Field Crops Research 121 (2011) 248–255

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Trade-off between oil and protein in rapeseed at high latitudes: Means to consolidate protein crop status?

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ARTICLE INFO

Article history:
Received 13 July 2010
Received in revised form 22 October 2010
Accepted 13 December 2010

Keywords:
Oilseed rape
Turnip rape
Oil content
Protein content
Protein crop
Protein self-sufficiency
Yield
Yield component

ABSTRACT

Crop-derived feed protein production is alarmingly low in Europe. Finland represents the northernmost growing region in the world and consequently lacks wide-ranging alternatives to improve crop-based protein production. Spring rapeseed, both turnip rape (*Brassica rapa* L.) and oilseed rape (*Brassica napus* L.), are adapted to such northern conditions. This study examines the potential for genotype and environment induced trade-off between oil and protein in rapeseed in order to enhance further the status of rapeseed as a protein crop for northern areas. Datasets on advanced breeding progenies (including cultivars) were provided by Boreal Plant Breeding Ltd., while environment-induced variability in combinations of protein and oil content was studied by using long-term, multi-location datasets of MTT Official Variety Trials. Oilseed rape has more potential as a protein producer than turnip rape, with some 100 kg/ha difference in protein yields. Selecting lines superior in seed protein content at the expense of oil was not a potential means to consolidate protein production capacity per hectare: seed and protein yields were higher the better the capacity of the line to store oil. This can only mean that obviously the lower energy demand for oil synthesis was not alternatively used to boost protein production, but actually *vice versa*. In the case of environment-induced variation, the highest protein yields were produced in experiments where relatively high protein content was associated with modest oil content, but such conditions were characterised as inefficient in general production capacity and thereby, excessive in applied nitrogen fertiliser. Hence, we were not able to identify promising opportunities for prompt and energy-efficient trade-off between protein and oil in rapeseed.

1. Introduction

Oilseed rape (*Brassica napus* L. var. *oleifera* subvar. *annua*) is the third most important source of plant oil in the world after soybean [*Glycine max* (L.) Merr.] and oil palm (*Elaeis guineensis* L.). It can be grown in wide variety of conditions, but in northern Europe it is the only significant oil crop. Oilseed rape is primarily an oil crop, but it also produces high quality proteins. Hence, oilseed rape meal, typically having 36% crude protein and 3.5% residual oil, is commonly used for animal feeds around the world: it is the second most widely traded protein ingredient after soybean meal (www.canola-council.org cited on 22nd June 2010).

In Europe, crop-based protein production is low compared with consumption: protein self-sufficiency in feeds averages ca. 30%, which is also the case for Finland, but only in the best years. Few alternative crops are available for protein production. In addition to spring sown oilseed rape, turnip rape (*Brassica rapa* L. var. *oleifera* subvar. *annua*), pea (*Pisum sativum* L.) and faba bean (*Vicia faba* L.) can be grown in the northernmost seed crop production region (Peltonen-Sainio et al., 2009a). Climate warming in the future may expand the potential growing regions of protein crops in Finland, but it could also open some prospects for lupin (*Lupinus* spp.) and sunflower (*Helianthus annuus* L.), though not for soybean cultivation (Peltonen-Sainio et al., 2009b).

Genotype (Peltonen-Sainio and Jauhiainen, 2008), growing conditions (Bouchereau et al., 1996; Tesfamariam et al., 2010) and crop management (Hocking et al., 1997; Lickfett et al., 1999; Rathke et al., 2006) control expression of yield and quality in oilseed rape and turnip rape (hereon together referred to as rapeseed). In Finland, only the earliest maturing spring cultivars can be grown, and in contrast to other regions, early maturing turnip rape dominates with close to 85% of the current area devoted to oil crops. In spite of limitations for producing rapeseed in such northern conditions, genetic improvements in yield potential and oil content have been continuous and marked (Peltonen-Sainio et al., 2007; Peltonen-Sainio and Jauhiainen, 2008).

Crop seeds accumulate proteins, oils and carbohydrates as such nitrogen (N) and carbon reserves are necessary for early seed ger-

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doi:10.1016/j.fcr.2010.12.010

mination and seedling growth (Weber et al., 2005; Agrawal and Thelen, 2006). Timing of accumulation of these major storage products differs depending on expression of genes that are involved in carbohydrate metabolism and oil and storage protein synthesis (Hills, 2004). Timing of serious stresses can therefore alter composition of seeds, which are the principal sinks for photosynthates during pod filling (Rood et al., 1984; Addo-Quaye et al., 1986). Plant breeding has been very successful in shaping the seed composition according to human preferences. Rapeseed is one of the masterpieces of such tailoring power in seed quality and composition, which has enabled a drastic shift of rapeseed status among the world's top crops: in 1961 the world production of rapeseed was <4 Mt and in 2008 it was 58 Mt (www.faostat.fao.org cited on 22nd June 2010).

Modern rapeseed cultivars adapted to northern growing conditions have higher seed oil content and oil yield compared with their predecessors, but at the expense of slightly reduced seed protein content, though not protein yield (Peltonen-Sainio and Jauhiainen, 2008). The need for emphasising crop-based protein production through tailoring high protein rapeseed crop is topical as there is currently generally very low total crop-based protein production capacity at high latitudes (and consequently low self-sufficiency), a lack of true variety of alternative protein crops for large-scale production, a heavy dependence on imported soybean, and not least the global demand for protein feed is likely to increase substantially in the future due to global population growth, elevation in standards of living, increase in consumption of meat in population-rich regions, and also climate change induced future constraints on availability of agricultural land and its production capacity. Therefore, this study investigates the potential for a trade-off between oil and protein in rapeseed breeding progenies that are well adapted to northern conditions, as well as the effects of environment on expression of the balance between oil and protein in seed and yield on a per hectare basis. We hypothesise that by re-examining the existing breeding material, we might be able to take prompt and successful action in finding a novel balance between oil and protein production and by such means the status of rapeseed as a highly productive protein crop might be emphasised.

2. Materials and methods

Variation among advanced breeding lines and cultivars (hereon jointly referred to as lines) was studied from a dataset provided by Boreal Plant Breeding Ltd. Data were collected during 1991–2009 and turnip rape data included 866 lines and 5995 recordings, while oilseed rape included 268 lines and 1243 recordings. It was not possible to use arithmetic means to compare lines because the tested set of the lines changed from year to year, but long-term check lines were used. Modern mixed models technique with REML (restricted maximum likelihood) estimation method made it possible to estimate mutually comparable means for all lines when the data were unbalanced. Later mutually comparable means can be used to found lines with similar genetic abilities related to oil and protein contents of seed. At first, the effects of environment and genotype were separated using the following statistical model:

$$y_{ijk} = \mu + \alpha_i + \beta_j + \chi_k + \delta_{jk} + \varepsilon_{ijk} \quad (1)$$

where y_{ijk} is the observed value for ith line in the jth year and the kth experimental site, while μ, α_i, β_j, χ_k, δ_{jk} and ε_{ijk} are the intercept, the fixed effect of line, the random effect of year, the random effect of experimental site, the year-by-experimental site interaction effect (random effect) and the residual effect, respectively. Analyses were done separately for 9 variables: oil content, protein content, yield, oil yield, protein yield, seeds/m^2, single seed weight, growing time (from sowing to ripeness) and lodging.

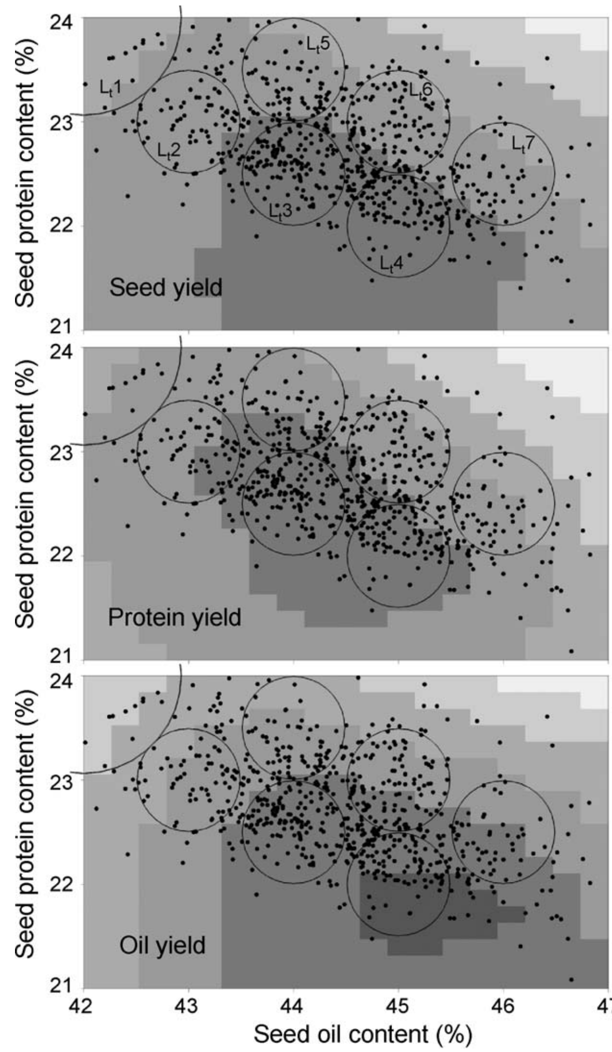

Fig. 1. Scatter diagrams of association between oil and protein content and seed yield, protein yield and oil yield in turnip rape cultivars and breeding lines according to results from field experiments carried out with advanced breeding material of Boreal Plant Breeding Ltd. Black circles indicate means for each line. Lines groups L_t1–L_t7 (n = 21–89 depending on L_t) are indicated with large circles. Seed yields ranging from 1650 to 2250 kg/ha are shown with darkening greys at intervals of 150 kg/ha, protein yields from 400 to 500 kg/ha at intervals of 25 kg/ha and oil yields from 800 to 1050 kg/ha at intervals of 50 kg/ha.

Line groups were created using estimated oil and protein contents of lines, $\hat{\alpha}_i^{\mathrm{OIL}}$ and $\hat{\alpha}_i^{\mathrm{PROTEIN}}$. Because the used model removed environmental effects from $\hat{\alpha}_i^{\mathrm{OIL}}$ and $\hat{\alpha}_i^{\mathrm{PROTEIN}}$, similarity of lines in the same line group came from genes not from environmental factors. Seven groups were created for turnip rape (L_t1,. . .,L_t7) and nine for oilseed rape (L_o1,. . .,L_o9). The ith line was included in the group if the Euclidean distance between ($\hat{\alpha}_i^{\mathrm{OIL}}$, $\hat{\alpha}_i^{\mathrm{PROTEIN}}$) and mid-point of the group was less than 0.50 (L_t2,. . .,L_t7), 0.70 (L_o1,. . .,L_o9) or 0.95 (L_t1). Mid-points for turnip rape were (42, 24), (43, 23), (44, 22.5), (45, 22), (44, 23.5), (45, 23) and (46, 22.5), while mid-points for oilseed rape were (42, 25), (43, 24), (44, 23), (44, 25), (45, 24), (46, 23), (46, 25), (47, 24) and (48, 23). The graphical illustration of the line groups can be found from Figs. 1 and 2. The number of lines in the line group ranged from nine to 89. One-way ANOVA was used to test the difference between line groups. Response variables were yield, oil yield, protein yield, seeds/m^2, single seed weight, growing time (from sowing to ripeness) and lodging calculated using Eq. (1) (= $\hat{\alpha}_i^{\mathrm{YIELD}}$, $\hat{\alpha}_i^{\mathrm{OIL\,YIELD}}$, $\hat{\alpha}_i^{\mathrm{PROTEIN\,YIELD}}$, $\hat{\alpha}_i^{\mathrm{SEED}\,M-2}$, $\hat{\alpha}_i^{\mathrm{SEED\,WEIGHT}}$, $\hat{\alpha}_i^{\mathrm{GROWING\,TIME}}$ and $\hat{\alpha}_i^{\mathrm{LODGING}}$).