.20	0.38	0.57	0.37
	H-2	0.18	0.18	0.27	0.21	0.37	0.55	0.37
	H-3	0.16	0.16	0.30	0.20	0.37	0.58	0.37
	H-4	0.16	0.16	0.28	0.20	0.37	0.57	0.37
Mean		0,16	0.16	0.28	0.20	0.39	0.57	0.37
Saturna	H-0	0.04	0.11	0.16	0.11	0.11	0.25	0.14
	H-1	0.04	0.12	0.15	0.10	0.10	0.27	0.13
	H-2	0.05	0.12	0.13	0.10	0.10	0.26	0.15
	H-3	0.04	0.11	0.14	0.09	0.09	0.32	0.13
	H-4	0.04	0.12	0.16	0.10	0.10	0.23	0.13
Mean		0,04	0.12	0.15	0.10	0.10	0.27	0.14
Mean for cultivars	H-0	0.09	0.13	0.22	0.15	0.28	0.42	0.26
	H-1	0.10	0.14	0.21	0.15	0.24	0.42	0.25
	H-2	0.11	0.15	0.20	0.15	0.24	0.40	0.25
	H-3	0.10	0.13	0.22	0.15	0.23	0.45	0.26
	H-4	0.10	0.14	0.22	0.15	0.24	0.40	0.25
Mean		0.10	0.14	0.22	0.15	0.24	0.42	0.25

$LSD_{p = 0.05}$ for the storage temperature	+8ºC	+4ºC
Cultivars	0.02	0.03
Herbicides used	ns	ns
Storage time	0.02	0.05
Herbicides used × cultivars	ns	ns
Cultivars x herbicides used	ns	ns
Storage time × cultivars	ns	0.07
Cultivars × storage time	ns	0.06
Storage time × herbicides used	ns	ns
Herbicides used × storage time	ns	ns
Cultivars × herbicides used × storage time	ns	ns

H-0, H-1, H-2, H-3, H-4, see Table 25

a)



b)

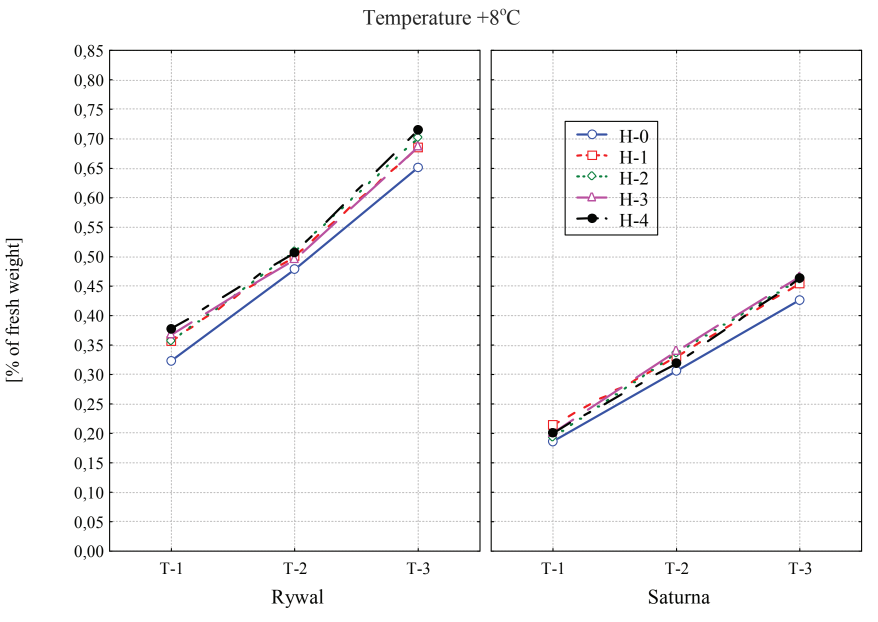


Fig. 9. Dependence of the content of total sugars in tubers of the potato cultivars researched on the herbicides used, storage temperature and measurement date: T1 – measurement after harvest, T2 – measurement after 3 months of storage, T3 – measurement after 6 months of storage; symbols of the herbicides used, see Table 25

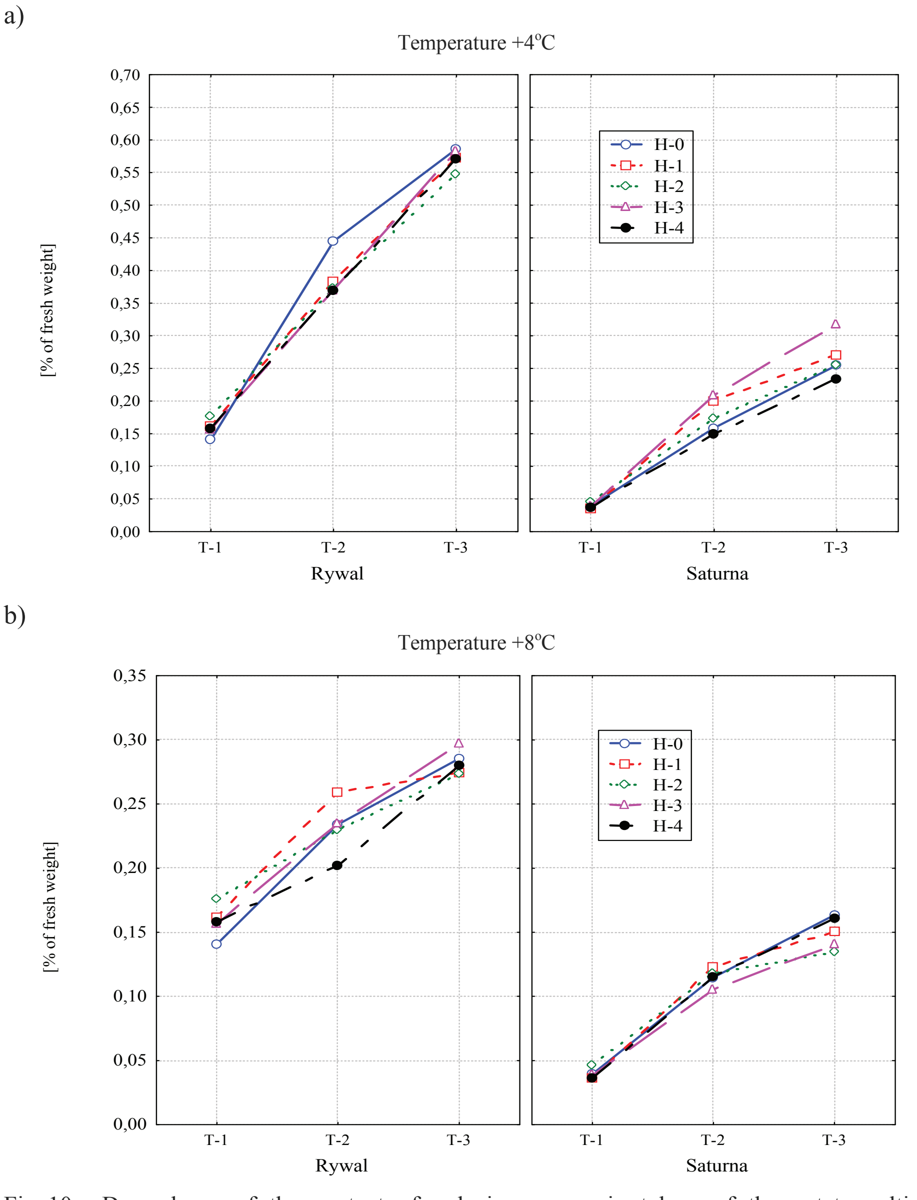


Fig. 10. Dependence of the content of reducing sugars in tubers of the potato cultivars researched on the herbicides used, storage temperature and measurement date: T1 – measurement after harvest, T2 – measurement after 3 months of storage, T3 – measurement after 6 months of storage; Symbols of the herbicides used, see Table 26

An increase in the content of reducing sugars in 'Rywal' tubers above the boundary value of 0.5% after 6 months of storage at the temperature of +4°C eliminated the cultivar researched from the production of french fries and chips (Fig. 10a). Similarly in 'Saturna' tubers stored at low temperature the amount of fructose and glucose exceeded the desired values for processing to obtain enriched products (Table 1).

4.3.2.4. Content of vitamin C

Content of vitamin C in the tubers of the cultivars researched decreased significantly after storage, both at the temperature of +8, and at +4°C, mean for objects, respectively, by 48.6% and 39.8% after 3 months of storage and in the tubers analyzed after 6 months by another 5.7% and 5.3% (Table 30, Fig. 11). The cultivars researched differed significantly one from another in their content of vitamin C; a higher amount of that compound was found in 'Saturna', as compared with 'Rywal'. The herbicides used during the vegetation period did not differentiate the research results after storage significantly.

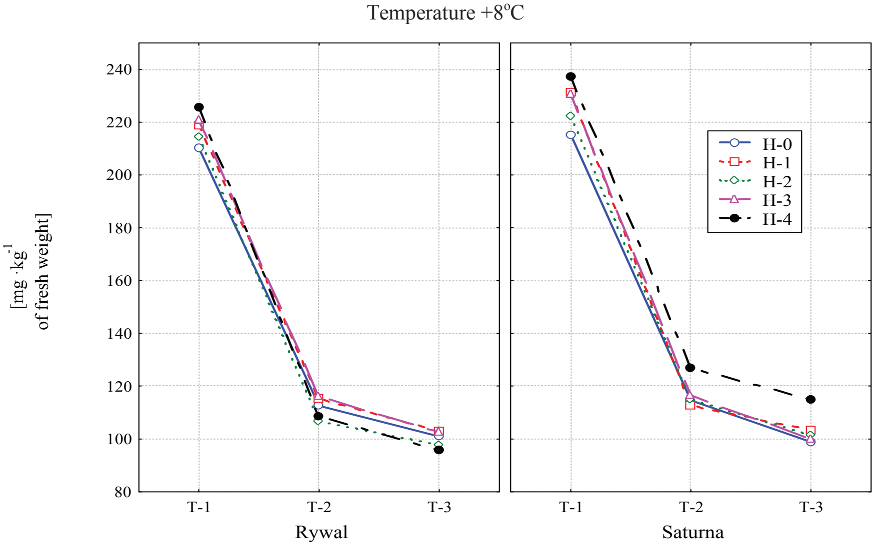
Table 30. Content of vitamin C in the fresh weight of tubers ($mg \cdot kg^{-1}$) of the potato cultivars depending on the herbicides used and the storage time at the temperature of +8ºC and +4ºC

Cultivar	Herbicides used	After harvest	Storage time					
			at the temperature of +8ºC			at the temperature of +4ºC		
			3 months	6 months	mean (3,4,5)	3 months	6 months	mean (3,7,8)
1	2	3	4	5	6	7	8	9
Rywal	H-0	210.0	112.6	101.0	141.2	125.8	114.4	150.1
	H-1	219.0	115.1	102.7	145.6	132.3	120.9	157.4
	H-2	214.0	106.7	97.7	139.5	127.3	116.9	152.7
	H-3	221.0	116.2	102.7	146.6	129.9	116.1	155.7
	H-4	226.0	108.4	95.7	143.4	135.7	116.6	159.4
Mean		218,0	111.8	99.9	143.3	130.2	116.9	155.1
Saturna	H-0	215.0	114.6	98.9	142.8	132.5	126.3	157.9
	H-1	231.0	112.6	103.2	149.0	141.9	131.1	168.0
	H-2	222.0	115.0	101.4	146.2	138.5	129.6	163.4
	H-3	231.0	116.5	100.0	149.2	134.1	125.9	163.6
	H-4	237.0	126.9	114.9	159.6	141.0	124.8	167.6
Mean		227,2	114.2	103.7	149.3	137.6	127.5	164.1
Mean for cultivars	H-0	212.5	113.6	99.9	142.0	129.1	120.4	154.0
	H-1	225.0	113.9	103.0	147.3	137.1	126.0	162.7
	H-2	218.0	110.9	99.6	142.8	132.9	123.2	158.0
	H-3	226.0	116.4	101.3	147.9	132.0	121.0	159.7
	H-4	231.5	117.7	105.3	151.5	138.4	120.7	163.5
Mean		222.6	114.5	101.8	146.3	133.9	122.3	159.6

$LSD_{p = 0.05}$ for the storage temperature:	+8ºC	+4ºC
Cultivars	5.2	4.7
Herbicides used	ns	ns
Storage time	7.5	7.9
Herbicides used × cultivars	ns	ns
Cultivars × herbicides used	ns	ns
Storage time × cultivars	ns	ns
Cultivars × storage time	ns	ns
Storage time × herbicides used	ns	ns
Herbicides used × storage time	ns	ns
Cultivars × herbicides used × storage time	ns	ns

H-0, H-1, H-2, H-3, H-4, see Table 25

a)



b)

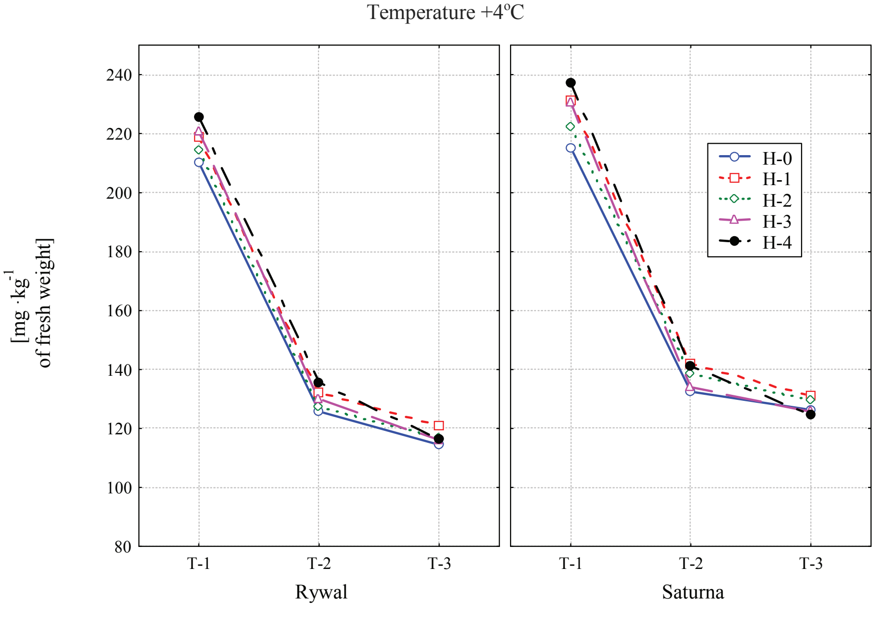


Fig. 11. Dependence of the content of vitamin C in tubers of the potato cultivars researched on the herbicides used, storage temperature and measurement date: T1 – measurement after harvest, T2 – measurement after 3 months of storage, T3 – measurement after 6 months of storage; symbols of the herbicides used, see Table 25

4.3.2.5. Content of chlorogenic acid

The content of chlorogenic acid after storage at the temperature of +8 and +4ºC was significantly affected by the cultivar factor as well as the storage time (Table 31). 'Saturna' showed a higher amount of that phenolic compound than 'Rywal'. After storage in the chambers with the temperature of +8°C the level of chlorogenic acid in tubers, mean for all the objects, increased significantly only after 6 months. The tubers stored at the temperature of +4°C contained significantly more chlorogenic acid both after 3 and after 6 months. Besides, an increase in the organic compound discussed in tubers stored in the chambers with the temperature of +8ºC was significantly affected by individual susceptibility of the cultivars.

Table 31. Content of chlorogenic acid in the fresh weight of tubers (mg· kg^{-1}) of the potato cultivars researched depending on the herbicides used and the storage time at the temperature of +8ºC and +4ºC

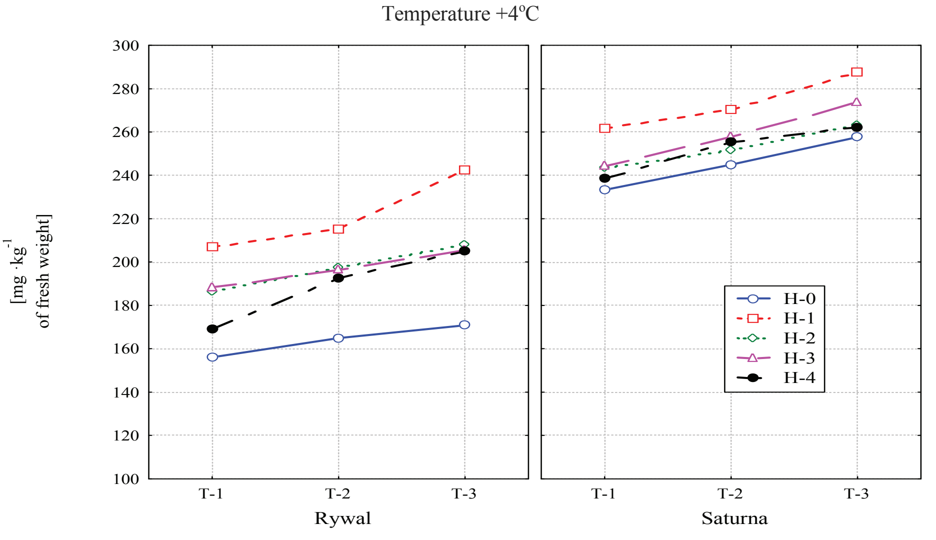
Cultivar	Herbicides used	After harvest	Storage time					
			at the temperature of +8ºC			at the temperature of +4ºC		
			3 months	6 months	mean (3,4,5)	3 months	6 months	mean (3,7,8)
1	2	3	4	5	6	7	8	9
Rywal	H-0	156.0	158.2	163.6	159.3	164.9	170.9	163.9
	H-1	207.0	204.7	215.1	208.9	215.0	242.6	221.5
	H-2	186.6	191.9	203.2	193.9	197.2	207.9	197.2
	H-3	188.3	185.7	202.6	192.2	196.4	205.7	196.8
	H-4	169.1	172.8	195.6	179.2	192.6	204.9	188.9
Mean		181.4	182.6	196.0	186.7	193.2	206.4	193.7
Saturna	H-0	233.2	238.9	241.4	237.9	244.9	257.7	263.7
	H-1	261.8	262.0	269.9	264.6	270.2	287.6	258.7
	H-2	243.3	246.6	251.8	247.2	251.4	262.9	258.3
	H-3	244.2	250.0	251.7	248.6	257.8	273.7	253.9
	H-4	238.6	244.9	247.2	243.6	255.3	262.1	254.4
Mean		244,2	248.5	252.4	248.4	255.9	268.8	257.8
Mean for cultivars	H-0	194.6	198.6	202.5	198.6	204.9	214.3	204.6
	H-1	234.4	233.3	242.5	236.7	242.6	265.1	247.4
	H-2	214.9	219.2	227.5	220.6	224.3	235.4	224.9
	H-3	216.3	217.8	227.1	220.4	227.1	239.7	227.7
	H-4	203.8	208.8	221.4	211.4	223.9	233.5	220.4
Mean		212.8	215.6	224.2	217.5	224.6	237.6	225.0

$LSD_{p = 0.05}$ for the storage temperature:	+8ºC	+4ºC
Cultivars	10.8	10.7
Herbicides used	ns	ns
Storage time	3.7	8.2
Herbicides used × cultivars	ns	ns
Cultivars × herbicides used	ns	ns
Storage time × cultivars	4.4	ns
Cultivars × storage time	5.3	ns
Storage time × herbicides used	ns	ns
Herbicides used × storage time	ns	ns
Cultivars × herbicides used × storage time	ns	ns

H-0, H-1, H-2, H-3, H-4, see Table 25

Greater tendencies to increasing the content of chlorogenic acid after storage were found in the tubers stored at the temperature of +4°C (Fig. 12).

a)



b)

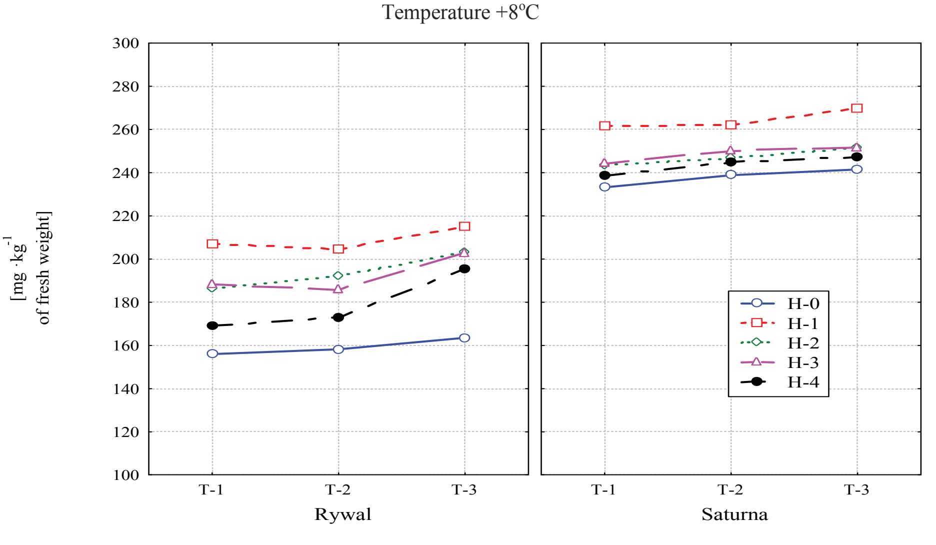


Fig. 12. Dependence of the content of chlorogenic acid in tubers of the potato cultivars researched on the herbicides used, storage temperature and measurement date: T1 – measurement after harvest, T2 – measurement after 3 months of storage, T3 – measurement after 6 months of storage; symbols of the herbicides used, see Table 25

4.4. FUNCTIONAL VALUE OF POTATO TUBERS AFTER 6 MONTHS OF STORAGE

4.4.1. Consumption value of potato tubers stored at the temperature of +4ºC

4.4.1.1. Tastefulness

The flavor and aroma qualities of cooked tubers for which organoleptic evaluation was performed after 6 months of storage slightly deteriorated as compared with the tubers investigated right after harvest (Tables 20, 32). Mean differences for objects were 0.1 point (in the 9-degree scale). The tastefulness of ‘Saturna’ was higher than in ‘Rywal’, and the tubers from the plots with the use of weed-killing agents, similarly as after harvest, also demonstrated a lower flavor and aroma value.

Table 32. Organoleptic evaluation of cooked potato tubers (mean for storage seasons 2002-2005)

Herbicides used	Cultivar	Tastefulness 9-degree scale[1]	Tuber flesh color 6-degree scale[2]	Culinary and functional type 4-degree scale[3]	Flesh blackening 9-degree scale[4]	
					after 10 min	after 24 hours
Without herbicide (control)	Rywal	6.3	4.6	2.1	8.5	8.2
	Saturna	6.5	4.7	2.3	8.0	7.8
	Mean	6.4	4.7	2.2	8.3	8.0
Afalon 50 WP	Rywal	6.2	4.7	1.9	7.9	7.7
	Saturna	6.4	4.6	2.0	7.8	7.2
	Mean	6.3	4.7	2.0	7.9	7.5
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal	6.2	4.9	2.0	8.0	7.8
	Saturna	6.4	4.5	2.1	7.6	7.5
	Mean	6.3	4.7	2.1	7.8	7.7
Apyros 75 WG+ adjuvant Atpolan 80 EC	Rywal	6.1	4.7	2.4	8.0	7.6
	Saturna	6.4	4.7	2.5	7.5	7.2
	Mean	6.3	4.7	2.5	7.8	7.4
Azogard 50 WP	Rywal	6.1	5.0	2.3	8.4	8.0
	Saturna	6.3	4.6	2.4	7.9	7.7
	Mean	6.2	4.8	2.4	8.3	7.9
Mean	Rywal	6.1	4.8	2.2	8.2	7.9
	Saturna	6.4	5.0	2.3	7.8	7.5
Mean		6.3	4.9	2.3	8.0	7.7

[1] grade scale: 9 – very good, 1 – very bad
[2] grade scale: 1 – white flesh, 2 – white with the shade of grey, 3 – cream, 4 – light yellow, 5 – yellow, 6 – dark yellow
[3] grade scale: 1 – salad type (A), 2 – general functional type (B), 3 – floury type (C), 4 – very floury type (D)
[4] grade scale: 9 – non-blackening flesh, 1 – black flesh

4.4.1.2. Tuber flesh color

Tuber flesh color is mostly cultivar-specific, however, it should change during storage. The two cultivars used in the present research did not differ from each other as far as that character was concerned. Tubers of both cultivars evaluated after storage showed slightly darker flesh color, as compared with the tubers investigated after harvest, especially ‘Saturna’ tubers (Tables 20, 32).

4.4.1.3. Culinary and functional type

Tubers analyzed after storage, from all the experimental objects, showed a greater tendency to overcooking, a more loose density, greater floury character, lower moisture and a more rough structure of the flesh than the tubers evaluated after harvest (Tables 20, 32). These evaluations, however, did not change the functional and consumption type. The differences in the 4-degree scale were on average for objects 0.3 degree. Both cultivars were classified as type B, similarly as after harvest.

4.4.1.4. Blackening of raw and cooked potato tuber flesh

The tendency of tuber to enzymatic blackening was significantly determined by the cultivar factor (Table 33). The herbicides used during vegetation, similarly as after harvest, slightly increased this tendency. The flesh of raw tubers of 'Saturna' was moderately susceptible to blackening, unlike 'Rywal' tuber flesh, qualifying it as moderately resistant to blackening. After 3 and 6 months of storage at the temperature of +4 and +8°C tubers of both cultivars, mean for all the objects, showed significantly greater tendency to enzymatic blackening than after harvest. Storage conditions at lower temperature also increased the tendency to blackening of raw flesh of the tubers analyzed (Fig. 13).

After 6-month storage cooked tubers, evaluated both after 10 minutes, and after 24 hours, showed a greater tendency to flesh blackening than the tubers analyzed right after harvest (Tables 20, 32). 'Saturna', similarly as after harvest, blackened more (on average by 0.4 degree in the 9-degree scale) than 'Rywal', and the herbicides used during the vegetation period increased that tendency from 0.1 to 0.6 degree in the 9-degree scale.

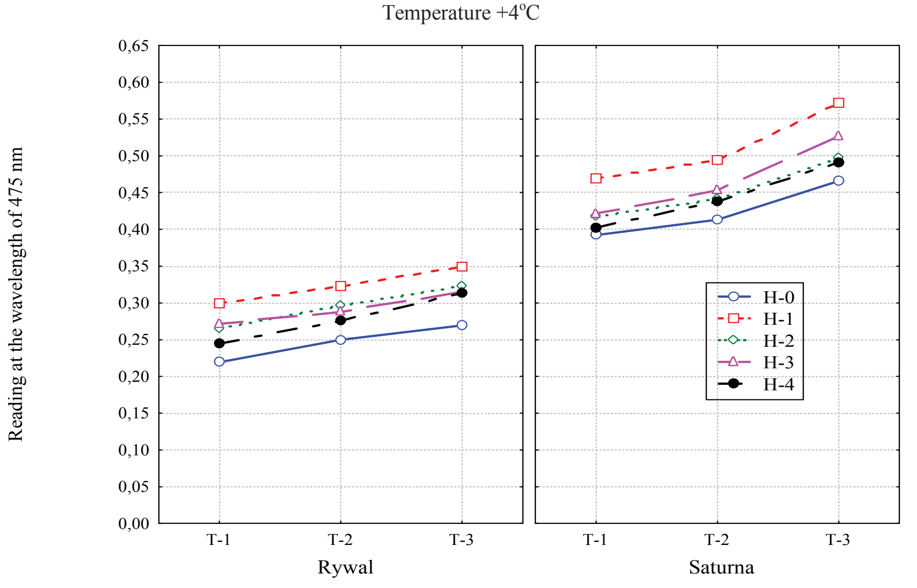
Table 33. Enzymatic blackening of tubers of the potato cultivars researched depending on the herbicides used and the storage time

Cultivar	Herbicides used	After harvest	Storage time					
			at the temperature of +8ºC			at the temperature of +4ºC		
			3 months	6 months	mean (3,4,5)	3 months	6 months	mean (3,7,8)
1	2	3	4	5	6	7	8	9
Rywal	H-0	0.22	0.23	0.24	0.23	0.25	0.27	0.25
	H-1	0.30	0.30	0.32	0.31	0.32	0.35	0.32
	H-2	0.26	0.28	0.31	0.29	0.30	0.32	0.29
	H-3	0.27	0.27	0.29	0.28	0.29	0.31	0.29
	H-4	0.24	0.26	0.28	0.26	0.28	0.31	0.28
Mean		0,26	0.27	0.29	0.29	0.31	0.31	0.29
Saturna	H-0	0.39	0.40	0.41	0.40	0.41	0.47	0.49
	H-1	0.47	0.47	0.49	0.48	0.49	0.57	0.47
	H-2	0.42	0.43	0.45	0.43	0.44	0.50	0.47
	H-3	0.42	0.44	0.45	0.44	0.45	0.53	0.45
	H-4	0.40	0.41	0.43	0.41	0.44	0.49	0.45
Mean		0,42	0.43	0.44	0.45	0.45	0.51	0.47
Mean for cultivars	H-0	0.31	0.31	0.33	0.31	0.33	0.37	0.34
	H-1	0.38	0.39	0.40	0.39	0.41	0.46	0.42
	H-2	0.34	0.35	0.38	0.36	0.37	0.41	0.37
	H-3	0.35	0.36	0.37	0.36	0.37	0.42	0.38
	H-4	0.32	0.33	0.36	0.34	0.36	0.40	0.36
Mean		0.34	0.35	0.37	0.37	0.41	0.35	0.37

$LSD_{p = 0.05}$ for the storage temperature:	+8ºC	+4ºC
Cultivars	0.02	0.02
Herbicides used	ns	ns
Storage time	0.01	0.02
Herbicides used × cultivars	ns	ns
Cultivars × herbicides used	ns	ns
Storage time × cultivars	ns	ns
Cultivars × storage time	ns	ns
Storage time × herbicides used	ns	ns
Herbicides used × storage time	ns	ns
Cultivars × herbicides used × storage time	ns	ns

H-0, H-1, H-2, H-3, H-4, see Table 25

a)



b)

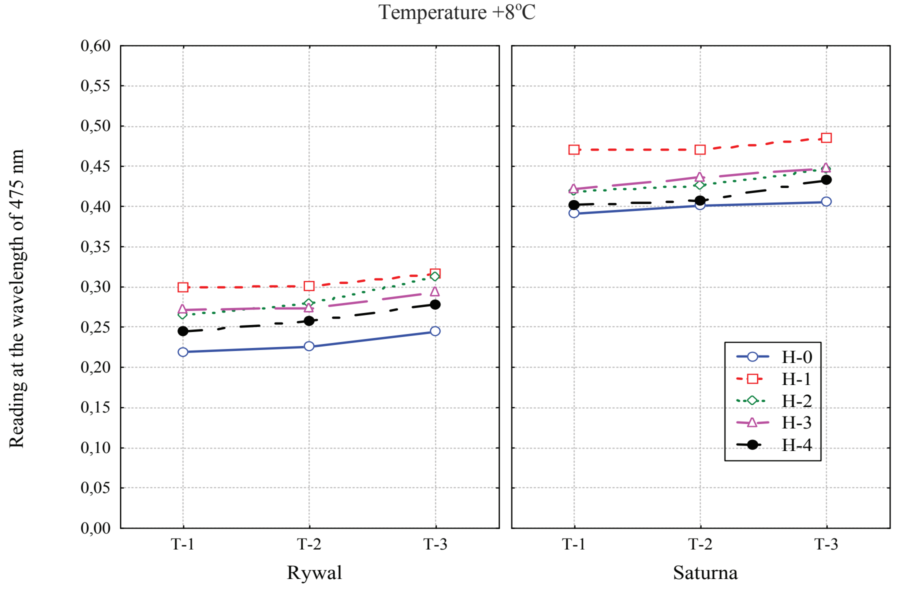


Fig. 13. Tendency to blackening of raw tubers of the potato cultivars researched on the herbicides used, storage temperature and measurement date: T1 – measurement after harvest, T2 – measurement after 3 months of storage, T3 – measurement after 6 months of storage; symbols of the herbicides used, see Table 25

4.4.2. Technological value of potato tubers stored at the temperature of +8ºC

4.4.2.1. French fries quality

The quality of french fries obtained from tubers stored for 6 months at the temperature of +8ºC deteriorated slightly, as compared with the quality evaluated right after harvest – mean for objects – by 0.15 degree (Tables 22, 34). ‘Saturna’ showed better parameters affecting the general evaluation of the end product than ‘Rywal’. However one shall not disregard the effect of meteorological conditions which coincided with the plant vegetation period as in the dry year (2003) the french fries produced from ‘Saturna’ showed a worse quality than the french fries from ‘Rywal’, as compared with the other research years.

Table 34. The score of the french fries quality obtained from tubers of the potato cultivars researched after storage depending on the herbicides used during the vegetation period (5-degree scale: 1 – unsatisfactory, 5 – very good)

Herbicides used	Cultivar	Storage seasons			
		2002/2003	2003/2004	2004/2005	Mean
Without herbicide (control)	Rywal Saturna	3.8 3.4	3.4 3.2	3.2 3.6	3.5 3.4
	Mean	3.6	3.3	3.4	3.5
Afalon 50 WP	Rywal Saturna	3.6 4.0	3.4 3.2	3.4 4.1	3.5 3.8
	Mean	3.8	3.3	3.8	3.7
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	3.6 3.8	3.3 3.1	3.5 3.6	3.5 3.5
	Mean	3.7	3.2	3.6	3.5
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	3.8 3.9	3.4 3.2	3.2 3.8	3.5 3.6
	Mean	3.9	3.3	3.5	3.6
Azogard 50 WP	Rywal Saturna	3.9 3.9	3.4 3.2	3.5 3.7	3.6 3.6
	Mean	3.9	3.3	3.6	3.6
Mean	Rywal Saturna	3.7 3.8	3.4 3.2	3.4 3.8	3.5 3.6
	Mean	3.8	3.3	3.6	3.6

4.4.2.2. Chips quality

Chips produced from tubers stored for 6 months were darker in color than those evaluated after harvest, mean difference for objects was 1.4 degree in the 9-degree scale (Tables 23, 35). Despite such a differences in the evaluation of the color of chips from tubers after harvest and storage, their general score was good. A comparison of the quality of chips obtained from tubers of two cultivars selected for the present research showed that ‘Saturna’ had a better technological value (on average by 0.3 degree). From potato tubers grown in the dry year of 2003, after long storage (6 months) there were obtained chips of the best parameters affecting their total score.

Table 35. Score of the quality of chips from tubers of the potato cultivars researched after storage depending on the herbicides used

Herbicides used	Cultivar	Storage season							
		2002/2003		2003/2004		2004/2005		mean	
		1*	2*	1*	2*	1*	2*	1*	2*
Without herbicide (control)	Rywal	5.8	4.1	6.8	4.4	5.0	3.0	5.9	3.8
	Saturna	6.8	4.5	7.5	4.5	7.7	4.0	7.3	4.3
	Mean	6.3	4.3	7.2	4.5	6.4	3.5	6.6	4.2
Afalon 50 WP	Rywal	6.2	3.8	6.2	4.3	5.7	3.2	6.0	3.8
	Saturna	7.7	3.9	6.7	4.3	6.7	3.6	7.0	3.9
	Mean	7.0	3.9	6.5	4.3	6.2	3.4	6.5	3.9
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal	6.0	4.2	6.7	4.4	5.8	3.3	6.2	4.0
	Saturna	7.2	4.4	7.3	4.3	7.3	4.0	7.3	4.2
	Mean	6.6	4.3	7.0	4.4	6.6	3.7	6.7	4.1
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal	6.5	3.8	6.7	4.2	5.3	2.9	6.2	3.6
	Saturna	6.7	4.0	7.3	4.2	7.5	3.9	7.2	4.0
	Mean	6.6	3.9	7.0	4.2	6.4	3.4	6.7	3.8
Azogard 50 WP	Rywal	6.3	3.9	6.5	4.3	5.8	3.2	6.2	3.8
	Saturna	6.7	3.9	6.5	4.3	7.7	3.9	7.0	4.0
	Mean	6.5	3.9	6.5	4.3	6.8	3.6	6.6	3.9
Mean	Rywal	6.2	4.0	6.6	4.3	5.5	3.1	6.1	3.8
	Saturna	7.0	4.1	7.1	4.3	7.4	3.9	7.2	4.1
	Mean	6.6	4.1	6.8	4.3	6.5	3.5	6.6	4.0

1* color according to 9-degree scale (9 – evenly light, 4-1 – disqualifying score)
2* quality of chips according to the 5-degree scale (5 – very good, 1 – unsatisfactory)

DISCUSSION

The volume of potato production in Poland, similarly as in other European countries, is becoming totally dependent on the consumer [Lisińska 2006]. The applicability of potato to a given direction of use (technological value) is determined foremost by the cultivar, but also a number of environmental factors (cultivation site, climate, type and kind of soil), agrotechnical factors (fertilization, irrigation, use of pesticides, planting date and equipment) as well as storage conditions. A cultivar of good technological properties grown in a single part of the country can be totally inadequate for industrial processing in another part due to unfavorable changes in the characters which determine its functional value.

For a producer the commercial yield size has been still most essential, which determines the profitability of the product. What is also important is that the raw material meets the potato tuber criteria depending on the direction of use. Especially high requirements are to be met by potato tubers for processing (Table 1). Facing a wide offer of foodstuffs on the market and changes in the culinary traditions concerning potato (e.g. favoring the so-called higher-level products, namely fruits and vegetables), the selection of the product by the consumer depends on the attractive flavor, aroma, look, content of nutrients and harmful components.

The quality of fried products made from potato depends on many factors, mainly the chemical composition of tubers. The main indicator of french fries quality is the density, which covers two terms: crunchiness of the outer part and the floury character of the inner part of the french fry. The outer part of french fries should not be hard, skinny or gummy, while the inner part should be floury, without feeling water or glutinous and not to come off from the peel [Lisińska and Leszczyński 1989, Tajner-Czopek and Lisińska 2004]. These characters depend mostly on the content of dry matter and starch in tubers, which also coincides with the present research results (the value of the correlation coefficient between the quality of french fries and the content of dry matter and starch was -0.61). French fries obtained from tubers with the content of dry matter >22% showed a hard density and scored lower.

The synthesis of results from respective research years confirmed the effect of the herbicides applied during the vegetation period on the content of dry matter and starch in potato tubers. These components decreased significantly, as compared with the object with the mechanical weed control only, especially in tubers from plots with the use of Afalon 50 WP. Similar results were reported also by Zarzecka and Gąsiorowska [2000, 2002c], following the use of a mixture of herbicides Sencor 70 WG (metribuzin) and Fusilade Super (fluazifop-P), as well as Basagran 600 SL (bentazon), in a mixture with Sencor 70 WP and a mixture of Bladex 50 WP (cyanazine) with Afalonem 50 WP (linuron). In the reports of other authors [Ceglarek *et al.* 1990, Pytlarz-Kozicka and Tajner-Czopek 2002] it was demonstrated that the use of chemical plant protection from weeds enhanced the growth of the content of dry matter and starch in tubers, while Kołpak *et al.* [1987], Mężykowska and Mazurczyk [1979] did not note significant differences in the percentage content of dry matter in tubers as a result of the use of herbicides. In the reports by Kołpak [1987] one finds tendencies to a decreasing content of dry matter in tubers treated with herbicides. In the present research the effect on the accumulation of dry matter and starch was also determined genetically by the cultivars, which coincides with numerous reports, e.g. by Zarzecka and Gąsiorowska [2002b], Zarzecka *et al.* [2000], Mazurczyk [1994], Hak [1990], Roztropowicz [1989]. The content of dry matter and starch in tubers of the cultivars studied was also influenced by meteorological conditions over the vegetation period. In the year with low rainfall, the tubers of the potato cultivars researched accumulated more dry matter than in the moist years of uneven rainfall distribution. Similar results were reported by, e.g. Leszczyński [2002], Mazurczyk and Lis [1999], Ceglarek *et al.* [1990], Kołpak *et al.* [1987].

The raw material for french fries production should not include more than 0.25% of reducing sugars (Table 1). What is also essential is uneven distribution of sugars in tubers as the so-called 'sugar-end' effect (brown ends of french fries) can be seen only in the end product ready to eat, which is in french fries after the second stage of frying, as a result of the Maillard reaction [Sowokinos *et al.* 2000]. In the potatoes researched the content of reducing sugars (glucose, fructose) was higher in tubers from the plots sprayed with herbicides, and the compound which differentiated the level of total sugars in tubers (which includes reducing sugars and disaccharide) was saccharose. According to Kraska [2002], Zarzecka and Gąsiorowska [2002a, b], Zarzecka and Gąsiorowska [2000], Lisińska [1981], the herbicides on potato plantations affect the metabolism of sugars in tubers, resulting in their increase. Most of the authors quoted in the present dissertation claim that cultivars react in an individual manner to chemical weed-killers, which is significantly confirmed by the present results. Similarly as reported by Zarzecka and Gąsiorowska [2002a, b], the cultivar factor had a significant effect on the content of sugars in tubers. 'Rywal' accumulated more total and reducing sugars than 'Saturna'. Similarly the meteorological conditions over the vegetation period differentiated the level of sugars in potato tubers. The greatest amount of reducing sugars and the lowest amount of saccharose were recorded in a more moist year, of uneven rainfall distribution (2004). According to Głuska [2000], the accumulation of sugars is mostly determined by weather conditions over tuber formation.

Blackening of raw and cooked tuber flesh is a defect of table potatoes. These characters are determined independently and result from two different processes in tubers.

Blackening of raw tuber flesh is connected with reactions of oxidation of phenolic compounds catalyzed by polyphenol oxidase (chlorogenic acid, caffeic acid) with the atmospheric oxygen [Horubała 1988, Bill and Jackowiak 1992, Kaaber *et al.* 2002].

In the present research the intensity of raw flesh blackening depended on the herbicides used. Weed-killing agents increased the tendency to enzymatic blackening. The tendency to increased blackening of the raw tuber flesh as affected by herbicides is also reported by Sawicka and Dialo [1997], Zarzecka *et al.* [1997], Kołpak *et al.* [1987], Gruczek [1980]. The reaction of tuber browning was also affected by, similarly as reported by Gąsiorowska and Zarzecka [2000], cultivar-specific properties. 'Rywal' blackened less than 'Saturna'. According to Horubała [1988], cold and wet years increase the tendency to enzymatic blackening of tuber flesh, similar relations were reported by Zarzecka [1998], stating that in the dry year raw flesh blackening was lowest, which also coincides with the present results. In the year with the lowest rainfall (2003), the intensity of raw tuber flesh of the cultivars researched was lowest.

Tuber flesh blackening after cooking is a non-enzymatic process which occurs as a result of oxidation in the atmospheric air of colorless complexes of chlorogenic acid with iron to dark chlorogenic complex with trivalent iron (chemical blackening). The tendency of the tuber flesh to blackening after cooking is a character which is highly-heritable, complex in character, conditioned poligenically [Zimnoch-Guzowska and Flis 2006]. In the wet and cold years the tendency to blackening is higher [Komorowska-

-Jędrys 1997]. The degree of cooked tuber blackening depends mostly on pH of the tuber (an increase in pH results in a greater blackening), and the rate of this reaction depends mostly on the content of citric acid which can react with iron, unlike chlorogenic acid, into a form of colorless complexes [Gabriel 1985, Grzesiuk and Górecki 1994, Griffiths and Bain 1997, Komorowska-Jędrys 1997, Rogozińska 2002].

In the present research, cooked tuber flesh blackening depended on the content of chlorogenic acid (the correlation coefficient was -0.38, Table 39) less considerably than raw tuber blackening (correlation coefficient was 0.95). The correlation between blackening and the content of chlorogenic acid was reported by many authors, including Rogozińska *et al.* [2008], Komorowska-Jędrys [1997], Grzesiuk and Górecki [1994], Bill and Jackowiak [1992]. The correlation coefficient between the degree of blackening of cooked tuber flesh and the content of citric acid in the potatoes researched was significant but not high (it was 0.39). Cooked tubers of 'Saturna' cultivar, from the plots sprayed with herbicides, evaluated after 10 minutes, and after 24 hours, blackened more than those collected from control plots, ranging from 0.1 to 0.8 in a 9-degree scale. The effect of the herbicides used during the vegetation period on the degree of cooked tuber blackening is also reported by Zarzecka [1998], Ceglarek *et al.* [1990], Kołpak *et al.* [1987]. Tendencies to tuber flesh blackening after cooking were greater in 'Saturna' than in 'Rywal', which points to different genetic conditions of the cultivar as far as the intensity of that character was concerned.

According to Lisińska [2006], the susceptibility of tuber flesh to enzymatic blackening is of a greater importance in the case of french fries than chips production because the technological process of french fries is much longer than that of chips and the material reduced in size can undergo enzymatic greying before blanching (inactivation of enzymes). The technological process of chips, on the other hand, from tuber peeling to end product packing takes less than half hour. Another unwanted phenomenon is also product greying due to the susceptibility of potato tubers to chemical blackening, which in french fries can be seen during storage of frozen product. However in the case of chips, the phenomenon is of less importance as in the product fried to the moisture of 2%, containing 33-39% of fat the greying process is not observed.

Compounds responsible for chemical and enzymatic blackening are phenols. In potato tubers they are represented mainly by chlorogenic acid. The acid is accumulated in the subcutaneous part of healthy tubers. According to Lewosz [1985], chlorogenic acid is synthesized after injury or infection at a different rate depending on the individual reaction of the cultivar. The accumulation of phenols in tubers is also facilitated by low growth temperature [Horubała 1988], as well as stress caused by drought over the vegetation period [Delgado *et al.* 2001b, Sulaiman 2005]. On the other hand, different results were reported by Pobereżny [2006], Roztropowicz [1989] as well as in the present research. In the years with low air temperature and high rainfall during the vegetation period, tubers of the highest content of chlorogenic acid were obtained. The cultivar factor, similarly as reported by Wojdyła [1993], Zgórska [1989], also differentiated the level of the compound discussed in the tubers of the cultivars researched; 'Saturna' synthesized more chlorogenic acid than 'Rywal'. An increase in the content of chlorogenic acid in the cultivars researched was also affected by the herbicides used during the vegetation period, especially Afalon 50 WP. The applicable literature offers no data on the extent of the effect of herbicides on the content of chlorogenic acid in potato tubers which plays an essential role in the blackening processes. The authors cover only the effect of herbicides on an increased susceptibility to tuber blackening [Ceglarek *et al.* 1990, Sawicka and Dialo 1997] or increased tendencies to this process in the tubers collected from plots sprayed with herbicides [Zarzecka *et al.* 1997].

Although the evaluation of french fries quality is most affected by the density, the quality of chips is mostly determined by their color. The color of chips is closely correlated with the content of monosaccharides in the tuber [Lisińska 1994, Mozolewski 2003, Mozolewski *et al.* 2011], which also coincides with the results of the present research (highly significant correlation coefficient = -0.58, Table 39). The right density of chips depends e.g. on the content of fat in chips which, in turn, is affected by the content of starch and dry matter in the raw material [Lisińska 1994, Lisińska 2000, Salvador *et al.* 2009]. A higher content of dry matter and starch in tubers of the cultivars researched had a positive effect on the density of chips, increasing the total score of the chips quality (correlation coefficient was highly significant and amounted to 0.70, Table 36).

The herbicides used during vegetation, decreasing the content of dry matter and starch and increasing total sugars, including reducing sugars in tubers, had a negative effect on the quality of fried products.

The requirements defining the quality characters of potato tubers for processing concern also, e.g. the tastefulness of tubers (Table 1). The tastefulness, namely a set of flavor and aroma sensations is a top character of culinary quality. It is a character which is difficult to define due to no possibility of defining the standard taste scale. The taste of an average consumer varies a lot and does not always coincide with sensations of people on the committee responsible for cultivar evaluation, adequately trained for that purpose. Based on the knowledge on the components affecting the flavor and aroma of potato, e.g.organic acids, sugars, solanine, volatile compounds, many researchers [Leszczyński 1994b, Wojdyła 1997, Lachman *et al.* 2001] have been trying to evaluate these characters by combining instrumental and sensory methods [Ulrich *et al.* 2000]. In the present paper the tastefulness of tubers, of all the characters studied, was affected by the following: the content of dry matter and starch, which is seen from significant positive values of correlation coefficient (Table 37). According to Leszczyński [2000], Rejewska and Kostyra [1991], Rogozińska [1987], watery potatoes of a low content of starch are usually less attractive in flavor than the cultivars containing more starch, that is more floury. The herbicides used on potato plantation in the present research slightly deteriorated the flavor and aroma qualities of tubers of both cultivars (on average by 0.5 using a 9-degree scale). Similarly as reported by Zarzecka [1997], Ceglarek *et al.* [1990], Kołpak *et al.* [1987], a lower tastefulness was found for tubers from objects treated with chemical weed killers, as compared with unprotected potato tubers.

The flesh color of potatoes cooked determines their esthetic qualities. What is looked for is the stability of the flesh color of tubers after cooking and possibly the lowest tendency to its change. As reported by Leszczyński [2000], Sawicka and Dialo [1997], Teodorczyk [1982], the color of the flesh is cultivar-specific, slightly modified by habitat conditions. The cultivars selected for the purpose of the present research differed slightly as far as the character discussed is concerned. The flesh of the tuber of 'Rywal' cultivar was more yellow than that of 'Saturna' cultivar, and the use of herbicides in potato growing did not affect the change in the flesh color. Methods of potato cultivation with the use of herbicides did not change the flesh color of tubers researched by Zarzecka [1997], either.

Table 36. Coefficients of correlation between selected characters after harvest

Character	Content of dry matter	Content of starch	Content of total sugars	Content of reducing sugars	Content of vitamin C	Content of chlorogenic acid
Tastefulness	0.36*	0.39*	ns	ns	ns	ns
Flesh color after cooking	ns	ns	ns	ns	ns	ns
Culinary and functional type	0.66**	0.64**	ns	-0.40*	ns	ns
Cooked flesh blackening (after 10’)	ns	ns	ns	ns	ns	ns
Cooked flesh blackening (after 24 h)	ns	ns	ns	ns	ns	-0.38*
Raw tuber flesh blackening	ns	ns	ns	ns	ns	0.95**
Quality of french fries	-0.61**	-0.61**	ns	ns	ns	ns
Quality of chips	0.70**	0.70**	ns	-0.58**	ns	ns
Chips color	ns	ns	-0.40*	-0.93**	ns	ns

* significant at $\alpha = 0.05$
** significant at $\alpha = 0.01$
ns – non-significant

Differences in the flesh texture make it possible to classify potatoes to a specific culinary and functional type, and thus defining their potential use [Komorowska-Jędrys 1997]. Of all the chemical components of tubers which can affect the texture, one can point to starch, pectin, metal ions, monosaccharides, phytin, nitrogen, citrates, phosphates and hydrogen ions [Hoff 1972, Horubała 1988]. An excessively high content of starch deteriorates the density, as swelling, it results in a destruction of cell structures [Leszczyński 1994b]. Of all the characters researched, the culinary and functional type of potatoes was significantly determined by the content of dry matter, starch, reducing sugars, which is seen from significant correlation coefficients (Table 36). The characters studied are affected by environmental factors [Komorowska-Jędrys 1997, Van Merle *et al.* 1997], but they are foremost cultivar-specific and depend on the degree of tuber maturity [Lisińska *et al.* 1989]. The herbicides used during the plant vegetation period did not change the functional and consumption type of potato tubers, which coincides with reports by Zarzecka [1997]. According to Ceglarek *et al.* [1990], Kołpak *et al.* [1987], Kłosińska-Rycerska [1971], the effect of herbicides on the texture of flesh is slight. According to the classification assumed by the Institute of Plant Breeding and Acclimatization, 'Rywal' is a cultivar classified as consumption and versatile functional type (B), while 'Saturna' – culinary intermediate – versatile functional to floury (BC). The present research results do not show such cultivar differences. Both cultivars, irrespective of the herbicides used during the vegetation period, demonstrated quite a compact density, were slightly floury, moist, of a delicate structure, which qualifies them as type B. In the reports by Zarzecka [1997], the genetic factor differentiated the cultivars as far as their functional and consumption type was concerned.

Defining the effect of herbicides on organoleptic characters of potato tubers (tastefulness, flesh color, culinary and functional type, tuber blackening after cooking) is very difficult, also due to a subjective character of the evaluation. The characters enumerated are mostly conditioned by the genetic factor and depend on the chemical composition of tubers [Komorowska-Jędrys 1997]. Transformations of chemical compounds considerably affect a comprehensive reception of sensory sensations by the consumer.

From the point of view of the nutritious value, the potato plays an essential role in supplying the man with high-quality protein, rich in exogenous amino acids (such which are not synthesized by the human body itself). Its applicability for anabolic purposes, which is very high biological value, is comparable to the best soybean protein, slightly inferior to the nutritious standard, which is the hen egg protein [Mazurczyk 2005]. In the present research the herbicides used on potato plantation significantly increased the content of total protein in tubers of both cultivars, as compared with the tubers from the control plots by 3.4%, and on average, for the objects with mechanical-chemical weed control, accounted for 10.25 $g \cdot 100\ g^{-1}$ of dry matter. Similar relations were also reported by Banaszkiewicz [1993], Ceglarek *et al.* [1990], Kołpak *et al.* [1987], Kłosińska--Rycerska *et al.* [1975, 1979]. Additionally the accumulation of protein in tubers is also affected by genetic conditions [Woda-Leśniewska 1993], which coincides with the results presented in this dissertation. 'Saturna' accumulated more protein than 'Rywal'. Dry years facilitate an increase in the content of total protein in tubers [Roztropowicz 1989, Pytlarz-Kozicka 2002], which is also seen from the present research. The highest content of protein was found in tubers collected in 2003 with the lowest rainfall (mean for objects 12.2 $g \cdot 100\ g^{-1}$ of dry matter).

Vitamin C is an essential wholesome exogenous nutrient for the man, and one of its main sources (according to the amount consumed) are potatoes [Borek--Wojciechowska 2000]. Many authors [Zarzecka and Gąsiorowska 2000, Zarzecka *et al.* 1997, Woda-Leśniewska 1993, Ceglarek *et al.* 1990, Kołpak *et al.* 1987] claim that herbicides increase the content of vitamin C in tubers, which coincides with the present results. As compared with the control, the content of vitamin C in tubers was higher by an average of 5.5%. The highest positive effect on the content of vitamin C in tubers was found for the weed-killing agent Azogard 50 WP. Other results are reported by Laaniste *et al.* [1999]; after the use of herbicides from triazine group which decreased the content of that compound in tubers. The factor which differentiated the level of vitamin C in the tubers researched were also genetic conditions. 'Saturna' accumulated more of it than 'Rywal'. Differences in vitamin C content across cultivars are also reported by Zarzecka and Gugała [2003], Rogozińska [2000], Zarzecka and Gąsiorowska [2000].

Potato tubers should demonstrate characters closely corresponding to the direction of use, also over the period long before harvest (e.g. production of chips and french fries is not seasonal and takes all year). Potato storage is a crucial element of production technology. During storage in potato tubers, containing from 75 to 85% of water, there occur processes of respiration, evaporation and sprouting, changing their chemical composition, as well as quantitative losses [Sobol 2005]. The storage is to create such temperature and humidity conditions which would limit tuber weight losses and which would allow maintaining adequate quality characters required by respective use directions.

Reports by Sowa-Niedziałkowska [1999, 2000], Rastovski [1981] on the effect of potato growth conditions, the cultivar, storage time and conditions on fresh weight losses coincide with the present research results. Low temperature and high relative air humidity over 95% limit the natural losses [Sowa-Niedziałkowska 2002, 2004a]. With an increase in temperature and prolonged storage time, natural losses (fresh weight losses) are higher, which is mainly due to the processes of water excretion from tubers and sprouting. In the present research, average for the objects and years, fresh weight losses of tubers stored at the temperature of +8°C accounted for 2%, and in chambers with the temperature of +4°C – 1.1%. The highest losses (mean from objects 8.9%) were reported after 6 months of storage in 'Rywal' stored in chambers at the temperature of +8°C. The storage life of tubers, conditioned by the genetic factor, depends on many interacting conditions both in the time of growth and time of storage [Sowa-Niedziałkowska 2000, 2001]. The present research results point to tendencies to lower losses of fresh weight of tubers from plots sprayed with herbicides, of a lower degree of weed infestation. Potato tubers collected from weed-infested plots are more exposed to mechanical damage which can increase the intensity of life processes during storage, thus increasing the natural losses. An increase in losses even by 1% decreases profits and the quality of the tubers stored [Sowa-Niedziałkowska 2004b].

During potato tuber storage, the content of dry matter and starch changes and it is connected with the process of respiration and sprouting [Zgórska and Frydecka--Mazurczyk 1985]. To weaken these processes, one shall maintain an adequate temperature which for most cultivars and directions of use ranges from +4 to +6ºC. Over that temperature range a decrease in the content of dry matter according to Kaaber *et al.* [2001] is about 0.5-1.5%. The storage of potatoes destined for processing only is quite different. They require higher temperatures +8 to +10ºC. In such conditions the content of dry matter increases. The increase, however, is apparent and is connected with a loss of water as a result of transpiration [Zgórska and Frydecka-Mazurczyk 2000, Kaaber *et al.* 2001]. Losses of dry matter and starch are unfavorable since a decrease in the content of dry matter by 2% results in a change in texture and tubers show a tendency to an uneven cooking, which decreases their technological value [Kaaber *et al.* 2001, Zgórska 2005a]. In the present research a decrease in the content of dry matter and starch in potato tubers stored at the temperature of +8°C, having considered natural losses, was on average for the objects 0.4% after 3 months and 0.9% after 6 months, as compared with the content of these compounds after harvest. On the other hand, changes in the content of dry matter and starch in tubers stored at the temperature of +4°C were inconsiderable and accounted for 0.2% (losses of dry matter and starch in fresh weight) after 3 months and 0.5% of the components discussed after 6 months.

The quality of french fries from tubers stored for 6 months at the temperature of +8ºC deteriorated slightly, as compared with the quality evaluated directly after harvest (mean for objects by 0.15 degree). 'Saturna' showed better parameters which affect the total evaluation of the end product. The quality of french fries was affected by, similarly as after harvest, the content of dry matter and starch (Table 37). The density of the french fries obtained from potato tubers stored for 6 months was harder than after harvest, which is connected with an apparent increase in the content of dry matter and starch as a result of water loss in the process of transpiration. Similar relationships were reported by Mozolewski [2003], obtaining french fries of better parameters after storage than after harvest since an apparent increase in the content of dry matter and starch in tubers of the cultivars he investigated was, in that case, favorable.

The process of an excessive transpiration can be prevented applying, apart from a high air humidity in the storage room (about 95%), also a low temperature (about +4°C). However, in these conditions there is a double (or higher) increase in the content of sugars, especially reducing sugars the level of which increases with the storage time, deteriorating the color of chips [Hertog *et al.* 1997, Lisińska and Leszczyński 1989, Cheong *et al.* 1999, Coob 2000]. It is a phenomenon commonly known which is a result of the decomposition of starch in tubers. A lowered temperature facilitates catalytic activity of phosphorylase; the enzyme results in starch decomposition by phosphorolyze to glucose-1-phosphate [Grzesiuk and Górecki 1994]. The present dissertation confirms an opinion that during storage the content of reducing sugars in tubers is much differentiated by genetic properties of the cultivar [Horubała 1988]. Tubers of 'Saturna' accumulated less reducing sugars during storage at low temperatures, unlike 'Rywal' and analyzed after 3 months met the requirements concerning that character for chips production (after 6 months the content of monosaccharides was higher than that recommended by IHAR, Table 1). 'Rywal' tubers after storage, both at the temperature of +8°C and at +4°C, did not meet the raw material requirements for chips production as far as the content of reducing sugars was concerned (the desired value is 0.15%). This cultivar can be a raw material for chips production, however after the technological treatments which enhance their color, e.g. a treatment of potato slices with hot water (blanching) [Lisińska 2000] or reconditioning [Zgórska and Czerko 2006]. The chips produced from tubers stored for 6 months were darker in color than those evaluated after harvest (the mean difference for objects was 1.4 degree in a 9-degree scale), and the coefficient of correlation between the content of reducing sugars and the chips color was highly significant (Table 37). The accumulation of monosaccharides is the main parameter defining the applicability of the cultivar to fried products [Hertog *et al.* 1997, Lisińska 2004, Putz 2004]. Despite a difference in the evaluation of the color of chips obtained from tubers after harvest and storage, their total score was good. A positive effect on the evaluation of chips was attributed to their density, which includes the content of dry matter and starch in tubers -apparently higher after storage (Table 37). In the cultivars researched the content of total sugars increased proportionally to the storage time in tubers stored for 6 months in different thermal conditions, especially in chambers with the temperature of +4°C. An increased content of the sum of reducing sugars and saccharose in the tubers researched had a negative effect on the color of chips (Table 37). Therefore it is recommended to use higher temperature to store raw materials for the production of enriched products.

Table 37. Coefficients of correlation between selected characters after 6-month storage at the temperature of +8°C

Character	Content of dry matter	Content of starch	Content of total sugars	Content of reducing sugars	Content of chlorogenic acid
Cooked flesh blackening (after 10’)	ns	ns	ns	ns	-0.79**
Cooked flesh blackening (after 24 h)	ns	ns	ns	ns	-0.84**
Raw tuber flesh blackening	ns	ns	ns	ns	0.38*
French fries quality	-0.36*	-0.40*	ns	ns	ns
Chips quality	0.38*	0.39*	ns	-0.87**	ns
Chips color	ns	ns	-0.39*	-0.95**	ns

* significant at $\alpha = 0.05$
** significant at $\alpha = 0.01$
ns – non-significant

During storage there is observed a considerable increase in blackening of the flesh of raw and cooked tubers, which is a result of the decrease in e.g. the content of vitamin C and increase in the chlorogenic acid. An especially clear increase in the intensity of blackening is noted in spring [Leszczyński 1994a], and it is connected with life processes, e.g. sprouting. At high storage temperature there occur excessive water losses (10%) which result in physiological blackening [Horubała 1988].

After 3 and 6 months of storage at the temperature of +4 and +8°C the tubers of the cultivars researched, mean of all the objects, demonstrated significantly higher tendency to enzymatic blackening than after harvest, and lower storage temperature was increasing that tendency. At lower storage temperature tubers accumulated a greater amount of chlorogenic acid which significantly determined the susceptibility to raw flesh blackening (correlation coefficient of 0.90).

Similar relations were reported by Pobereżny [2006], Pawelzik and Delgado [1999]. According to many authors [Amberger and Schaller 1975, Rogozińska *et al.* 1986, Zgórska 1989, Lisińska 1994, Archana 2000], the content of chlorogenic acid increases during storage, especially at low temperature. Besides the amount of the organic acid discussed in tubers stored in chambers with the temperature of +8ºC individual predisposition of cultivars to a change in the content of chlorogenic acid during storage had a significant effect.

After 6-month storage period, cooked tubers, evaluated both after 10 minutes, and after 24 hours, had a greater tendency to flesh blackening than the tubers analyzed right after harvest. ‘Saturna’, similarly as after harvest, blackened more (on average by 0.4 in a 9-degree scale) than ‘Rywal’. The degree of cooked tuber blackening exposed for 10 minutes and 24 hours at the temperature of about 21°C was affected by chlorogenic acid, which is shown by significant coefficients of correlation (Table 38). Chlorogenic acid increased the tendency to chemical blackening. Such relations are reported by Lisińska and Leszczyński [1989], Leszczyński [1994b]. In practice tuber blackening depends on the ratio of the citric acid to chlorogenic acid [Müller 1988, Rogozińska 2002, Wichrowska *et al.* 2009].

Table 38. Correlation coefficients between selected characters after 6 months of storage at the temperature of +4°C

Character	Content of dry matter	Content of starch	Content of chlorogenic acid
Tastefulness	0.68**	0.68*	ns
Flesh color after cooking	ns	ns	ns
Culinary and functional type	0.69**	0.68**	ns
Cooked flesh blackening (after 10’)	ns	ns	-0.36*
Cooked flesh blackening (after 24 h)	ns	ns	-0.39*
Raw tuber flesh blackening	ns	ns	0.90**

* significant at $\alpha = 0.05$
** significant at $\alpha = 0.01$
ns – non-significant

Characters defining the consumption value of tubers (tastefulness, tuber flesh color, culinary and functional type) did not undergo considerable changes during storage. The characters listed were affected by the same factors as after harvest. The tastefulness was positively correlated with the content of dry matter and starch (Table 39), similarly as after harvest. The flesh color after cooking depends on the content of carotenoids and anthocyanins and is cultivar-specific [Leszczyński 2000]. Texture--forming characters, determining the functional and consumption type did not change essentially during storage. With an increase in the content of dry matter and starch, the evaluation of the tendency to overcooking, density, floury character, moisture and flesh structure were higher.

The length of the storage period and thermal and moisture conditions of the storage room can deteriorate the technological value of tubers, (by changes in the content, e.g. of dry matter, starch, sugars), and they can also affect the changes in the content of nutritive substances including vitamin Cand protein [Rogozińska 1989, Zgórska and Frydecka-Mazurczyk 1997, Gąsiorowska 2000] and harmful substances e.g. decrease nitrates [Cieślik *et al.* 2007, Wichrowska and Wojdyła 2011].

The content of total protein in tubers stored in chambers with the temperature +4 and +8°C differed significantly depending on the cultivar and storage time, similarly as reported by Rogozińska [1987, 1989]. After storage total protein losses occurred, similarly as losses of the dry matter and starch in tubers. After 3 months of storage in chambers with the temperature of +8°C protein losses were 2.9%, and after 6 months – 4.9%. At lower storage temperature the losses of that component were lower and after 3 months accounted for 1%, and after 6 months – for 2.9%.

During storage both forms of vitamin C (ascorbic acid and dehydroascorbic acid) undergo irreversible oxidation to products biologically inactive (2,3- diketo-L-gluconic acid). The process intensifies during tuber sprouting [Zgórska 1996], and so an optimal temperature to minimize vitamin C losses is +4 to +6°C. The content of vitamin C in tubers of the cultivars researched decreased significantly after storage, both at the temperature of +8, and +4°C, mean for objects, respectively, by 48.6% and 39.8% after 3 months of storage and in tubers analyzed after 6 months – 5.7% and 5.3% more. According to Frydecka-Mazurczyk and Zgórska [2000c], the content of vitamin C after seven-month storage decreases even by 60-80%.

In modern agriculture to protect potato plantation from weeds, it is recommended to use herbicides since it is possible to obtain high weed-killing effectiveness and a considerable increase in tuber yield and desired economic indices [Gruczek 2000, Zarzecka *et al.* 2000]. For potato producer selecting the potato plantation weed control method, the cost-effectiveness of treatments is decisive [Mierzejewska 1992].

The present research results showing a greater effectiveness of the mechanical-and-chemical control method, as compared with the mechanical weed control method, coincide with reports by many authors [Zarzecka 1997, 2000, Zarzecka *et al.* 1997, Gruczek 2001, 2003, Zarzecka and Gugała 2004 b, c, Urbanowicz 2005]. The use of herbicides decreased the number of weeds determined before row-closing and prior to tuber harvest. The most effective herbicide in weed control was Afalon 50 WP (linuron) which decreased the number of weeds over 5-fold determined before row-closing. The weed infestation determined at the end of vegetation period facilitated the right comparison of all the objects and defining the dependence of yielding on the degree of weed infestation. Least effective in weed control was Azogard 50 WP (prometrin), even though it decreased the number of weeds by more than half. A definite advantage of mechanical-and-chemical over mechanical weed control is also reported by Gruczek [2000, 2001], where treatments with the use of herbicides killed 65-96% of weeds, Rymaszewski *et al.* [1996] – 42-96%, Domańska *et al.* [1988] – 45-90%. According to Zarzecka [1997], the highest effectiveness in weed control both prior to row closing and prior to tuber harvest was reported for spraying twice, up to emergence with Afalon 50 WP twice, and after emergence – with Fusilade Super (fluazifop-p-ethyl 7,5), as well as herbicide Bladex 50 WP (cyanazine) used before emergence, and after emergence Nabu 20 EC (sethoxydim), limiting weed infestation at the beginning of vegetation period 10- and 6-fold, and prior to harvest over 5-fold, as compared with the control.

The weed infestation is also significantly affected by the cultivars researched, similarly as reported in the experiments carried out by Zarzecka and Baranowska [2004], Zarzecka and Gąsiorowska [2002c]. Cultivars with stem habit were little competitive as compared with weeds. In the reports by Zarzecka and Gugała [2004c], as well as reported in the present research, the lowest weed infestation was found in 'Rywal', demonstrating leaf-and-stem habit and the earliest emergence and producing the highest plants. The relationship between the development rate and the amount of the overground part tuber weight and the weed infestation is also reported by Zarzyńska [2006], who claims that 'Wawrzyn' of the highest stem and leaf weight was least weed-infested. Similar results were also provided by Pawłowski and Pomykalska [1987b], Zawiślak *et al.* [1986] and Zarzecka [1997].

The number of weeds co-depended on the herbicides used and rainfall and temperature distribution during the vegetation period of potato plants. A negative effect of a low soil moisture on the weed-killing effectiveness of active substances of herbicides is reported by Zarzecka [2000], Urbanowicz [1999], Sawicka and Skalski [1993]. According to Dobrzańska and Dobrzański [1979], the most optimal temperature for herbicides application is 10-25°C. In the present research in 2003, due to drought during the use of herbicides, the amount of the spray liquid was doubled, the effect of which was high effectiveness, especially that of the agents used after potato emergence (at air temperature of about 15°C).

As reported by many authors [Pawłowski and Pomykalska 1988, Ceglarek and Zarzecka 1991, Pomykalska 1991, Pałys 1994, Zarzecka and Gąsiorowska 2002a, Zarzecka and Gugała 2004a], the level of weed infestation is a factor determining potato yielding and yield losses caused by the presence of weeds can account for as much as 80% [Domańska 1988, Renner 1998, Adamczewski 2000, Gruczek 2000]. In the present research the highest total yield was reported from plots which were least weed-infested, with mechanical-and-chemical weed control with the use of herbicide Afalon 50 W; it was 20% higher for 'Rywal' and 26.5% for 'Saturna', as compared with the control (Table 40). From that object also the highest commercial yield for both cultivars was recorded (Table 40). A decrease in the yield of commercial fraction of both cultivars by 2.5-7.8%, as compared with the control, was reported on the plots with the use of herbicide Apyros 75 WG + adjuvant Atpolan 80 EC. From these objects the smallest tubers were collected even though weed infestation was significantly lower than on the control plots. The reaction to the herbicide used was stronger in 'Saturna'. A negative reaction of cultivars to the herbicides used, expressed in yield decreases, was also noted by Boligłowa 2004, Ceglarek and Księżak [1992], Adamiak [1985], which can be an effect of phytotoxicity to the active substance of the herbicide, e.g. in the case of the use of the preparation with metribuzin, but also other herbicides, as reported by Zarzecka and Gąsiorowska [2002c] (Basagran 600 SL – bentazon), while in reports by Pawłowski and Pomykalska [1988] herbicides did not modify the yielding of potato cultivars significantly, however they caused slight but favorable changes in the structure of tuber yield. According to Zarzecka [2000], herbicides play a yield-protecting role, which also applies to the commercial fraction.

The total yield and that of commercial fraction are significantly differentiated by the cultivar factor, which is reported by Zarzecka and Gugała [2004a]. Of all the cultivars they researched, 'Rywal' yielded highest in all the research years and the total yield was on average 47.6 $t \cdot ha^{-1}$. Similar results were obtained in the present research where the total yield for 'Rywal' was on average 46.8 $t \cdot ha^{-1}$ and it was higher in each research year than in 'Saturna', which considerably resulted not only from its genetic characters but also tolerance to climatic-and-soil requirements. The level of yielding was also modified by pluviometric conditions in the research years. The highest yield was reported in 2002, 2004, of the most favorable rainfall and temperature distribution in the initial development phase of potato plants and over tuber formation. The lowest potato yield was recorded in 2003, showing a low total rainfall over the vegetation period. Similar yielding dependence on thermal-and-moisture conditions was demonstrated by Głuska [1994] and Mazurczyk [1996].

Table 40. Relation between the total and commercial yield of ‘Rywal’ and ‘Saturna’ potato tubers as affected by the herbicides used, as compared with the control (%)

Herbicides used	Cultivars	Total yield	Commercial yield*
Without herbicide (control)	Rywal Saturna	100.0	
Afalon 50 WP	Rywal Saturna	120.0 126.5	119.3 135.4
Sencor 70 WG + adjuvant Olbras 88 EC	Rywal Saturna	115.2 114.3	105.6 108.3
Apyros 75 WG + adjuvant Atpolan 80 EC	Rywal Saturna	110.6 121.8	97.5 92.2
Azogard 50 WP	Rywal Saturna	119.3 126.5	102.8 107.5

* tuber fractions > 40 mm in diameter

Obtaining a high yield of tubers from the plantations protected (not only from weeds), guarantees a return on costs connected with potato production and its storage, provided that the raw material is of high quality, including its nutritious and functional value. Modern potato production technology involves e.g. the use of herbicides, which can affect the metabolism of components, changing their content in tubers after harvest and storage. In the production of foodstuffs it is essential to ensure food safety. It is possible e.g. by implementing the HACCP system (Hazard Analysis and Critical Control Points), which covers control over the entire production process of potato products from obtaining the raw material to the end product. The principles of GMP (Good Manufacturing Practice) cover everything which is connected with hygiene and sanitary requirements which cover physical, chemical and microbiological threats at each stage of product manufacturing. The HACCP concept involves the identification of critical points in the entire product manufacturing process. They require a constant monitoring to guarantee that the foodstuffs produced totally comply with health safety. It concerns raw materials, technical equipment and the pattern of the technological process which affects the health status of the end product. For that reason performing research on the effect of weed killing agents used during the vegetation period on the qualitative characters of cultivars and their individual reaction to the active substance of herbicides, throughout the raw material use for consumption and processing. Based on the present domestic and foreign literature review, one can state that there is little coverage on the scope of research on that problem, especially little coverage on the effect of storage conditions on the content of components responsible for the creation of colorful complexes in tubers. There are no reports on the effect of herbicides on the potato yield size and quality and the evaluation of cultivars grown in the macroregion of the South Pomeranian Lakeland. These problems call for further research.

CONCLUSIONS

The research results obtained make it possible to formulate the following conclusions:

1. The synthesis of the research results after harvest for long-term experiments showed that the application of herbicides over the plant vegetation period significantly affected the following:
   - a decrease in weed infestation of the plantation, on average by about 67%,
   - an increase in the total yield of tubers per hectare, an average of about 16%,
   - differences in the structure of the tuber yield, the biggest number of tubers the diameter of which exceeded 55 mm was obtained from the object least weed--infested after the use of Afalon 50 WP agent,
   - a decrease in the content of dry matter and starch in tubers, respectively by 3.6% and 5.1%,
   - an increase in the content of wholesome compounds in tubers, namely total protein and vitamin C, compounds decreasing the technological applicability of the raw material, namely total sugars, respectively by 3.5%, 5.5%, 24.6%, 13.8%, as well as chlorogenic acid in tubers by 11.7%, which increased the susceptibility of tubers to blackening of flesh, especially raw flesh.
2. The herbicides used for potato weed control had a negative effect on the consumption and technological value of tubers, deteriorating their flavor and aromatic qualities, they also increased the degree of blackening of the flesh of cooked tubers and had a negative effect on the color of chips.
3. The characters given above and the content of reducing sugars, the content of the following chlorogenic acid in tubers as well as the tuber flesh color were conditioned by the genetic factor:
   - the total yield of tubers of 'Rywal' was significantly higher than of 'Saturna', by 26% and accounted for 46,8 $t \cdot ha^{-1}$,
   - the content of dry matter, starch, protein, vitamin C, chlorogenic was higher in tubers of 'Saturna', the content of the other components, namely total sugars, including reducing sugars was higher in 'Rywal' tubers,
   - The flesh of raw and cooked 'Rywal' tubers was blackening less than in 'Saturna'.
4. The synthesis of research results after storage for long-term experiments demonstrated that the storage time modified the level of the components in potato tubers of both cultivars. Genetic conditions significantly differentiated the content of the compounds researched after storage, similarly as after harvest:
   - the content of dry matter and starch decreased significantly proportionally to the storage time, greater decreases in both components occurred in tubers stored at a higher temperature (+8°C),
   - the content of total protein in potato tubers significantly decreased after 3 and 6 months of storage in chambers with the temperature of +8°C, while a significant decrease in the content of this component in tubers stored at the temperature of +4°C was recorded only after 6 months,

- potato tubers stored in different thermal conditions, especially at lower temperature (+4°C), demonstrated significantly higher content of total and reducing sugars as compared with the content after harvest. This tendency decreased the tuber processing applicability,
- vitamin C losses, irrespective of the tuber storage conditions, were very high in the first storage period (they accounted for over 44%). Another 3 months of tuber storage did not result in such high vitamin C losses (further losses were about 5%),
- the content of chlorogenic acid citric acid was increasing with storage time, more considerably in tubers stored in chambers with lower temperature (+4°C),
- an increase in the content of chlorogenic acid in tubers after storage increased the susceptibility of tuber flesh to blackening.

5. The storage life of tubers measured with the amount of natural losses and changes in the chemical composition depended on the genetic conditions of the cultivar and the storage time. The interactive effect of the storage time and the herbicides over the vegetation period differentiated only the level of dry matter in tubers stored in chambers with the temperature of +8°C. The highest losses of fresh weight were recorded after 6 months of storage for ‘Rywal’ stored at a higher temperature.
6. ‘Saturna’ demonstrated a higher storage life and better characters conditioning its applicability to chips production than ’Rywal’, both after harvest and after storage, irrespective of the herbicides applied over the vegetation period.
7. The selection of herbicides to potato plantation weed control should depend not only on the weed control effectiveness but also on their effect on the plant development, yielding, chemical composition and the technological and consumption value of the raw material:
   - as compared with the herbicides selected for the purpose of the present research, the most effective in weed control as well as modifying quality parameters to a degree facilitating the use of the raw material for consumption and processing purposes was Afalon 50 WP agent.

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