PERSPECTIVES OF WINTER TURNIP RAPE (*Brassica rapa* L. *var oleifera subvar. Biennis*) FOR BIOFUEL IN ESTONIA

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Abstract
The utilization of biofuels is a possible alternative to fossil-based liquid fuels. Rapeseed oil is the most exploited raw material for biodiesel production in Europe. In Estonian growing conditions winter turnip rape (WTR) is most suitable for this purpose. Good resistance to pests and plant diseases is the advantage of WTR compared to spring rapeseed. Thus, the cultivation of WTR is inexpensive and environmentally friendly because of the minimised usage of pesticides and herbicides.
The oil yield of WTR per hectare is the most important trait for biodiesel production. WTR has proved itself to Estonian farmers as an oil crop with high yield and very good quality.
Raw fat content, seed yield and raw fat yield of the two varieties and seven perspective breeds were estimated in a two-year experiment at the Jõgeva Plant Breeding Institute. As a result, the most promising breed for biodiesel production was JSv 01-13051: seed yield in 2004 – 3,179*** kg ha^{-1} and in 2006 – 3,756*** kg ha^{-1}; raw fat content in 2004 – 449 g kg^{-1} and in 2006 – 446 g kg^{-1}; raw fat yield in 2004 – 1,427*** kg ha^{-1} and in 2006 – 1,675*** kg ha^{-1} (all the data represented on moisture content 75 g kg^{-1}).

Key words: seed yield, raw fat content, raw fat yield

Introduction

Global energy demand increases rapidly. According to the International Energy Agency World Energy Outlook reference scenario, economic growth and increasing population will lead to an increase in global energy consumption of 18% between 2000 and 2030. Utilization of reproductive sources of energy is a possible alternative to fossil-based liquid fuels. One opportunity is using biofuels made from biomass (Clini *et al*., 2005).
Liquid biofuels can decrease the pollution level caused in some microenvironments such as urban centres by cars and other motor vehicles fuelled by fossil fuels. At present about 30 billion litres per year of biofuels are commercialised in North and South America, Europe and South Africa (Clini *et al*., 2005). Vegetable oils have the potential to serve as a substitute for petroleum diesel fuel. Of the more than 350 known oil bearing crops, those with the greatest production potential are sunflower, safflower, soybean, cottonseed, rapeseed, canola, corn and peanut oil. The development of vegetable oil as an alternative fuel would make it possible to provide energy for agriculture from renewable sources located in the area close to where it could be used (Peterson, 2002).
Europe currently imports 50% of its total energy needs. In transport, which relies heavily on oil, 80% of the energy is imported. In 2003, the European Parliament and the Council have adapted the Directive 2003/30/EC aiming to promote the use of biofuels for transport. Biodiesel is one possible alternative fuel options that has the potential to help to reduce oil dependence and global warming pollution (Union of…).
Unlike the US where biodiesel is produced from soybean, the EU uses mainly rapeseed and to some extent sunflower seed. Production of biodiesel in Europe jumped by in 2006 – to 4.89 million tonnes up from 3.184 million tonnes in 2005 according to the European Biodiesel Board. This follows a 65% record growth in 2005 over 2004 (European Biodiesel…).
Although natural fats and oils are among the main biological raw material for chemical and technical application (the estimated annual consumption in Europe is about 2.6 million tons), only a limited fraction (according to different estimations between 15 and 25%) of the total vegetable oil supply in the world are used in the industrial sectors, in non-food or technical applications (Riva and Calzoni, 2003). First generation biofuels like ethanol from corn and biodiesel from rapeseed have effects on food prices (Krenn, 2007).

Cultivation of oil crops has increased in Estonia from 45.500 ha in 2003 up to 72.500 ha in 2007 (Statistics Estonia, 2007). Spring oilseed rape is the main cultivated oil crop in Estonia; winter oilseed rape and winter turnip rape (WTR) are more used as alternatives (Narits, 2006 a). The success of the cultivation of spring oilseed rape depends on plant protection, because rape is attractive to a large number of insect species, both beneficial and pests (Winfered, 1986). The winter hardiness of winter rape is very low in Estonian climatic conditions (Norman, 1994); therefore the cultivation of winter rape is not economically beneficial. WTR as an oil crop that has achieved popularity among Estonian farmers. The raw fat content and seed yield of WTR are equal or in some years even exceed spring oilseed rape (Narits 2006 b). WTR needs less plant protection against pests and diseases, compared to spring oilseed rape, which is its definite economical advantage, both financially and environmentally. It is also of great importance that oil cake used as an animal feed has no residuals of plant protection chemicals.

The Jõgeva Plant Breeding Institute (Jõgeva PBI) started a cooperation with the Svalöf Weibull AB in WTR breeding in 1993. The WTR varieties Prisma and Largo obtained in the cooperation are registered in the Estonian Variety List. In the beginning of the cooperation winter hardiness was the main breeding objective but currently high and stable raw fat yield is defined to be a more important breeding task. The Svalöf Weibull AB transferred all its WTR breeding material to the Jõgeva PBI in 2002. Samples of each breeding line are maintained in the genebank of the Jõgeva PBI. Looking for alternatives to fossil fuels is an important activity all over the world, thus researchers from Sweden, Norway, Finland and Canada have requested the WTR varieties and breeds from the Jõgeva PBI for testing in their climatic conditions.

The aim of this study was to estimate the seed yield, raw fat content and raw fat yield of WTR varieties and perspective breeds and to determine the most promising as raw material for biodiesel production.

Materials and Methods

Experiments were conducted at the Jõgeva PBI in the growing seasons of 2003-2004 and 2005-2006. The field trial with the WTR varieties Prisma and Largo and seven perspective breeds was established on 10 m² plots using NNA (nearest neighbour adjustment) randomised design in three replications. Herbicide 'Triflurex 480' (trifluralin) at 2 l ha^{-1} and complex fertilizer 'Kemira Skalsa' N5-P10-K25, of 300 kg ha^{-1} were applied before sowing. The sowing rate was 6 kg ha^{-1}; seeds were not treated. The trial was top-fertilized with 'Kemira Power' N30-P6-S2, of 200 kg ha^{-1} (N 60 kg ha^{-1}on agent) in spring. The winter hardiness of all varieties and breeds of both the trial years was very good (9 points). No pesticides and fungicides were applied during the growing period. Weather conditions of the growing seasons of the trial years were different: 2004 was wet and 2006 dry. Seeds were dried to the moisture content of 75 g kg^{-1} and cleaned/separated after the harvest. The seed yield of all varieties and breeds from each replication was estimated. Seeds of all the three replications were mixed and an average sample of 200 g of each variety and breed was analysed at the laboratory of the Jõgeva PBI. Raw fat, raw protein and glycosinolates content in seeds were analysed by Free and Open Source Software for Near Infrared Reflectance Spectroscopy (FOSSNIRS) system at the laboratory of the Jõgeva PBI. NIRS is widely used for the analysis of bulk rapeseed samples for oil, protein and glucosinolate content (Sato *et al*., 1998; Velasco *et al*., 1999; Velasco *et al*., 2004, Font *et al*., 2004, Aulric and Böhm, 2007). Raw fat yield per hectare was estimated.

The Least Significant Difference (LSD) procedure was used when the F-test was significant ($P=0,001$) and correlation was analysed ($p< 0,005$). The results were processed by the statistical program STATISTICA 4.5 (www.statsoft.com).

Results and Discussion

The following traits of each variety and breed were determined: seed yield as a main crop characteristic; raw fat yield as a main characteristic for oil production; raw fat content as a main quality characteristic of the oil crop; protein content and glucosinolate content as a characteristics of cake as an animal feed.

The results of 2004 are presented in Table 1. The average (Control) seed yield of tested varieties and breeds was 2,890 kg ha^{-1}. The seed yield of the variety Largo (3,326 kg ha^{-1}) and the breed JSv

01-13051 (3,179 kg ha^{-1}) exceeded significantly the Control. Significantly lower was the seed yield of the variety Prisma (2,473 kg ha^{-1}) and the breed JSv 01-13084 (2,537 kg ha^{-1}).

Table 1. Seed yield, raw fat yield (kg ha^{-1}), raw fat and protein content (g kg^{-1}) and glucosinolate content (μmol g^{-1}) of the varieties and breeds of winter turnip rape in 2004

Variety/breed	Seed yield, kg ha^{-1}	Raw fat content, g kg^{-1}	Raw fat yield, kg ha^{-1}	Protein content, g kg^{-1}	Glucosinolate content, μmol g^{-1}
Prisma	2,473***	454	1,123***	306***	132***
Largo	3,326***	437***	1,455***	327	98
JSv 00-13426	2,937	462***	1,357	328	89
JSv 00-15588	2,716	450	1,222	348	73
JSv 01-11403	2,912	448	1,308	314***	80
JSv 01-11449	2,919	442***	1,290	342	93
JSv 01-13051	3,179***	449	1,427***	355***	53***
JSv 01-13102	2,537***	452	1,147***	353***	78
JSv 01-13102	3,007	444	1,335	333	101
Average of 2004 (Control)	2,890	449	1,296	334	89

*** - significance at 0.001 probability level

The average raw fat content was 449 g kg^{-1}. The breed JSv 00-13426 (462 g kg^{-1}) showed significantly higher raw fat content compared to the Control; the variety Largo (437 g kg^{-1}) and the breed JSv 01-11449 (442 g kg^{-1}) had significantly lower raw fat content.

The average raw fat yield was 1,296 kg ha^{-1}. The raw fat yield of the variety Largo (1,455 kg ha^{-1}) and the breed JSv 01-13051 (1,427 kg ha^{-1}) was significantly higher; the raw fat yield of the variety Prisma (1,123 kg ha^{-1}) and the breed JSv 01-13084 (1,147 kg ha^{-1}) was significantly lower compared to the Control.

The average protein content was 334 g kg^{-1}. Significantly higher was the protein content of the breeds JSv 01-13051 (355 g kg^{-1}) and JSv 01-13084 (353 g kg^{-1}). Significantly lower was the protein content of the variety Prisma (306 g kg^{-1}) and the breed JSv 01-11403 (314 g kg^{-1}).

The average glucosinolate content was 89 μmol g^{-1}. Significantly lower was the glucosinolate content of the breed JSv 01-13051 (53 μmol g^{-1}) and higher of the variety Prisma (132 μmol g^{-1}).

The results of 2006 are presented in Table 2. The average seed yield was 3,512 kg ha^{-1}. The seed yield of the breeds JSv 01-11449 (3,832 kg ha^{-1}) and JSv 01-13051 (3,756 kg ha^{-1}) was significantly higher compared to the Control. Significantly lower was the seed yield of the variety Prisma (3,274 kg ha^{-1}) and the breed JSv 01-13102 (3,177 kg ha^{-1}).

Table 2. Seed yield, raw fat yield (kg ha^{-1}), raw fat and protein content (g kg^{-1}) and glucosinolate content (μmol g^{-1}) of the varieties and breeds of winter turnip rape in 2006

Variety/breed	Seed yield, kg ha^{-1}	Raw fat content, g kg^{-1}	Raw fat yield, kg ha^{-1}	Protein content, g kg^{-1}	Glucosinolate content, μmol g^{-1}
Prisma	3,274***	453***	1,483	351	175***
Largo	3,307	448	1,482	359	94
JSv 00-13426	3,445	444	1,530	351	90
JSv 00-15588	3,381	439***	1,484	356	123
JSv 01-11403	3,707	443	1,642	347***	95
JSv 01-11449	3,832***	435***	1,667***	368***	108
JSv 01-13051	3,756***	446	1,675***	358	79***
JSv 01-13102	3,732	442	1,650***	365	106
JSv 01-13102	3,177***	448	1,423***	365	97
Average of 2006 (Control)	3,512	444	1,556	358	107

*** - significance at 0.001 probability level

The average raw fat content was 44.4 g kg^{-1}. Significantly higher was the raw fat content of the variety Prisma (453 g kg^{-1}) and lower of the breeds JSv 01-11449 (435 g kg^{-1}) and JSv 00-15588 (439 g kg^{-1}) compared to the Control.
The average raw fat yield was 1,556 kg ha^{-1}. Significantly higher was the raw fat yield of the breeds JSv 01-13051 (1,675 kg ha^{-1}), JSv 01-11449 (1,667 kg ha^{-1}) and JSv 01-13084 (1,650 kg ha^{-1}). Significantly lower was the raw fat yield of the breed JSv 01-13084 (1,423 kg ha^{-1}).
The average protein content was 358 g kg^{-1}. Significantly higher was the protein content of the breed JSv 01-11449 (368 g kg^{-1}). Significantly lower was the protein content of the breed JSv 01-11403 (347 g kg^{-1}).
The average glucosinolate content was 107 μmol g^{-1}. Significantly lower was the glucosinolate content of the breed JSv 01-13051 (79 μmol g^{-1}) and higher of the variety Prisma (175 μmol g^{-1}).
In 2006, the seed yield of all the tested WTR varieties and breeds was higher than three tons per hectare. Only three trial components exceeded the three-ton level in 2004. The breed JSv 01-13051 showed good seed yield in both the years. The breeds JSv 01-11449, JSv 01-13051 and JSV 01-11403 had better seed yield stability compared to the other varieties and breeds. Correlation between seed yield and weather conditions was significant (r=0,80).
The raw fat content of the tested material was good in both the years (higher than 440 g kg^{-1}). JSv 00-13426 had the highest raw fat content in 2004 (462 g kg^{-1}). A negative correlation was observed between raw fat content and seed yield (r=-0,51). Seed yield was higher in 2006 compared to 2004; raw fat content was, in opposite, higher in 2004 and lower in 2006. This tendency particularly appeared in the variety Largo in 2004 and the breed JSv 01-11449 in 2006.
To describe better the varieties and breeds as potential raw material for oil producers, the raw fat yield per hectare was calculated (Figures 1, 2). A high correlation between raw fat yield per hectare and seed yield was revealed (r=0,99), but the correlation between raw fat yield and raw fat content was not significant (r=0,44). The breed JSv 01-13051 showed high raw fat yield in both years. Due to the coincidence of better than the average results of all the quality characteristics, such as seed yield, raw fat yield and raw fat content, the outcome of the mentioned breed was the best in 2006. High level of raw fat yield content and its stability are necessary features for oil production (Narits, 2007 a).
To show WTR varieties and breeds as the potential material for animal feed, raw protein yield per hectare was calculated (Figures 1, 2). The protein content of the WTR varieties and breeds was higher in the dry year of 2006. Year effects on protein content and seed yield were significant (r=0,73 and r=0,65, respectively). The breed JSv 01-13051 had high protein content in both the years, thus the oil cake of this breed has good nutritive value.

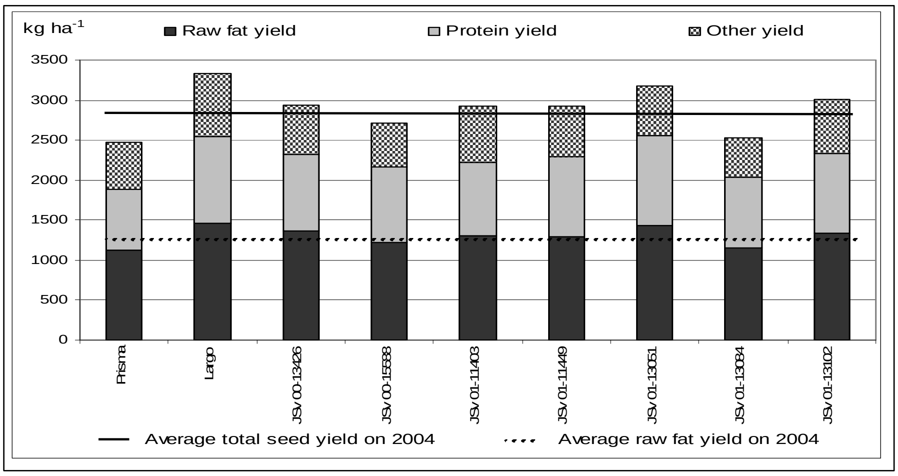

Figure 1. The distribution of total seed yield of WTR varieties and breeds in 2004

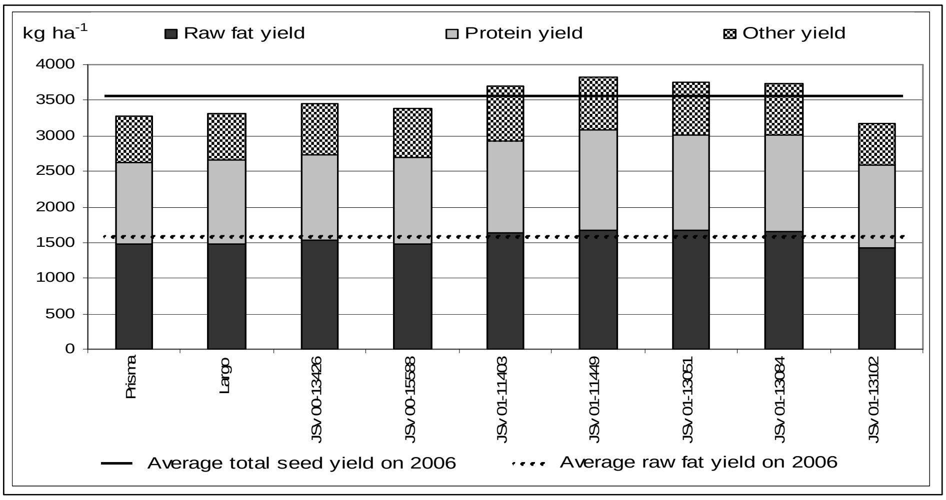

Figure 2. The distribution of total seed yield of WTR varieties and breeds in 2006

The glucosinolate content of the WTR varieties and breeds differed in 2004 and 2006. The effect of the variety in glucosinolate content was significant (r=0,52). It was the only indicator having a significant effect to the variety. The breed JSv 01-13051 had good results in both the years when the glucosinolate content was lower than that of the other varieties and breeds. The content of glycosinolates is a variety specific characteristics. For example, Prisma has always a high content of glycosinolates, but concerning the breeds, this characteristic is yet unstable. Correlation between year interaction and glucosinolate content was low (r=0,38), thus glucosinolate content depended on weather conditions to a small extent. In drought stressed plants, glucosinolate content increases in all plant parts, including seeds (Narits, 2007 b).

Conclusions

WTR has good seed yield and raw fat yield potential. Summarizing all data we can conclude that the most promising breed for biodiesel production among nine tested varieties and breeds was JSv 01-13051 with a seed yield of 3,179*** kg ha^{-1} in 2004 and of 3,756*** kg ha^{-1} in 2006; and a raw fat yield 1,427*** kg ha^{-1} in 2004 and 1,675*** kg ha^{-1} in 2006. Furthermore, this breed had low glucosinolate content and high protein content, which results in healthy oil cake as an animal feed.
WTR has good potential for growing as the raw material of biodiesel production in Estonian climatic conditions.

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ZIEMAS RIPŠA (*Brassica rapa* L. *var oleifera subvar. Biennis*) PERSPEKTĪVAS BIODEGVIELAS RAŽOŠANAI IGAUNIJĀ

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Biodegvielu izmantošana ir iespējama alternatīva fosilajām šķidrajām degvielām. Eiropā biodīzeļa ražošanai visvairāk izmantotā izejviela ir rapšu eļļa. Igaunijas augšanas apstākļos šim mērķim vispiemērotākais ir ziemas ripsis (WTR). Tam ir labāka rezistence pret kaitēkļiem un augu slimībām nekā vasaras rapsim. Tādējādi, samazinātas pesticīdu un herbicīdu lietošanas rezultātā WTR kultivēšana ir lēta un videi draudzīga.
Biodīzeļa ražošanai visnozīmīgākais rādītājs ir WTR eļļas raža uz hektāru. Igaunijas zemnieki atzinuši WTR kā eļļas kultūru ar augstu ražu un ļoti labu kvalitāti.
Jēltauku saturs, sēklu raža un jēltauku raža divām pamatšķirnēm un septiņām perspektīvām šķirnēm tika novērtēta divu-gadu izmēģinājumā Jõgeva laukaugu selekcijas institūtā. Rezultātā, visdaudzsološākā šķirne biodīzeļa ražošanai bija JSv 01-13051: sēklu raža 2004. gadā – 3,179*** kg ha^{-1} un 2006. gadā – 3,756*** kg ha^{-1}; jēltauku saturs 2004. gadā – 449 g kg^{-1} un 2006. gadā – 446 g kg^{-1}; jēltauku raža 2004. gadā – 1,427*** kg ha^{-1} un 2006. gadā – 1,675*** kg ha^{-1}.

SIMPLIFICATION OF WINTER RYE (*SECALE CEREALE* L.) GROWING TECHNOLOGY

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Abstract
The paper presents the data on winter rye cultivation technology studies conducted during the period 1994-2006. The field trials carried out on a *Haplic Luvisol* were designed to estimate the effects of soil preparation, seed rate and nitrogen fertilization on winter rye grain yield and on the