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Energy and economic efficiency of camelina and crambe biomass production on a large-scale farm in north-eastern Poland

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ABSTRACT

The aim of this study was to determine the energy and economic efficiency of *Camelina sativa* and *Crambe abyssinica* production on a commercial plantation. The study was based on a three-year large-scale trial. The energy and economic inputs in the production of camelina and crambe were similar and were dominated by the consumption of fertilisers. The average yield of camelina and crambe seeds was very similar but the yield of camelina was more stable. The average energy gain from production of camelina was higher by 4.9% compared with the crambe. The average income from camelina seeds production (876.3 € ha^{-1}) was higher by almost 12% than for crambe. The average energy efficiency ratio for production of camelina seeds (2.00) was higher by 5.7% compared with the crambe. The average energy efficiency ratio for the production of total biomass (seeds and straw) of camelina (4.74) was higher by 4.2% compared with the crambe. The revenue from camelina seeds was on average 312 € ha^{-1} and was 36% higher than that from crambe seeds, while the revenue from camelina total biomass production was on average 432.6 € ha^{-1} and was 26% higher than the value obtained from crambe production.

1. Introduction

Energy from renewable sources (RES) accounts for over 25% of the production of primary energy in the EU–28 [1]. The proportion of RES in energy production can be increased further, but all of its potential sources must be taken into account: sun, water, wind, geothermal energy and biomass. The development rates of different RES depend on geographic, climatic and economic conditions, but they also have to take into account pressure in four various areas: cost, environment, safety and potential for creating jobs. Moreover, efforts should be made to save energy and increase energy efficiency in the consumption of electricity and heat and liquid fuels used in transport [2,3]. Biomass is the main raw material used in the production of liquid biofuels for transport. In Europe, rape is the main oil crop; it can be used for the production of fuel, in industry and in food production. Frequently, there is no difference regarding production technology in growing plants for food or energy. However, an assessment of energy efficiency of biomass production is important in the production of a specific crop for energy purposes. Moreover, the energy efficiency ratio of biomass is influenced mainly by the crop species and production regime. The production technology determines the demand for energy (energy input) and the amount of energy accumulated in biomass (energy output) [4–8].

Camelina (*Camelina sativa* L. Crantz) and crambe (*Crambe abyssinica* Hochst ex R.E. Fries) can be an alternative to rape, especially on poorer soils. Camelina and crambe are oil crops which are becoming an attractive feedstock in bio-industry and energy production owing to their beneficial agronomical properties, such as a short growing season, resistance to drought and frost, low requirements regarding fertilisers and pesticides consumption as well as a high content of oil in seeds and its valuable composition. These species have been attracting the interest of many research centres and companies interested in using their oil and biomass for the production of bioproducts and biofuels [9–12].

Crambe [13] and camelina [14] are species which in the future

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may provide a source of renewable energy. It is believed that, in some cases, camelina can offset on-farm diesel use, making it economically feasible for farmers to grow their own fuel. This may contribute to an increase in farm income and to diversify rural economic development [14]. Moreover, camelina oil and meal have the potential to find application as a drop-in product for adhesives, films, coatings, packing materials and plastics. Extension of this niche market (outside biodiesel) for camelina may, this way, increase the economic attractiveness of its production [15].

The novelty of the authors' studies is an analysis of the energy and economic production efficiency of two niche spring oil crop species (camelina and crambe) under commercial production conditions. This is a very important issue, which in the future may justify the production and potential use of these crops as a source of bioproducts. Therefore, the aim of this three-year study was to determine (i) the energy input and energy efficiency, and (ii) the costs, income and revenue from camelina and crambe biomass production (seeds, straw).

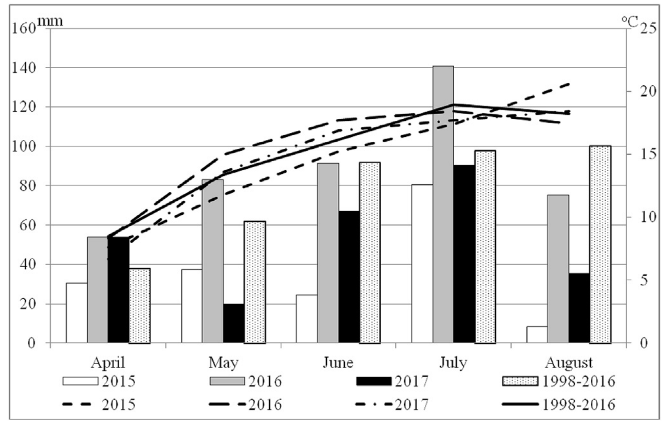

Fig. 1. Weather conditions in successive growing seasons of 2015–2017 and multi-year period 1998–2016; bars represent precipitation; curves represent air temperatures.

2. Materials and methods

2.1. Field experiment

The study was based on a three-year large-scale trial, carried out in 2015–2017, in north-eastern Poland. The experiment was conducted on agricultural areas owned by the University of Warmia and Mazury in Olsztyn (UWM), situated within a distance of approx. 3 km from each other, on Eutric Cambisols soil. In 2015, an experiment was set up in the village of Samławki (53°59′ N, 21°05′ E) on a plot of 1.5 ha (0.5 ha crambe +1 ha camelina). A traditional tillage system was applied in the experiment, with winter wheat as a forecrop. In 2016, another experiment was set up in the village of Kocibórz (54°1′ N, 21°09′ E) on a plot of 2 ha (1 ha crambe +1 ha camelina). Winter wheat was used as a forecrop, which was followed by winter rape in autumn 2015. However, winter rape was frozen in winter 2015/2016 and spring oil crops were sown on the plot (camelina and crambe). Soil cultivation on this plot was carried out in a reduced tillage system, and soil treatment with a cultivation unit and harrowing was carried out in spring 2016 before camelina and crambe were sown. In 2017, another experiment was set up in the village of Łężany (53°57′ N, 21°08′ E) on a plot of 11 ha (5 ha crambe + 6 ha camelina). A traditional tillage system was applied in this experiment, with winter wheat as a forecrop. In each of these experiments, seeds of crambe (Galactica variety) and camelina (Midas variety) were sown by drill; 13 kg ha^{-1} and 6 kg ha^{-1} respectively. The dates of sowing and harvesting are shown in Table 1. Detailed data on the weather conditions in the years when the experiments were carried out and in the multi-year period are presented in Fig. 1.

2.2. Energy output analysis

Samples of seeds and straw for laboratory analyses were collected during the harvest in each year of the study. The parameters determined in a laboratory included thermophysical and chemical properties. Moisture content and higher heating value were used to calculated lower heating value of seeds and straw of the species under study. Subsequently, the yield energy value of camelina and crambe crops was calculated as the product of harvested seeds and straw and their lower heating values (1):

$$Y_{ev} = Y_b \cdot Q_i^r \quad (1)$$

where:

Y_{ev} – biomass yield energy value seeds or straw (GJ ha^{-1}),
Y_b – biomass yield seeds or straw (Mg ha^{-1}),
$Q^r{}_i$ – biomass lower heating value seeds or straw (GJ Mg^{-1}).

Table 1
Dates of sowing and harvesting of camelina and crambe in the study years.

Item	Year		
	2015	2016	2017
Sowing	24 April	07 April	10 April
Harvesting	20 August	26 August	31 August

2.3. Energy input analysis

The energy inputs used to produce the camelina and crambe biomass were analysed, including several energy sources: direct energy carriers (diesel fuel), exploitation of fixed assets (tractors, machines, equipment), consumption of materials (fertilisers, pesticides, seeds for sowing) and human labour (2):

$$E_{i\ total} = E_{i\ diesel} + E_{i\ fixed\ assets} + E_{i\ materials} + E_{i\ human\ labour} \quad (2)$$

where:

$E_{i\ total}$ – total energy input for camelina and crambe production (GJ ha^{-1}),
$E_{i\ diesel}$ – energy input for diesel fuel consumption (GJ ha^{-1}),
$E_{i\ fixed\ assets}$ – energy input for fixed assets (GJ ha^{-1}),
$E_{i\ materials}$ – energy input for materials (GJ ha^{-1}),
$E_{i\ human\ labour}$ – energy input for human labour (GJ ha^{-1}).

The total energy input for camelina and crambe biomass production was calculated based on the unit consumption of materials and the energy intensity of their production. The energy conversion coefficients for diesel fuel (43.1 MJ kg^{-1}), nitrogen fertilizers (48.99 MJ kg^{-1} N), mineral-organic fertiliser (15.23 MJ kg^{-1}) and pesticides (268.4 MJ kg^{-1} of active substance) were based on the indexes presented in literature [16]. The energy input for the use of seeds for sowing (12 MJ kg^{-1}), use of tractors (125 MJ kg^{-1}), machines (110 MJ kg^{-1}) and human labour (60 MJ h^{-1}) in the production process was calculated with the coefficients provided in the literature and data provided in materials published by manufacturers of tractors and machines [17,18]. The types of equipment