ROŚLINY OLEISTE – OILSEED CROPS 35: 21-35 2014

Teresa Piętka, Jan Krzymański, Krystyna Krótka, Iwona Bartkowiak-Broda
Instytut Hodowli i Aklimatyzacji Roślin – Państwowy Instytut Badawczy, Oddział w Poznaniu
Autor korespondencyjny – J.Krzymański, e-mail: krzym@nico.ihar.poznan.pl
DOI: 10.5604/12338273.1146157

Double low white mustard (*Sinapis alba* L. syn. *Brassica hirta*) is a source of protein and oil*

Podwójnie ulepszona gorczyca biała (*Sinapis alba* L. syn. *Brassica hirta*) – jako źródło białka i oleju

Key words: white mustard (syn. yellow mustard), erucic acid, n-3/n-6 polyunsaturated fatty acids, glucosinolates, sinalbin, fodder protein, edible protein, edible oil

Abstract

Research on improvement of the chemical composition of white mustard seeds has been carried out in Plant Breeding and Acclimatization Institute in Poznań (Poland) for 30 years. This work was undertaken because of the huge deficit of protein fodder in Europe. This deficit is covered by imports of soybeans and soy meal, mostly GMO.

In the presented study, the genetic source was the plant population produced by inter-crossing of 17 varieties and lines or strains of white mustard. Individual plant selection linked with inbreeding was used. Plant selection was made based on chemical analyses of seeds. Lines characterized by low erucic acid content in seed oil or by low glucosinolate content in seeds were bred.

Then a number of new double low ("00") lines of white mustard were selected from the hybrids between low erucic lines and lines with very low glucosinolate content. Based on field experiments carried out in many different environments a new double low ('00') variety was selected from this material. Low yielding linked with elimination of erucic acid and sinalbin (the main glucosinolate of white mustard) was overcome in the new variety. This variety is characterized by very low erucic acid content in oil (less than 1.5%), lack of sinalbin and very low content of other glucosinolates in seeds (less than 15 $\mu M \cdot g^{-1}$). In Poland, it was licensed as the 'Warta' variety in 2011. This type of white mustard varieties can help to reduce the European deficit of plant protein for fodder and food purposes.

Słowa kluczowe: gorczyca biała, kwas erukowy, n-3/n-6 wielonienasycone kwasy tłuszczowe, glukozynolany, sinalbina, białko pastewne, białko jadalne, olej jadalny

Streszczenie

Badania nad ulepszaniem składu chemicznego nasion gorczycy białej na drodze hodowlanej są prowadzone w Instytucie Hodowli i Aklimatyzacji Roślin w Polsce od 30 lat. Prace te podjęto ze względu na olbrzymi deficyt białka paszowego w Europie. Deficyt ten jest pokrywany importem soi i śruty sojowej, głównie GMO.

* Last three years of the study was sponsored by Polish Ministry of Science and Higher Education – project R12 006 01.

W przedstawionych badaniach wyjściową bazą genetyczną była populacja roślin otrzymanych przez przekrzyżowanie pomiędzy 17 odmianami i liniami lub rodami gorczycy białej. W pracach wykorzystywano selekcję indywidualną pojedynczych roślin połączoną z chowem wsobnym. Wyboru roślin dokonywano na podstawie analiz chemicznych nasion. Początkowo zostały wyselekcjonowane linie i rody charakteryzujące się niską zawartością kwasu erukowego w oleju z nasion lub niską zawartością glukozynolanów w nasionach.

Następnie szereg nowych podwójnie ulepszonych linii gorczycy białej zostało wyselekcjonowanych z mieszańców pomiędzy liniami niskoerukowymi i liniami z bardzo niską zawartością glukozynolanów. Po doświadczeniach polowych, przeprowadzonych w wielu zróżnicowanych środowiskach, nowa podwójnie ulepszona odmiana została wybrana z tego materiału. Niska produktywność powiązana z eliminacją kwasu erukowego i sinalbiny (główny glukozynolan gorczycy białej) została przełamana w nowej odmianie, która charakteryzuje się bardzo niską zawartością kwasu erukowego w oleju (mniej niż 1,5%), brakiem sinalbiny oraz bardzo niską zawartością innych glukozynolanów w nasionach (mniej niż 15 $\mu M \cdot g^{-1}$). W Polsce została ona zarejestrowana jako odmiana Warta w 2011 roku. Tego typu odmiany gorczycy białej mogą przyczynić się do zmniejszenia europejskiego deficytu białka roślinnego, zarówno paszowego jak i spożywczego.

Introduction

EU countries are not self-sufficient in terms of protein production for the feed and food uses. In recent years, annual import of soybean seeds and meal as a source of protein for food and feed to the European Union is about 30 million tons (de Visser 2014). Table 1 shows import of soybean seeds and meal to the European Union (EU27) in last years which was calculated from the USDA (2014) data based on the assumption that 80% of the soybean ends up in the meal. Under these conditions, the search for new alternative plants that can be introduced into cultivation has become very important especially because of the shortage of protein sources in European Union and the necessity of sustainable production in agriculture. One of such domestic sources of plant protein may be white mustard.

White mustard (*Sinapis alba* L. syn. *Brassica hirta*) belongs to the genus *Brassica*, which is considered as one of the most important genera contributing to agricultural production. Today *Brassica napus*, *Brassica rapa* and *Brassica juncea* are cultivated worldwide as a result of successful breeding programs which altered the chemical composition of seeds of these species. *Brassica* seeds are characterized by high content of oil and protein but the seeds of traditional varieties contain antinutritional compounds like: erucic acid (25–50% in seed oil) and glucosinolates (up to 180 µmol/g of seeds). The antinutritive character of erucic acid has been associated with poor animal growth and abnormal lipid metabolism in heart and skeletal muscle tissue (Abdellatif 1972, Abdellatif and Vles 1970, 1971, Roine et al. 1960). Glucosinolates disturb iodine metabolism and some of them possess strong goitrogenic properties besides other adverse effects (European Food Safety Authority 2008). Sharp unpleasant smell of oils from the seeds of Brassica is caused by glucosinolate breakdown products arising in the course of processing the seed at the oil mill. Particularly strong odor occurs during frying on such oils (George and Töregård 1978).

Table 1

Import of soybean seeds and meal to the European Union (EU27) in the last 15 years (in thousand metric tons) — *Import nasion i śruty sojowej do Unii Europejskiej (UE27) w ostatnich 15 latach (w tysiącach ton)*

Market year *Rok rynkowy*	Import of — *Import*		
	meal — *śruta*	seeds — *nasiona*	meal and seeds×0,8 *śruta + nasiona×0,8*
1999	18 012	14 122	29 309,6
2000	17 776	17 675	31 916,0
2001	20 011	18 783	35 037,4
2002	20 633	17 023	34 251,4
2003	22 128	14 751	33 928,8
2004	22 019	14 591	33 691,8
2005	22 947	14 014	34 158,2
2006	22 362	15 181	34 506,8
2007	24 619	15 139	36 730,2
2008	21 153	13 213	31 723,4
2009	20 879	12 683	31 025,4
2010	21 877	12 472	31 854,6
2011	20 872	12 070	30 528,0
2012	16 943	12 506	26 947,8
2013	18 900	12 300	28 740,0
2014[a]	19 800	12 500	29 800,0

[a] Estimated — *Przewidywane*

Data calculated on the basis of USDA (2014) — *Dane obliczone na podstawie USDA (2014)*

The discovery or development of *Brassica* genotypes with very low erucic acid content in seed oil or with very low glucosinolate content in seeds give the possibility to develop double low varieties. The genetic source of very low glucosinolate content was ‘Bronowski’, the Polish variety of spring *B. napus* (selected from Polish local variety, licensed in 1956). Low glucosinolate content in seeds of Bronowski variety was discovered in 1967 (Krzymański 1968, 1970, Finlayson et al. 1973, Busch et al. 1994, Stefansson and Downey 1995). The genetic sources of low erucic acid content in seed oil of spring *Brassica napus* were zero erucic lines selected from the variety ‘Liho’ (Stefansson et al. 1961, Stefansson and Hougen 1964, Stefansson and Downey 1995). Liho variety is a German selection from local variety collected in Poland. Zero erucic turnip rape *B. rapa* was selected from interspecific crosses with *B. napus* (Downey 1964). Zero erucic brown mustard *B. juncea* was obtained in a similar manner (Love et al. 1991).

New double low varieties of *Brassica* genus should comply with the Polish requirements according their seed composition. This requirements concern fatty acid composition of seed oil and the glucosinolate content in seeds. Erucic acid content in seed oil should be lower than 2% and the glucosinolate content in seeds below 15 μM per gram. Similar Canadian requirements has canola standard. The official definition of canola is: "Seeds of the genus *Brassica* (*Brassica napus*, *Brassica rapa* or *Brassica juncea*) from which the oil shall contain less than 2% erucic acid in its fatty acid profile and the solid component shall contain less than 30 micromoles of any one or any mixture of 3-butenyl glucosinolate, 4-pentenyl glucosinolate, 2-hydroxy-3-butenyl glucosinolate, and 2-OH-4-pentenyl glucosinolate per gram of air-dry, oil-free matter" (canola standard of Canola Council 2012). This standard concerns only four alkenyl glucosinolates: gluconapin, glucobrassica-napin, progoitin and napoleiferin but lack in it sinigrin the main glucosinolate of *Brassica juncea*. Canola standard is not applicable for white mustard which contains sinalbin as main glucosinolate. Polish standard is more demanding, it refers to all glucosinolates.

Development of new varieties with canola like quality has made these species important sources of oil for edible and technological purposes and of protein for fodder purposes. 'Tower', the first low erucic acid and low glucosinolate spring variety of oilseed rape was developed at the University of Manitoba in 1974 (Stefansson and Kondra 1975). The first variety of turnip rape with double low quality was 'Candle' developed by AAFC (Agriculture and Agri-Food Canada, Saskatoon, Canada) in 1977 (Canola Council of Canada 2012a). Canola quality *B. juncea* varieties 'Avid' and 'Amulet' were also developed in Canada in 2002 (Potts et al. 2003, Canola Council of Canada 2012a). The first double low quality winter oilseed rape variety 'Jantar' was developed in Poland and licensed in 1985 (Krzymański et al. 1987).

White mustard is an annual plant of the family *Brassicaceae*. This plant is another species adapted to temperate climate, characterized by high protein and oil content in seeds, but in order to be acceptable as a source of fodder or edible protein and edible oil, it needs to meet at least the canola standards. In Poland, to be considered as "double improved" (or "double low" or "00") quality, the seeds of winter or spring oilseed rape (*B. napus*) should contain less than 2% erucic acid in its fatty acid profile and the total of alkenyl- and indolyl glucosinolates should be less than 15 $\mu M \cdot g^{-1}$ of seeds. Development of the white mustard variety of this kind was the aim of the presented works.

The main oilseed crop in Poland is winter oilseed rape. This plant produces the highest seed and oil yields in the agronomic and climatic conditions of Poland. However, during severe winters, which occurred during some years (for example 2011/12) in Poland, there are substantial losses of winter oilseed rape plantations. Farmers try to compensate for these winter losses by the sowing of spring oilseed rape. Seed yields of spring oilseed rape in comparison to winter form are much lower. In addition, this yield is highly variable because of periodic droughts.

White mustard, as compared with spring rapeseed, is characterized by a more stable yield and especially by its better resistance to temporary droughts frequent in climatic conditions of Poland (Muśnicki et al. 1997, Toboła and Muśnicki 1999, Jankowski and Budzyński 2003). Its economic importance is continuously increasing due to many possible uses (Sawicka and Kotiuk 2007), such as: seed production, for sowing as after crop, as plant important for nematode control in crop rotation and also as plant suitable for bees collecting the honey. White mustard cultivated as an after crop may serve also as a phytosanitary treatment. The green mass of white mustard produced as after crop can be used as pasture or ploughed as manure.

Seeds of white mustard are pale yellow which is connected with lower fiber and higher protein contents as compared with seeds of rapeseed. High glucosinolate content (about 180 $\mu M \cdot g^{-1}$ of seeds), favorable for the spices and table mustard production, does not permit the use of white mustard seeds, meal or expeller-cake as a protein source in the feed or food (Krzymański 1995, Slominski et al. 1999). The content of these harmful sulphur compounds causes poor animal growth and disorders of iodine metabolism associated with thyroid hypertrophy. The main glucosinolate occurring in seeds of white mustard is sinalbin (about 150 $\mu M \cdot g^{-1}$). These seeds also contain small quantities of glucotropeolin (precursor of sinalbin), alkenyl and indolyl glucosinolates.

The seed oil of currently cultivated varieties of white mustard contain a large amount of erucic acid (about 40%) harmful for health. The only exception is zero erucic 'Bamberka' variety (COBORU 2006, Piętka and Krzymański 2007a).

The target of research described in this paper as well as breeding works was to develop the new genotype of white mustard with double improved quality according to Polish standard. These works were performed in the programs carried out at the Poznan Division of the Plant Breeding and Acclimatization Institute. This publication summarizes the results of more than 30 years of such works and it tries to show the benefits of growing double-low white mustard.

Materials and methods

Starting material was the population created as a result of free inter-crossing of 17 varieties and strains of white mustard of different origin (Table 2). These items were chosen from 30 varieties and strains of white mustard evaluated for seed yield in field trials in 1981. Some of the varieties used in the development of the prebreeding material had traits desirable for seed quality and yield improvement. For example: variety 'Borowska' produced very large seeds compared to other varieties, variety 'Kastor' had over 10 seeds per pod, variety 'Trico' contained high oil content in seeds, Canadian strains were characterized by lower erucic acid content in seed oil.

Table 2
Characteristics of varieties and strains of white mustard used in development of the initial population for breeding for seed quality traits (Poznań 1982) — *Charakterystyka odmian i rodów gorczycy białej użytych do otrzymania populacji wyjściowej do hodowli na cechy jakościowe nasion*

Varieties/strains *Odmiany/rody*	Origin *Pochodzenie*	Quality traits — *Cechy jakościowe*	
		erucic acid in seed oil (%)* *kwas erukowy w oleju nasion*	sinalbin in seeds (μmol·g^{-1})** *sinalbina w nasionach*
Albatros	Germany	43.4	180
BHL-6-3553	Canada	4.3	157
BHL-6-3561	Canada	5.0	176
Borowska	Poland	38.9	177
Budakalliassi Sanga 785111	Hungary	40.5	187
Budakalliassi Sanga 795127	Hungary	37.4	183
Ceska krajova	Czech Republic	39.5	182
Erbachshofska	Germany	38.8	193
Kastor	Germany	33.0	170
Nakielska	Poland	37.4	186
Primex	Sweden	38.1	155
Prerovska bila	Czech Republic	41.5	165
Seco	Sweden	36.1	184
Svalofska	Sweden	38.4	196
Trico	Sweden	39.6	189
WNIMK – 162	Russia	32.8	176
Zaria	Russia	36.6	196
Mixture of varieties after intercrossing		35.8	170

* analysed by gas liquid chromatography of fatty acid methyl esters — *analizowane za pomocą chromatografii gazowej estrów metylowych kwasów tłuszczowych*
** analysed by estimation of glucose released after myrosinase treatment — *oznaczane poprzez określanie glukozy uwalnianej pod działaniem mirozynazy*

At the beginning, the breeding work was conducted in two directions: to select from initial population lines with very low erucic acid content in seed oil or to select lines with low content of glucosinolates in seeds. The low glucosinolate content was concerned mainly with the elimination of sinalbin. These two kinds of lines were obtained by individual plant selection linked with inbreeding conducted over several generations. Inbreeding in white mustard was very difficult because of its self incompatibility (Olsson 1960). It was necessary to use sib mating or bud pollination. In recurrent selection, controlled pollination between chosen individual plants with desired chemical composition was also applied (Krzymański et al. 1991a, 1991b, Piętka et al. 1998, 2004, 2007b, 2010, 2011).

The strains or varieties used to obtain prebreeding population by free intercrossing were varied according to erucic acid content in seed oil. This gave a possibility to select plants and lines with very low erucic acid content in seed oil. The situation in the case of glucosinolate content was different. All intercrossed materials were high in glucosinolate content. The source of selected individual plants and lines with low glucosinolate content can come either from natural mutant or were formed by spontaneous crossbreeding with double low (“00”) oilseed rape because breeding plots and field trials of white mustard were grown for many years on the same field as breeding plots and field trials of double low oilseed rape.

The new prebreeding population for the breeding of double improved white mustard was obtained by the crosses between zero erucic lines and lines with low glucosinolate content — without sinalbin the main glucosinolate of white mustard (Piętka et al. 2010).

Recurrent selection was based on the results of chemical analyses of seeds. Selection for fatty acid composition was performed with gas chromatography analyses (Byczyńska and Krzymański 1969, the method giving results compatible with the Polish Standard PN-EN ISO 5508:1996). Preliminary screening for fatty acid composition in seed oil was made with the use of half seed method. Selections in further stages of breeding were based on gas chromatography analyses of seeds from individual plants.

Screenings of individual plants for low glucosinolate content in seeds were performed with glucotest tape (Byczyńska and Krzymański 1977) or with measurements in the near infrared spectroscopy (NIRS) (Michalski 2003). In the further stages of breeding, selection was based on the results of chemical analyses performed by gas chromatography (Michalski et al. 1995, the method giving results compatible with the Polish Standard PN ISO 9167-1:1999). Sinigrin was used as an internal standard in the analyses of glucosinolate content (Slominski et al. 1999).

Selection for seed yield was conducted based on field experiments made at several locations and years in randomized complete block design with 4 replications for each of the mentioned environments. Trials designing and randomization before sowing and statistical multi trait analyses of results after harvest were done with the use of standard programs (Excel – Analysis Tool Pack). This work was necessary to rebuild yielding ability after losses observed during selection for quality (Piętka et al. 2010).

Results

Single low variety of white mustard was bred using selected low erucic lines but with high glucosinolate content. This variety, the first Polish zero erucic variety of white mustard was licensed in 2006 to the national register of varieties of Research Centre for Cultivar Testing (COBORU) under the name of ‘Bamberka’ (Piętka and Krzymański 2007a). Oil from the seeds of this variety has high dietary value similar to the value of oil from double low oilseed rape. The proportion n-6 to n-3 polyunsaturated fatty acids is very suitable for edible purposes (Gebauer et al. 2006, Wathes et al. 2007). This variety is useful for purposes of spices, table mustard production, and edible oil production and in pharmaceutical industry.

Table 3

Characteristics of double low white mustard variety ‘Warta’ as compared to the conventional variety ‘Nakielska’ and zeroerucic variety ‘Bamberka’ – Results of preliminary field experiments conducted in Experimental Stations: Łagiewniki (51°45’40”N, 17°14’13”E) and Karżniczka (54°29’19”N, 17°14’01”E) in 2009 – *Charakterystyka podwójnie ulepszonej odmiany gorczycy białej ‘Warta’ w porównaniu z tradycyjną odmianą ‘Nakielska’ i bezerukową odmianą Bamberka, wyniki doświadczeń wstępnych w 2009 roku*

Trait *Cecha*	Variety — *Odmiana*		
	‘Nakielska’	‘Bamberka’	‘Warta’
Beginning of flowering – days after sowing *Początek kwitnienia – liczba dni po siewie*	52.0	47.5	49.5
End of flowering – days after sowing *Koniec kwitnienia – liczba dni po siewie*	79.0	75.0	76.0
Time of harvest – days after sowing Czas zbioru – *liczba dni po siewie*	126.5	126.5	126.5
Plant height [cm] — *Wysokość roślin*	166.8	142.5	148.0
1000 seeds weight [g] — *Masa 1000 nasion*	7.2	5.7	6.3
Seed yield [$dt \cdot ha^{-1}$] — *Plon nasion*	22.4	17.3	20.2
Seed oil content [% dry matter] *Zawartość oleju w nasionach*	27.8	29.6	30.2
Erucic acid content [%] *Zawartość kwasu erukowego*	36.6	1.3	1.3
Glucosinolates [$\mu M \cdot g^{-1}$ seeds] — *Glukozynolany*:			
— glucotropeolin — *glukotropeolina*	0.1	0.0	1.3
— sinalbin — *sinalbina*	156.2	132.5	0.0
— gluconapin — *glukonapina*	0.0	0.0	0.8
— glucobrassicanapin — *glukobrassicanapina*	0.0	0.0	0.0
— progoitrin — *progoitryna*	4.7	3.2	12.7
— napoleiferin — *napoleiferyna*	0.1	0.1	0.5
— brassicin — *brassycyna*	0.2	0.3	2.8
— 4-hydroxybrassicin — *4-hydroksybrassycyna*	0.4	0.6	3.7
Total of glucosinolates — *Suma glukozynolanów*	161.7	136.7	20.4
Total of alkenyl glucosinolates *Suma glukozynolanów alkenylowych*	4.8	3.3	13.9

Double low white mustard lines and strains with zero erucic seed oil and very low glucosinolate content were bred as a result of many years of recurrent selection. At first the proper chemical composition of seeds was obtained. Then the next step was to improve the seed yield of these new strains, which was lost during breeding for quality. New variety to be licensed should link the desirable qualitative characteristics with the yielding ability at a level comparable to the traditional varieties of white mustard. The best new strain has been given to the official testing by COBORU in 2009 under the provisional designation POH-209 (Piętka et al. 2011). In 2012, this strain has been entered as a new variety in the national register of plant varieties of COBORU under the name 'Warta'. Low yielding linked initially with the elimination of erucic acid and sinalbin was overcome in this variety (Tables 3 and 4).

Table 4

Results of official COBORU testing for 'Warta' variety of white mustard as compared to traditional variety 'Nakielska' and zeroerucic variety 'Bamberka' (average values for years 2010 and 2011, 12 field trials) — *Oficjalne wyniki badań COBORU odmiany 'Warta' w porównaniu do tradycyjnej odmiany 'Nakielska' oraz odmiany bezerukowej 'Bamberka' (średnie z lat 2010 i 2011 z 12 doświadczeń polowych).*

Trait *Cecha*	Variety — *Odmiana*		
	'Warta'	'Bamberka'	'Nakielska'
Seed yield [dt·ha^{-1}] — *Plon nasion*	18.5	16.1	18.3
Oil yield [dt·ha^{-1}] — *Plon oleju*	5.4 108% of standard	4.6	4.9
Protein content in meal [per cent fat free dry matter] *Zawartość białka w śrucie* *[w procentach masy beztłuszczowej]*	43.1	42.0	45.3
1000 seeds weight [g] — *Masa 1000 nasion*	6.2	6.4	7.4
Oil content in seeds [per cent dry matter] *Zawartość oleju w nasionach* *[w procentach suchej masy]*	32.5	31.4	29.0

The chemical composition analyses of seeds of the new variety 'Warta" were carried out during the official testing on seeds collected from the plots of field experiments. These compositions altered because of the cross-pollination with traditional varieties grown also in trials. Therefore, the chemical composition of variety 'Warta' can be characterized only by analysis of seeds collected from plants protected from out crossing by foreign pollen. Variability of single plants in glucosinolate content and in fatty acid composition is shown in tables 5 and 6. These values concern the plants obtained during the selection in maintenance of 'Warta' variety.

Table 5

Fatty acid composition in seeds oil from individual plants of double low variety ‘Warta’ (n = 73 plants) — *Skład kwasów tłuszczowych oleju z nasion pojedynków (n = 73 pojedynków)*

Fatty acid *Kwas tłuszczowy*	Fatty acid content in oil [%] — *Zawartość kwasu tłuszczowego w oleju*				
	mean *średnia*	standard deviation *odchylenie standartowe*	coefficient of variability [%] *współczynnik zmienności*	maximum *maksimum*	minimum *minimum*
Palmitic — *Palmitynowy*	4.4	0.25	5.7	3.8	5.0
Stearic — *Stearynowy*	1.5	0.10	6.7	1.4	1.8
Oleic — *Oleinowy*	63.0	1.51	2.4	59.3	66.7
Linoleic — *Linolowy*	9.8	0.82	8.4	8.4	13.1
Linolenic — *Linolenowy*	17.9	1.41	7.9	14.1	20.9
Eicosenoic — *Eikozenowy*	2.5	0.44	17.4	1.8	3.8
Erucic — *Erukowy*	0.8	0.35	42.3	0.0	1.5

Table 6

Glucosinolate content in seeds from individual plants of double low variety ‘Warta’ (n = 73)
Zawartość glukozynolanów w nasionach pojedynków podwójnie ulepszonej odmiany ‘Warta’ (n = 73)

Glucosinolate *Glukozynolan*	Glucosinolate content in seeds [$\mu M \cdot g^{-1}$] *Zawartość glukozynolanów w nasionach*				
	mean *średnia*	standard deviation *odchylenie standartowe*	coefficient of variability [%] *współczynnik zmienności*	maximum *maksimum*	minimum *minimum*
Gluconapin — *Glukonapina*	0.2	0.13	65.8	0.0	0.9
Progoitrin — *Progoitryna*	10.7	1.64	15.3	7.9	14.2
Brassicin — *Brazycyna*	1.0	0.64	65.9	0.3	3.5
4-hydroxybrassicin *4-hydroksybrazycyna*	1.8	0.55	30.4	0.8	3.5
Total of glucosinolates *Suma glukozynolanów*	14.7	1.96	13.4	10.9	18.3
Total of alkenyl glucosinolates *Suma glukozynolanów alkenylowych*	11.9	1.66	14.0	9.0	15.3
Glucotropeolin *Glukotropeolina*	1.0	0.42	44.1	0.2	2.0

Discussion

White mustard was converted into a valuable protein and oil crop by creating new double-low genotypes. Variety 'Warta', the first double low variety of white mustard in Poland, overcomes the negative characteristics of low yield usually linked with the crucial changes of the chemical composition of the seed, i.e. deletion of erucic acid and sinalbin. The variety 'Warta' meets the canola standards for erucic acid and glucosinolate content. This variety is characterized by very low content of erucic acid (below 1.5% in seed oil), low contents of: alkenyl glucosinolates (gluconapin and glucobrassicanapin – about 11.9 $\mu M \cdot g^{-1}$), indolyl glucosinolates (brassicin and 4OH-brassicin about 2.8 $\mu M \cdot g^{-1}$), benzyl glucosinolates (contents of glucotropeolin less than 2.0 $\mu M \cdot g^{-1}$) and lack of sinalbin – the main glucosinolate of white mustard.

Oil from the seeds of white mustard variety 'Warta' has a composition similar to that of oil from double low rapeseed and therefore it is all-purpose useful oil for food, fodder, and technical use. Its dietary value is even slightly better than rapeseed oil because of higher contents of desired omega-3 fatty acid. In addition, it has a better ratio of omega-6 to omega-3 acids (1:2). Besides, this oil has a desired high content of oleic acid and very low content of saturated fatty acids (Packman 1990, De Lorgeril 1994, Dubnov and Berry 2003, Gebauer et al. 2006, Hooper et al. 2006, Wathes et al. 2007, Szostak 2008).

White mustard seeds are bright yellow with lower content of fiber and higher protein content as compared to rapeseed (Ochodzki and Piotrowska 1997). Protein has good amino acid composition. Seeds, extraction meal or press cake from seeds of this new variety of white mustard may be a valuable high protein component of feed for animals. The amino acid composition of white mustard is fairly well balanced and similar to that of oilseed rape. Compared to soybean, it contains less amino acid lysine, but more of the sulphur amino acids methionine and cysteine (Bell 1993, Słomiński et al. 1999, Tan et al. 2011).

Thanks to the above mentioned characteristics, the double low variety Warta of white mustard can improve the protein balance in Poland and can help to lower the import of GM soybean seeds.

Thermally deactivated seeds of double low white mustard can be used as a protein supplement to meat products **without glucosinolates removal process**. White mustard seed has a protein to fat ratio similar to the average content of these ingredients in meat products and due to the mucilage content it can absorb large quantities of water (Cui et al. 1993). Mustard mucilage gives a thick consistency and viscosity to salad dressing and pasta sauces (Weber et al. 1974).

'Warta' variety can also be a valuable rotation crop due to its property to reduce the cyst population of beet-root eelworm (*Heterodera schachti* Schmidt) in soil. 'Warta' variety has desirable agronomical traits, which are characteristic of the existing varieties of white mustards. It is a more stable yielding spring oil-protein crop. Plants are more resistant to diseases as compared to oilseed rape and more tolerant to periodical droughts that frequently occur in the climate of Poland. It can be used for seed production and as a plough down crop (green manure), as well as a plant valuable to honey bees. 'Warta' variety grown as after crop may fulfill the role of phytosanitary and forage crop.

Conclusions

1. The double low white mustard has quality value comparable to double low oilseed rape and even better regarding the meal or press cake as a source of protein for animal feeding and human nutrition. Its introduction as the new source of edible oil and protein into European cropping system will be easy because this plant is domestic in Europe and the double low genotype has been obtained using classical breeding methods without GM.
2. Double low white mustard cannot be used as spices but its production could help to overcome the shortage of the fodder protein in Europe.
3. The 'Warta' variety is the first double low variety of white mustard which can be introduced to field production. It is necessary to continue research and breeding works on double low white mustard (00) to obtain new varieties with improved seed yield and resistance to diseases and pests.
4. White mustard is a highly self-incompatible plant. It is typically cross-pollinated mainly by insects; therefore protection of varietal purity is very important to ensure the quality of harvested seed. Its introduction to cultivation should be done in the manner similar to the manner used in the introduction of double low oilseed rape varieties to cultivation. The annual use of certified seed, avoiding fields with volunteer plants of the traditional white mustard varieties and field mustard (charlock, *Sinapis arvensis* L.) and the spatial isolation from plantations of other white mustard are recommended and necessary to obtain yield of good quality seeds.

References

Abdellatif A.M.M, Vles R.O. 1971. The effects of various fat supplements on the nutritional and pathogenic characteristics of diets containing erucic acid in ducklings. Nutr. Metab., 13: 65-74.

Abdellatif A.M.M. 1972. Cardiopathogenic effects of dietary rapeseed oil. Nutr. Rev., 30: 2-6.

Abdellatif A.M.M., Vles R.O. 1970. Pathological effects of dietary rapeseed oil in rats. Nutr. Metab., 12: 285-295.

Ackman R.G. 1990. Canola fatty acids – An ideal mixture for health, nutrition and food use. [In:] Canola and Rapeseed: production, chemistry, nutrition and processing technology. Ed. F. Shahidi, Van Nostrand Reinhold, New York, 81-98.

Bell J.M. 1993. Factors affecting the nutritional value of canola meal: A review. Can. J. Anim. Sci., 73: 679-697.

Busch L., Gunter V., Mentele T., Tachikawa M., Tanaka K. 1994. Socializing Nature: Technoscience and the Transformation of Rapeseed into Canola. Crop Science, 34 (3): 607-614.

Byczyńska B., Krzymański J. 1969. Szybki sposób otrzymywania estrów metylowych kwasów tłuszczowych do analizy metodą chromatografii gazowej (A quick way of receiving the methyl esters of fatty acids for analysis by gas chromatography). Tłuszcze Jadalne, 13: 108-114 (in Polish).

Byczyńska B., Krzymański J. 1977. Testowanie nasion rzepaku na zawartość glukozynolanów (Seeds testing for glucosinolate content). Zeszyty Problemowe IHAR, Wyniki Badań nad Rzepakiem Ozimym lata 1975-76, 2: 206-211 (in Polish).

Canola Council of Canada, http://www.canolacouncil.org/oil-and-meal/what-is-canola/ (accessed 05.12.2012).

Canola Council of Canada, http://www.canolacouncil.org/oil-and-meal/what-is-canola/the-history-of-canola/ (accessed 05.12.2012a).

COBORU 2006. Lista opisowa odmian. Rośliny Rolnicze (Descriptive list of varieties. Agricultural plants), Słupia Wielka, Poland, 2006 (www.coboru.pl, accessed 05.12.2012).

Cui W., Eskin N.A.M., Biliaderis C.G. 1993. Chemical and physical properties of yellow mustard (*Sinapis alba* L.) mucilage. Food Chem., 46: 169-176.

de Lorgeril M., Renaud S., Mamelle N., Salen P., Martin J-L., Monjaud I., Guidollet J., Touboul P., Delaye J. 1994: Mediterranean alpha-linolenic acid rich diet in secondary prevention of coronary heart disease. The Lancet, 343: 1454-1459.

de Visser C.L.M., Schreuder R., Stoddard F. 2014: The EU's dependency on soya bean import for the animal feed industry and potential for EU produced alternatives. OCL 2014, 21 (4) D407 DOI, http://dx.doi.org/10.1051/ocl/2014021.

Downey R.K. 1964. A selection of *Brassica campestris* L. containing no erucic acid in its seed oil. Can. J. Plant Sci., 44: 295-297.

Dubnov G., Berry E.M. 2003. Omega-6/Omega-3 Fatty Acid Ratio: The Israeli Paradox. [In:] Simopoulos A.P., Cleland L.G. (eds): Omega-6/Omega-3 Essential Fatty Acid Ratio: The Scientific Evidence. World Review of Nutrition and Dietetics, 92: 81-91.

European Food Safety Authority. 2008. Glucosinolates as undesirable substances in animal feed, Scientific Panel on Contaminants in the Food Chain (Question N° EFSA-Q-2003-061), Adopted on 27 November 2007. The EFSA Journal, 590: 1-76.

Finlayson A.J., Krzymański J., Downey R.K. 1973. Comparison of chemical and agronomic characteristics of two *Brassica napus* L. cultivars, Bronowski and Target. J. Am. Oil Chem. Soc., 10: 407-410.

Gebauer S.K., Psota T.L., Harris W.S., Kris-Etherton P.M. 2006. n-3 fatty acid dietary recommendations and food sources to achieve essentiality and cardiovascular benefits. Am. J. Clin. Nutr., 83 (6 Suppl.): 1526S-1535S.

George P., Töregård B. 1978. An investigation into the presence of degradation products from glucosinolates in rapeseed oil – 5th International Rapeseed Conference, Malmö, Sweden 12-16.06.1978, 2: 348-359.

Hooper L., Thompson R.L., Harrison R.A., Summerbell C.D., Ness A.R., Moore H.J., Worthington H.V., Durrington P.N., Higgins J.P.T., Capps N.E., Riemersma R.A., Ebrahim S.B.J., Smith G.D. 2006. Risks and benefits of omega 3 fats for mortality, cardiovascular disease, and cancer: systematic review. British Medical Journal, 332: 752-760.

Jankowski K., Budzyński W. 2003. Rola elementów struktury plonu w kształtowaniu plonu niektórych jarych roślin oleistych (The role of yield components in the management of yielding of some spring oilseed crops). Rośliny Oleiste – Oilseed Crops, XXIV: 443-454 (in Polish).

Krzymański J. 1968. Variation in thioglucosides in rapeseed meal (*Brassica napus*). The Meeting of Associate Committees of the National Research Council on Plant Breeding. 20.02.1968, Winnipeg, Canada.

Krzymański J. 1970. Genetyczne możliwości ulepszania składu chemicznego nasion rzepaku ozimego (Genetic possibilities to improve the chemical composition of winter oilseed rape). Hodowla Roślin, Aklimatyzacja i Nasiennictwo, 14: 95-133 (in Polish).

Krzymański J. 1995. Biosynteza i fizjologiczne funkcje glukozynolanów w roślinie (Biosynthesis and physiological functions of glucosinolates in plant). Rośliny Oleiste – Oilseed Crops, XVI: 113-126 (in Polish).

Krzymański J., Bartkowiak-Broda I., Krótka K. 1987. Recent achievements in breeding work on winter rape (*Brassica napus* L.). In: Proceedings of 7th International Rapeseed Congress, Poznan, Poland, 40-45.

Krzymański J., Piętka T., Ratajska I., Byczyńska B., Krótka K. 1991a. Development of low glucosinolate white mustard (*Sinapis alba* syn. *Brassica hirta*). Proceedings of 8th International Rapeseed Congress, Saskatoon, Canada, 5: 1545-1548.

Krzymański J., Piętka T., Ratajska I., Byczyńska B., Krótka K. 1991b. Selekcja gorczycy białej o niskiej zawartości glukozynolanów (Selection of white mustard for low glucosinolate content). Zeszyty Problemowe IHAR – Rośliny Oleiste, XIII: 115-122 (in Polish).

Love H.R., Rakow G., Raney J.P., Downey R.K. 1991. Breeding improvements towards canola quality *Brassica juncea*. Proceedings of 8th International Rapeseed Congress, Saskatoon, Canada, 164-169.

Michalski K. 2003. Oznaczanie glukozynolanów za pomocą NIRS w nasionach ulepszonej gorczycy białej dla potrzeb prac hodowlanych (Determination of glucosinolate content by means of NIRS in white mustard seeds for breeding purposes). Rośliny Oleiste – Oilseed Crops, 24: 307-316 (in Polish).

Michalski K., Czernik-Kołodziej K., Krzymański J. 1995. Quantitative analysis of glucosinolates in seeds of oilseed rape – Effect of sample preparation on analytic results. Proceedings of 9th International Rapeseed Congress, Cambridge, UK, 3: 911-913.

Muśnicki Cz., Toboła P., Muśnicka B. 1997. Produktywność alternatywnych roślin oleistych w warunkach Wielkopolski oraz zmienność ich plonowania (The productivity of alternative oil crops in conditions of Great Poland and variability of their seed yield). Rośliny Oleiste – Oilseed Crops, 18: 269-278 (in Polish).

Ochodzki P., Piotrowska A. 1997. Zmienność składu chemicznego odtłuszczonych nasion rzepaku o niskiej zawartości włókna (Variation of chemical composition of defatted rape seeds selected for low fiber content). Rośliny Oleiste – Oilseed Crops, XVIII: 511-524 (in Polish).

Olsson G. 1960. Self-incompatibility and outcrossing in rape and white mustard. Hereditas, 46: 241-252.

Piętka T., Krótka K., Krzymański J. 2004. Gorczyca biała podwójnie ulepszona – alternatywna jara roślina oleista (Double improved white mustard (*Sinapis alba* L.) – Polish alternative spring oilseed crop. Rośliny Oleiste – Oilseed Crops, XXV: 403-413 (in Polish).

Piętka T., Krzymański J. 2007a. ‘Bamberka’ zeroerukowa gorczyca biała (‘Bamberka’ zero-erucic white mustard). Rośliny Oleiste – Oilseed Crops, XXVIII: 119-124 (in Polish).

Piętka T., Krzymański J., Bartkowiak-Broda I. 2011. White mustard (*Sinapis alba* L.) breeding for oil and meal quality. Proc. of 13th International Rapeseed Congress, Prague, Czech Republic, 891-894.

Piętka T., Krzymański J., Krótka K. 2010. Pierwsza podwójnie ulepszona odmiana gorczycy białej (*Sinapis alba* L.) (First double improved variety of white mustard (*Sinapis alba* L.). Rośliny Oleiste – Oilseed Crops, XXXI: 177-200 (in Polish).

Piętka T., Krzymański J., Michalski K., Krótka K. 1998. Postępy prac nad tworzeniem gorczycy białej podwójnie ulepszonej (Progress in the breeding of white mustard (*Sinapis alba* L.) for double low quality). Rośliny Oleiste – Oilseed Crops, XIX: 455-462 (in Polish).

Piętka T., Ogrodowczyk M., Krzymański J. 2007b. Progress in breeding research on double low white mustard (*Sinapis alba* L.) in Sustainable Development in Cruciferous Oilseed Crops Production. In: Proceedings of 12th International Rapeseed Congress, Wuhan, China, 1: 203-205.

Potts D.A., Rakow G.W., Males D.R., Woods D.L. 2003. The development of canola – quality *Brassica juncea*. Can. J. Plant Sci., 83: 117-118.

Roine P., Uksila E., Teir H., Rapola J. 1960. Histopathological changes in rats and pigs fed rapeseed oil. Zeitschrift für Ernährungswissenschaft, 1: 118-124.

Sawicka B., Kotiuk E. 2007. Gorczyce jako rośliny wielofunkcyjne (Mustards as multifunction plants). Acta Sci. Pol. Agric., 6: 17-27 (in Polish).

Słomiński B.A., Kienzle H.D., Jiang P., Campbell L.D., Pickard M., Rakow G. 1999. Chemical composition and nutritive value of canola-quality *Sinapis alba* mustard. Proceedings of the 10th International Rapeseed Congress, Canberra, Australia (www.regional.org.au/au/gcirc/1/274 htm, accessed 05.12.2012).

Słomiński B.A., Rakowska M., Krzymański J. 1983. The nutritive value of low glucosinolate rapeseed meal processed at different heat-moisture conditions. Proc. 6th Inter. Rapeseed Conf., Paris 17-19.05.1983, 2: 1456-1459.

Stefansson R.B., Downey R.K. 1995. Rapeseed. [In:] Slinkard A.E., Knott D.R. (eds). Harvest of Gold: The History of Crop Breeding in Canada. University Extension Press, University of Saskatchewan, 140-152.

Stefansson R.R., Hougen F.W. 1964. Selection of rape plants (*Brassica napus*) with seed oil practically free of erucic acid. Can. J. Plant Sci., 44: 359-364.

Stefansson R.R., Hougen F.W., Downey R.K. 1961. Note on the isolation of rape plants with seed oil free of erucic acid. Can. J. Plant Sci., 42: 218-219.

Stefansson R.R., Kondra Z.P. 1975. Tower summer rape. Can. J. Plant Sci., 55: 343-344.

Szostak W.B. 2008. Rola oleju rzepakowego w profilaktyce przewlekłych chorób niezakaźnych (The role of rapeseed oil in the prevention of chronic non-communicable diseases). Teraz Rzepak Teraz Olej: t. 2 rozdział II.

Tan S.H., Mailer R.J., Blanchard Ch.L., Agboola S.O. 2011. Canola proteins for human consumption: extraction, profile, and functional properties. Food Sci., 76: R16-R28.

Toboła P., Muśnicki Cz. 1999. Zmienność plonowania jarych roślin oleistych z rodziny krzyżowych (Yielding variability of spring sown oilseed crops of cruciferous family). Rośliny Oleiste – Oilseed Crops, XX: 93-100 (in Polish).

USDA 2014. Foreign Agricultural Service – EU-27 Oilseeds and Products Annual 2013 – www. indexmundi.com/agriculture/?country=eu&commodity=soybean-meal&graph=imports, accessed 28.06.2014.

Wathes D.C., Abayasekara D.R., Aitken R.J. 2007. Polyunsaturated fatty acids in male and female reproduction. Biol. Reprod., 77 (2): 190-201.

Weber F.E., Taillie S.A., Stauffer K.R. 1974. Functional characteristics of mustards mucilage. J. Food Sci., 39: 461-466.