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ENERGY POTENTIAL OF OILSEED CROPS

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ABSTRACT

The paper presents results of studies on energy efficiency of production of some *Brassica* oilseed crops: winter and spring oilseed rape (*Brassica napus* L.), white mustard (*Sinabis alba* L.), Indian mustard (*Brassica juncea* L.), spring false flax (*Camelina sativa* L.) and crambe (*Crambe abyssinica* Hochst.), which in the international commercial trade are referred to as oilseed rape. In the agronomic and ecological conditions of Poland, 1 ha of winter oilseed rape can generate over 166 GJ energy, including about 45 GJ of energy utilisable for production of methyl (ethyl) esters. Having subtracted the crop production input (about 21 $GJ \cdot ha^{-1}$), the cumulated energy gain from 1 ha winter oilseed rape is energy equivalent to nearly 3.5 t of diesel oil or 8.5 t of firewood. The energy potential of spring oilseed crops seeds and straw is relatively lower: 31-39% less for spring oilseed rape and white mustard, 51-53% less for false flax and Indian mustard, and 62% less for crambe. It needs to be emphasised, however, that production of spring oilseeds consumes less energy than cultivation of winter oilseed rape. The value of energy consumed producing 1 ha of spring oilseeds ranges from 74% (spring oilseed rape) to as little as 59-66% (the remaining spring oilseeds) of the input for production of winter oilseed rape. Moreover, the unit energy value of spring oilseeds, and their oil in particular, is better than that of winter oilseed rape. Our analysis of the energy balance for seed production of oilseed plants enables us to claim that, as regards production of energy utilizable for production of liquid biofuel, the highest energy efficiency, comparable to that of winter oilseed rape, is attained from white mustard cultivation, lower (by 13-23%) for spring false flux and spring oilseed rape, and the lowest (by 48-58%) for Indian mustard and crambe. Having included the energy value of straw, the highest energy efficiency ratio was obtained from cultivating 1 ha of white mustard.

Key words: winter oilseed rape, spring oilseed rape, white mustard, Indian mustard, spring false flax, crambe, yield energy value, energy efficiency index.

INTRODUCTION

Seeds (fruits) of oilseed plants are a valuable raw material for oleo-chemical industry, whose rapid development reflects the present tendencies in the world economy to turn to renewable resources. In Poland, one of the major sources of renewable energy is associated with solar activity. Solar energy can be used directly (solar collectors, solar ponds, solar power stations) or indirectly (e.g. biomass) [11]. The use of biomass seems to offer the highest potential of solar energy utilisation. Solar energy provided 93.5% of the renewable energy produced in Poland in 2001 [14]. Biomass can be used for power production directly via burning or as liquid fuel, e.g. ethanol, methyl and ethyl esters of plant fats. Apart from being used for production of biofuel, esters find other important applications, such as production of lubricants, linoleum, protective coatings, printing ink, solvents, plastifiers, polymers, etc [10,20]. Although they serve different functions, all these products share one thing in common – they are all derivatives of plant fats.

At present, the demand of the European petrochemical industry for oil raw material is covered in large part by winter oilseed rape plantations. The CAP reform limiting production of edible plants and introducing the so-called 'O_2 credit' [17], provisions of the Madrid declaration of 1994 declaring 15% share of energy from renewable sources in the total energy balance of the EU [11] and Directive 2001/0265/COD on increased share of biofuels on the petrochemical market [16], all create very good conditions for higher demand for plant fats on the EU petrochemical market. With a large demand for biocomponents necessary to produce biofuels, winter oilseed rape, which is rather expensive to grow, can be replaced by less costly spring oil crops.

Of spring oilseed crops, plants of *Brassicaceae* family are most adapted to the European climatic conditions [20]. White mustard and crambe have the highest yield potential of spring oilseed plants grown in Europe [4,5,12,19]. The other species of spring oilseed plants yield corresponding to 62% (spring false flax) and 58% (Indian mustard) of an average white mustard yield [12]. The economic importance of spring oilseed plants is low not only due to their smaller yield potential compared to winter oilseed rapes [12], but also because of a limited nutritional use of their oil and fat-free seed residue [13]. As a result, spring oilseed crops are of only marginal economic importance, even though their agricultural value is indisputable [18]. A growing demand for plant fats to produce biofuel can soon attract more interest of farmers and oleo-chemical industry in these species, especially as the CAP is expected to offer compensation payments for oilseed crops on fallow land (besides the traditional set-aside subsidies) [9].

In contrast to the energy efficiency of winter oilseed rape production, which has been studied fairly extensively [2,3,6,7], hardly any information is available on the energy expenditure of production spring oilseeds, known as 'oilseed rape' in the international trade.

The aim of this study was to quantify the energy efficiency of producing seeds (fruits) and straw of spring oilseed rape (*Brassica napus* L.), white mustard (*Sinapis alba* L.), Indian mustard (*Brassica juncea* L.), spring false flax (*Camelina sativa* L.) and crambe (*Crambe abyssinica* Hochst.) relative to winter oilseed rape (*Brassica napus* L.).

The paper compares energy efficiency (measured by the energy of yield to the energy expended in its production) of spring oilseed plants versus winter oilseed rape. The working hypothesis assumed that a lower energy value of yield should be compensated for by a relatively lower energy consumption of spring oilseed crop production.

MATERIAL AND METHODS

The study compared 5 species of oilseed crops from *Brassicaceae* familiy: spring oilseed rape ('Star'), white mustard ('Nakielska'), Indian mustard ('Małopolska'), spring false flax ('Borowska') and crambe ('Borowski') versus winter oilseed rape ('Kana'). The following data were used to compare the energy efficiency of the five crops: yield of seeds (fruits), yield of straw, content of crude fat and total protein in seeds (fruits), oil energy value, fat-free dry matter of seeds and straw (gross energy). The material for collecting the relevant information was obtained from a three-year (1997-1999) strict field trial located on the fields of the Experimental Station at Bałcyny, in the vicinity of Ostróda, of the University of Warmia and Mazury in Olsztyn. The trial was conducted using randomly blocks design in 3 replications.

Each year the trials were set on typical grey-brown podzolic soil of good wheat complex formed from light loam. The forecrop consisted of cereals grown after a mixture of legumes and cereals. Once the winter oilseed rape forecrop had been harvested, full pre-sowing tillage (ploughing) of soil was performed including plough skimming and pre-sow ploughing. Stubble and pre-winter soil tillage were carried out on fields for spring oilseed crops. Winter oilseed rape seeds were sown between 15th and 20th August using 110 full sowing-value seeds per 1 m^2. Spring oilseed species were sown in the first or the last decade of April using 140 germinating seeds per 1m^2 of spring oilseed rape, 120 seeds per 1m^2 of white mustard, 220 seeds per 1m^2 of Indian mustard, 300 seeds per 1m^2 of spring false flax, and 100 fruits per 1m^2 of crambe. Plot harvesting area amounted to 15 m^2.

Winter oilseed rape was pre-sowing fertilised with 40 kg $N \cdot ha^{-1}$, 80 kg $P_2O_5 \cdot ha^{-1}$ and 120 kg $K_2O \cdot ha^{-1}$. In spring, when vegetation of plants began, 120 kg $N \cdot ha^{-1}$ was applied in one dose. Spring oilseed rape was fertilised prior to sowing with 40 kg $N \cdot ha^{-1}$, 40 kg $P_2O_5 \cdot ha^{-1}$ and 65 kg $K_2O \cdot ha^{-1}$. The fertilisation was supplemented with 70 kg $N \cdot ha^{-1}$ applied over stem elongation. White and Indian mustard were fertilised before sowing with 60 kg $N \cdot ha^{-1}$, 36 kg $P_2O_5 \cdot ha^{-1}$ and 65 kg $K_2O \cdot ha^{-1}$. The fertilisation was supplemented with 30 kg $N \cdot ha^{-1}$ applied at the phase of stem elongation. Prior to sowing spring false flax and crambe, 40 kg $N \cdot ha^{-1}$, 30 kg $P_2O_5 \cdot ha^{-1}$ and 55 kg $K_2O \cdot ha^{-1}$ were applied. At the stem elongation phase, 40 kg $N \cdot ha^{-1}$ was applied to soil. Segetal weeds in winter oilseed rape fields were controlled using 1200 $g \cdot ha^{-1}$ of metazochlor, 105 $g \cdot ha^{-1}$ of chlopyralid and 104 $g \cdot ha^{-1}$ of haloxyphop-R. In fields with spring oilseed rape, weeds were controlled with a pre-sowing application of 1200 $g \cdot ha^{-1}$ of metazochlor or 720 $g \cdot ha^{-1}$ of trifluraline (the other spring oilseeds). Pests in winter and spring oilseed rape as well as Indian mustard were chemical-controlled four times, using deltametrine (twice), beta-cyfluthrin (once) and lambda cyhalotrine (once). White mustard was treated with deltametrine (twice) and beta-cyfluthrin (once), while to limit the occurrence of pests in crambe and spring false flax a double treatment of deltametrine was applied. Crops were harvested using two-stage method at the phase of agronomic maturity (from 20th July to 20th August).

Cumulated energy input for production was estimated with processes analysis according to own direct measurements of diesel oil consumption, labour expenditure and real machinery performance on production fields of the area of 1 ha at the Bałcyny Experimental Station, with typical agricultural machines and appliances: U1224 + U103/1 Atlas 4H (ploughing), U1224 + U774/2 (cultivation aggregate), U4512 + U212/2 (harrowing), U4512 + N035 RNW-3 (NPK pre-sowing fertilisation), U1224 + S052/C Mazur 5 (seed sowing), U1224 + N039 RNZ-3 (N top dressing), U4512 + Pilmet 612 (chemical weed control), Bizon-Record (harvest of seeds or fruits), U4512 + Z224/1 (harvest of straw), U4512 + D734 (transport). The type and sequence of agronomic treatments complied with the methods used in strict field trials.

The energy analysis comprised four sources of energy: human labour, machinery and tractors, energy carriers, and materials (seeds, fertilisers, pesticides, etc.). The energy input of applying machines and tractors to production process was computed from the multiplication of unit material consumption of a machinery set by the energy equivalent of 112 $MJ \cdot kg^{-1}$ mass [15]. Human labour was calculated with the equivalent of 40 $MJ \cdot manhour^{-1}$ [1,8,15]. The volume of the energy input of materials was computed with the cumulated energy index presented by Juszkiewicz et al. [8].

The total protein content in dry matter of seeds (fruits) was determined with Kjeldhal's method, while that of crude fat with electromagnetic resonance. The gross energy value of seeds (fruits), oil, fat-free seed residue and straw was determined through adiabatic burning in a calorimetric bomb.

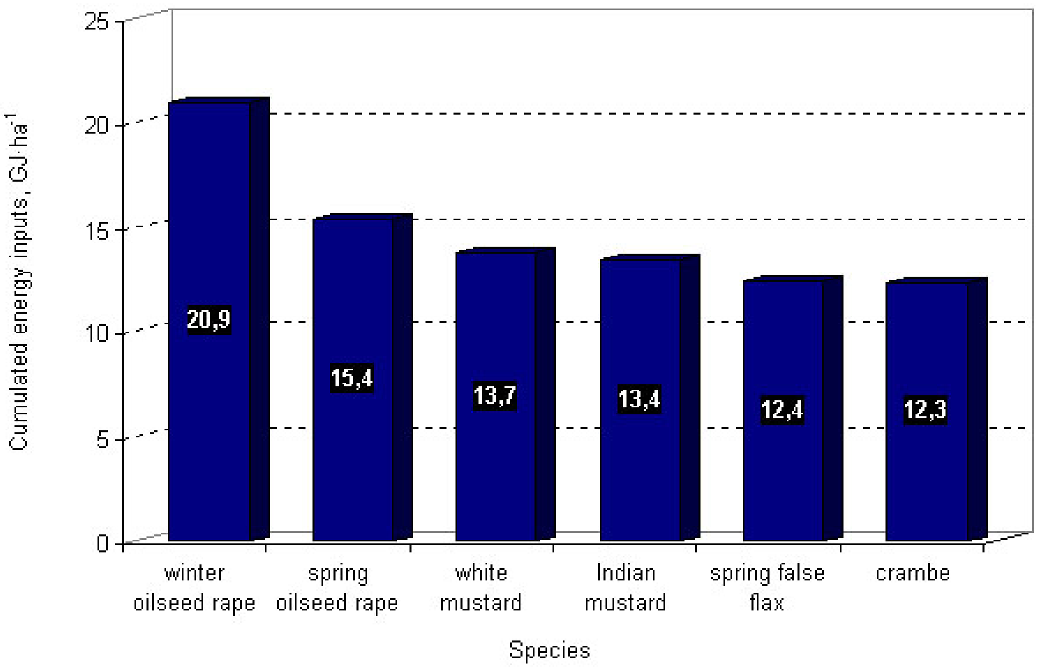
The energy efficiency evaluation comprised the categories of cumulated energy gain and energy efficiency (performance) ratio [21,22].

RESULTS AND DISCUSSION

Cumulated energy input

The cumulated energy input per 1 ha of winter oilseed rape amounted to 20.9 GJ, which was about 36-70% higher than the cumulated energy input to produce spring oilseed crops under the same field and climatic conditions. Of the spring oilseed species, spring oilseed rape turned out most energy-consuming, followed by the two species of mustard, spring false flax and crambe (Fig. 1).

Fig. 1. Cumulated energy input per 1 ha of oilseed crop production (3-year mean)



The most energy-consuming link in the chain of agronomic practices the production of oilseeds was mineral fertilisation, which consumed from 64 to 68% for spring crops and to 74% for winter oilseed rape of the total cumulated energy input (Table 1). Energy consumption for growing oilseeds being largely affected by fertilisation has been also implied in previous investigations by Jankowski et al. [7].

Table 1. Cumulated energy input structure per 1 ha of oilseed crop production, according to operations (3-year mean)

Operation		Species					
		Winter oilseed rape	Spring oilseed rape	White mustard	Indian mustard	Spring false flax	Crambe
Soil tillage	$MJ \cdot ha^{-1}$	1 768	2 049	2 049	2 049	2 049	2 049
	%	8.5	13.3	15.0	15.2	16.6	16.7
Sowing	$MJ \cdot ha^{-1}$	338	362	430	359	337	424
	%	1.6	2.4	3.1	2.7	2.7	3.5
Fertilisation	$MJ \cdot ha^{-1}$	15 412	10 452	8 856	8 856	7 902	7 902
	%	73.8	67.9	64.6	65.8	63.9	64.4
Weed control	$MJ \cdot ha^{-1}$	570	454	116	116	116	116
	%	2.7	2.9	0.8	0.9	0.9	0.9
Pest control	$MJ \cdot ha^{-1}$	325	325	243	325	80	80
	%	1.6	2.1	1.8	2.4	0.7	0.7
Harvesting*	$MJ \cdot ha^{-1}$	2 460	1 750	2 011	1 750	1 883	1 693
	%	11.8	11.4	14.7	13.0	15.2	13.8

*seeds (fruits) and straw

The stream analysis of the energy input structure shows that materials (mainly fertilisers) and energy carriers play a decisive role (in total they consumed 93-95% of the total energy input per 1 ha of oilseed crops) (Table 2). The energy value of the fuel used was not much varied (from 3.9 to 4.3 $GJ \cdot ha^{-1}$) by the technology of production applied for the species investigated. More variation between species was observed for fertiliser inputs (7.1-14.6 $GJ \cdot ha^{-1}$). Fertilisers accounted for as much as 70% of the total energy input in winter oilseed rape production. As for spring oilseed plants, the fertilisers applied corresponded to from 9.7 (spring oilseed rape) to 7.1 (false flax and crambe) $GJ \cdot ha^{-1}$, which in absolute values accounted for 63-58% of the cumulated energy consumption for the total production process.

Table 2. Cumulated energy input per 1 ha of oilseed crops production, according to energy streams (3-year mean)

Energy stream			Species					
			Winter oilseed rape	Spring oilseed rape	White mustard	Indian mustard	Spring false flax	Crambe
Labour force		$MJ \cdot ha^{-1}$	303	303	303	303	278	270
		%	1.5	2.0	2.2	2.3	2.2	2.2
Machinery and tractors		$MJ \cdot ha^{-1}$	653	573	612	573	576	538
		%	3.1	3.7	4.5	4.3	4.7	4.4
Energy carriers		$MJ \cdot ha^{-1}$	4 257	4 084	4 194	4 084	3 998	3 854
		%	20.4	26.5	30.6	30.3	32.3	31.4
Materials total		$MJ \cdot ha^{-1}$	15 660	10 432	8 596	8 495	7 514	7 601
		%	75.0	67.8	62.7	63.1	60.8	62.0
including	fertilisers	$MJ \cdot ha^{-1}$	14 640	9 680	8 084	8 084	7 130	7 130
	other	$MJ \cdot ha^{-1}$	1 020	752	512	411	384	471

Yield value

The highest content of crude fat in seeds was found in winter oilseed rape (44.3% seed d.m.). Of the spring oilseed plants, oilseed rape and false flax contained relatively large contents of crude fat (42.0 and 37.2% d.m., respectively). White mustard seeds had much lower content of crude fat (26.7% d.m.).

The highest unit fat productivity (1588 kg) was obtained from 1 ha of winter oilseed rape. The volume of biological fat yield of spring oilseeds was obviously lower, reaching 55% (spring oilseed rape), 44% (false flax), 39% (white mustard), 26% (Indian mustard) and 19% (kale) of the fat yield produced by winter oilseed rape (Table 3). Also long-term experiments conducted by Muśnicki et al. [12] showed that among *Brassica* oilseed plants winter and spring oilseed rape had the highest concentration of fat in seeds (40-47%). The authors [12] also pointed to a relatively high oil content in spring false flax seeds (38%), exceeding that in seeds of mustard species or in crambe fruits. The evaluation of *Brassica* oilseed plants showed that under the agronomic conditions of Wielkopolska no oilseed species could compete with winter oilseed rape in terms of fat yield (1.3 $t \cdot ha^{-1}$). Of the spring oilseed plants, the highest fat yield per unit (365-360 $kg \cdot ha^{-1}$) was obtained from fruits of crambe and seeds of white mustard [12].

Table 3. Protein and fat content as well as total yield of nutrients and fat-free dry matter of oilseed crops (3-year mean)

Species	Crude fat		Fat-free dry matter of seeds (fruits)		
	content % d.m. of seeds	yield $kg \cdot ha^{-1}$	yield $kg \cdot ha^{-1}$	total protein content %	protein yield $kg \cdot ha^{-1}$
Winter oilseed rape	44.3	1 588	1 994	39.1	779
Spring oilseed rape	42.0	870	1 201	37.5	450
White mustard	26.7	619	1 713	36.3	624
Indian mustard	33.4	419	845	34.7	293
Spring false flax	37.2	696	1 170	37.6	439
Crambe	31.4	308	656	28.4	185
$LSD_{0.05}$	3.63	42.1	72.3	2.97	25.9

In the present study, the total protein content in fat-free seed residue of oilseed rape, mustard and false flax was only slightly varied (35-39% fat-free d.m.) (Table 3). Fat-free residue from fruits of crambe contained considerably less total protein – by 7-11%. The highest total protein yield was obtained from 1 ha of winter oilseed rape (779 kg) and white mustard (624 kg). White mustard exceeded the protein yield of the other spring oilseeds by from 28% (spring oilseed rape) to 70% (crambe).

The gross energy value of whole seeds (fruits) and straw did not differ much across species (Table 4). The largest differences appeared in the energy value of oil and fat-free seed residue. The smallest unit energy value was determined for oilseed rape and false flax oil (about 28 $MJ \cdot kg^{-1}$). The energy value of these oils was 11-13% lower than that of white mustard seed oil.

Table 4. Energy value of seeds (or fruits) and raw materials of oilseed crops (3-year mean)

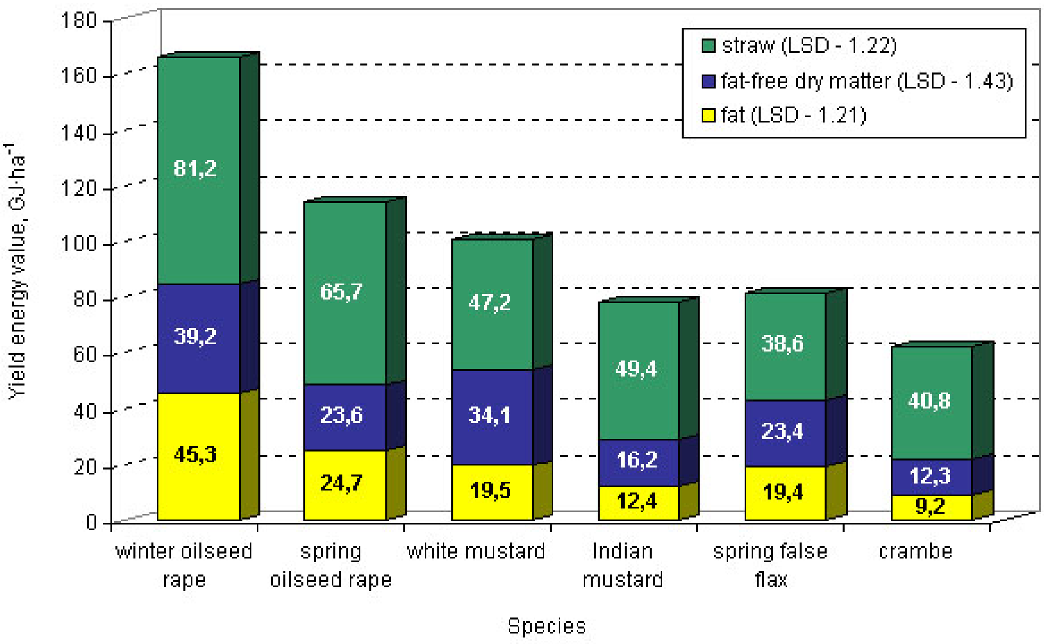
Species	Energy value, $MJ \cdot kg^{-1}$			
	whole seeds/fruit*	crude fat	fat-free dry matter of seeds (fruit)	straw*
Winter oilseed rape	23.5	28.4	19.7	16.5
Spring oilseed rape	23.5	28.5	19.7	16.5
White mustard	23.0	31.5	19.9	16.3
Indian mustard	22.7	29.6	19.2	16.0
Spring false flax	22.9	27.9	20.0	16.2
Crambe	22.2	29.8	18.7	16.0
$LSD_{0.05}$	ns	1.41	1.26	ns

* in dry matter
ns – non-significant

The highest unit energy volume was contained in 1 kg fat-free seed residue of false flax, rape (either form) and white mustard. Fat-free dry matter of Indian mustard seeds and crambe fruits showed considerably lower energy value (by about 3-6%) (Table 4).

The energy value of the yield of whole seeds, oil, fat-free seed residue and straw is presented in Fig. 2. The highest amount of energy that can be used as a component for liquid fuels (contained in oil) was obtained from 1 ha of winter oilseed rape (45.3 $GJ \cdot ha^{-1}$). The energy value of oil produced from 1 ha of spring oilseed plants ranged from 54-43% (spring oilseed rape, white mustard and false flax) to 20-27% (crambe and Indian mustard) of the energy value of winter oilseed rape yield obtained from the same area. The energy value of fat-free seed (fruit) residue yield was relatively more varied in comparison to the standard (winter oilseed rape), only 13% lower for white mustard and as much as 3.2-fold lower for crambe. The energy value of straw yield from 1 ha of winter oilseed rape was 81.2 GJ. Of the spring oilseeds, the highest energy value of straw was obtained from 1 ha of spring oilseed rape (81% of the energy value of winter oilseed rape straw yield). The energy contained in the straw of spring oilseed rape was 33-70% higher than that of the other spring oilseed species (which in absolute values accounted for about 16-27 $GJ \cdot ha^{-1}$).

Fig. 2. Energy value of oilseed crops yield (3-year mean)



Energy efficiency of production

The highest cumulated energy gain in seed and straw yield was obtained from 1 ha of winter oilseed rape production (145 GJ). It was about 47% higher than the cumulated energy gain from the spring oilseed rape (i.e. about 46 GJ·ha^{-1}). The effective energy gain (seeds/fruits and straw) obtained from per 1 ha production of the other spring oilseed crops was from 1.7-fold (white mustard) to 2.9-fold (crambe) lower than in winter oilseed rape.

The energy efficiency ratio for the seed yield showed the most desirable values for winter oilseed rape and white mustard (4.0-3.9) (Table 5). The second homogenous energy-efficiency group was made up of spring oilseed rape (3.1) and spring false flax (3.5), while the third one, characterised by the lowest energy efficiency ratio – Indian mustard and crambe (2.1-2.7).

Table 5. Energy evaluation parameters for production of 1 ha of oilseed crops (3-year mean)

Item		Species					
		oilseed rape		mustard		spring false flax	crambe
		winter	spring	white	Indian		
Energy input per 1ha (GJ)		20.9	15.4	13.7	13.4	12.4	12.3
Yield energy value per 1ha (GJ)	A	84.5	48.3	53.6	28.6	42.8	21.5
	B	165.7	114.0	100.8	78.0	81.4	62.3
Cumulated energy gain per 1 ha (GJ)	A	63.6	32.9	39.9	15.2	30.4	9.2
	B	144.8	98.6	87.1	64.6	69.0	50.0
Energy efficiency ratio	A	4.0	3.1	3.9	2.1	3.5	1.7
	B	6.9	6.4	7.4	5.8	6.6	5.1

A – seeds (fruit)
B – seeds (fruit) and straw

Having considered possible energy utilization of straw, the highest energy efficiency ratio was obtained from 1 ha cultivation of white mustard and was 7% higher than the value of the energy efficiency ratio per 1 ha of winter oilseed rape.

CONCLUSIONS

1. Under the agronomic and ecological conditions of Poland, 1 ha of winter oilseed rape generated over 166 GJ energy, including about 27% of the energy utilisable for the production of methyl (ethyl) esters, 24% – for animal nutrition and 49% – potentially used for power production (burning). Having subtracted the agronomic treatments inputs (about 21 GJ·ha^{-1}), the cumulated energy gain per 1 ha of winter oilseed rape cultivation corresponded to 3.5 tons of diesel oil.
2. The energy potential contained in seed and straw yield of spring *Brassica* oilseed plants is relatively lower than in spring oilseed rape and white mustard: by 31-39%, spring oilseed false flax and white mustard – by 51-53%, and crambe – 62%. The energy input for agronomic treatments per 1 ha of spring oilseed plants is from 26% (spring oilseed rape) to 34-41% (the other spring oilseed plants) lower than winter oilseed rape.
3. The analysis of the energy balance for seed production of oilseed plants suggests that as for production of energy utilizable for liquid biofuel production, the highest energy efficiency, comparable to that of winter oilseed rape, is obtained from cultivation of white mustard. It is lower (by 13-23%) for spring false flax and spring oilseed rape, and the lowest (by 48-58%) for Indian mustard and crambe. Having considered the energy value of straw, the highest energy efficiency ratio was recorded for 1 ha cultivation of white mustard.

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