Morphological bases of yield in new oilseed rape hybrids with different shoot vigour

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Introduction

Oilseed rape (OSR) is nowadays one of the most widespread oil crops at world level, and yield improvements are the main goal of breeding programs. To develop high-yielding OSR genotypes, plant physiologists must focus on identifying simple morphological characters influencing processes which determine the yield of economic organs (Thurling, 2003). Better insights into OSR yield bases and detection of new morphological traits linked to final seed yield are crucial for efficient breeding programs.

In OSR, the main factors affecting yield are: plant density, number of pods per plant, seeds per pod, and seed weight (Diepenbrock 2000). However, canopy structure is very plastic and can be adjusted over a wide range of plant densities without significant changes in yields. At low densities, plants branch more and differentiate a greater number of pods, extending the seed development phase. Plants grown at high densities are often more susceptible to lodging but, carrying fewer pod-bearing branches, they have more uniform seed maturation (Morrison et al., 1990; Leach et al., 1999; Momoh et al., 2001).

These compensatory mechanisms, among various plant structures, are based on "source-sink" relationships. From this point of view, dry matter production and stem weight are considered good indicators of assimilate availability and are normally well correlated to the potential pod number and therefore to seed yield (Diepenbrock 2000; Habekottè 1993). These relations also depend on the responses of phenological development, organ formation, assimilates and dry matter partitioning to environmental factors and cultivar choice (Habekottè 1993).

New semi-dwarf hybrids, characterised by reduced shoot size, may have different source-sink relationships with respect to traditional cultivars. In particular, they may show diverse dry matter partitioning and therefore morphological seed yield bases. In this study, the relations between seed yield and some morphological traits in OSR hybrids with different shoot vigour were assessed by varying sowing densities.

Materials and methods

Aiming at investigating the morphological bases of yield in new OSR genotypes, a two-year field trial (2008-09, 2009-10) was set up at the Experimental farm of the University of Padova at Legnaro (45°21'N, 11°58'E, NE-Italy). In a split plot design (n=3), three cultivars, Excalibur (CHH, 'Composite Hybrid Hybrid'), PR45D01 (semi-dwarf CHH) and Viking (open-pollinated variety), were sown at 63, 44 and 22 seeds m^{-2} (3.5, 5 and 10 cm along the row, respectively) with a fixed inter-row distance of 0.45 m. In both years, OSR was sown with a seed drill (sowing depth ~3 cm) at the end of September (September 26, 2008; September 29, 2009) and harvested at mid-June (June 11, 2009, June 14, 2010). Pre-sowing (0-60-60 kg N-P-K ha^{-1}), and spring fertilization (80 kg N ha^{-1}) were the same for each plot.

In both years, OSR phenological development was recorded according to the BBCH scale. At 10 and 20 days after sowing (DAS) the seedling emergence rate (%) was assessed in order to examine the true plant density of each plot. Above-ground biomass accumulation (g DM m^{-2}) was monitored in both years throughout the crop cycle, particularly at the 29, 35, 65, 80 and 90 BBCH stages (beginning of shooting, full shooting, full flowering, seed filling and maturation). At the end of vegetative growth (end of flowering) and during the seed filling period, the weight fraction (% w/w) of green leaves, stems, branches and pods was revealed by biomass partitioning (15 plants for each plot). At the seed filling stage, the numbers of branches and pods bearing on the main raceme and branches were counted and, at maturity, seed yield and 1000-seed weight were analysed.

Statistical analysis was carried out by Statgraphics software (Manugistic Inc., Rockville, Maryland). ANOVA (analysis of variance) and the LSD test ($P \leq 0.05$) were used to evaluate differences among means for morphological parameters and seed yield. Correlation analysis and stepwise regression, with both forward and backward variable selection, were applied to seed yield in relation to fourteen independent morphological variables. Before regression analysis, the data of each variable were standardised by subtracting the mean and dividing by the standard deviation in order to make the regression coefficients of variables in the model comparable.

Results and discussion

Emergence was high (~82%) and similar among genotypes, so that the true density in the plots was comparable and not very different from theoretical sowing density. As regards shoot biomass, the main effect 'genotype' ($P \leq 0.05$) was significant: the conventional hybrid (Excalibur) showed higher DM compared with the semi-dwarf and open-pollinated genotypes. The interaction 'genotype x sampling date' was also significant ($P \leq 0.05$); in particular, great differences among genotypes were observed at the shooting stage (35 BBCH), when Excalibur accumulated higher DM (370 g m^{-2}) than Viking and PR45D01 (317 and 284 g DM m^{-2}, respectively). This result suggests greater assimilate availability for the reproductive part of the cycle in Excalibur with respect to the other genotypes. Considering the main effect 'plant density', no significant differences were found for biomass ($P>0.05$), showing that compensatory mechanisms had taken place among plant structures. However, at 22 seeds m^{-2}, OSR produced significantly lower DM at the two early observation dates (29 and 35 BBCH stages).

In addition, the tested genotypes showed different biomass allocation strategies in both partitioning surveys (Figs. 1, 2). The semi-dwarf genotype exhibited greater incidence of branches at full flowering and also at seed filling, whereas the other two cultivars allocated more DW to stems ($P \leq 0.05$). In particular, Excalibur and Viking both provided relative stem weights of ~51% at full flowering and ~35% at the seed filling stage. For PR45D01, the values were significantly lower: 43.5% at 65 BBCH and 29.2% at 80 BBCH, respectively (mean of two years). Considering the number of branches (Fig. 3), no significant differences were detected among genotypes (main effect 'genotype': $P>0.05$). However, a significant interaction 'genotype x sowing density' was highlighted ($P=0.09$), PR45D01 providing more branches at 63 seeds m^{-2}, whereas Excalibur and Viking did not show any difference between the highest and intermediate sowing densities. As regards pods (Fig. 4), the conventional hybrid achieved the highest values, in particular at 44 seeds m^{-2} (~7400 pods m^{-2}; mean of two years). The semi-dwarf hybrid confirmed its good adaptability at high sowing densities, differentiating the highest number of pods at 63 seeds m^{-2} (~6900 pods m^{-2}; mean of two years).

These morphological responses, also concerning seed yield, showed a significant interaction 'genotype × sowing density' (Fig. 5). Excalibur showed the greatest productivity (4.0 t ha^{-1} DM) at the lowest plant density and Viking (3.1 t ha^{-1} DM) at the intermediate density.

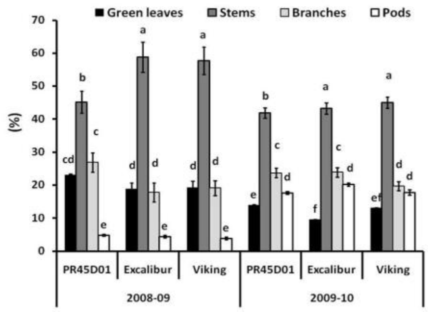

Fig. 1. Relative weight (%) of green leaves, branches, stems and pods on total DM (g m^{-2}) produced at full flowering (65 BBCH) by PR45D01, Excalibur and Viking. Each year analysed separately. Letters: statistically different values within same year (LSD test, P≤0.05). Vertical bars: standard error.

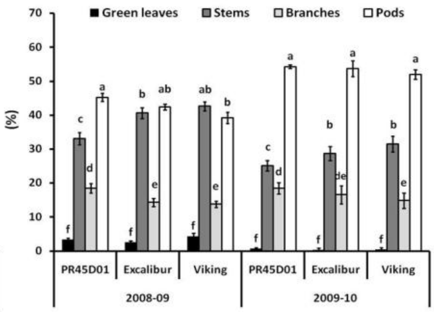

Fig. 2. Relative weight (%) of green leaves, branches, stems and pods on total DM (g m^{-2}) produced at seed filling (80 BBCH) by PR45D01, Excalibur and Viking. Each year analysed separately. Letters: statistically different values within same year (LSD test, P≤0.05). Vertical bars: standard error.

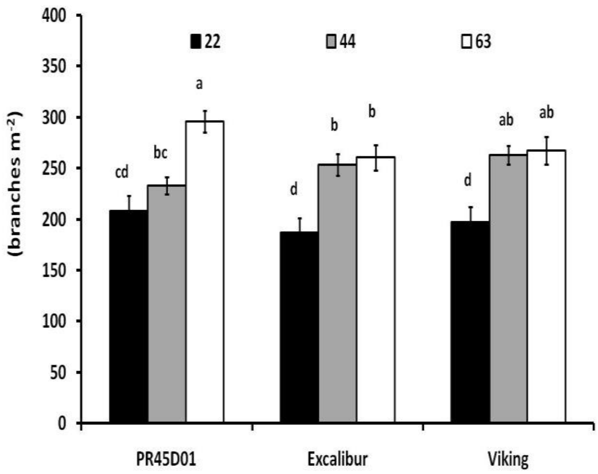

Fig. 3. Number of branches (n m^{-2}) of PR45D01, Excalibur and Viking sown at 22, 44 and 63 seeds m^{-2}. Mean of two years. Letters: statistically different values (LSD test, P≤0.05). Vertical bars: standard error.

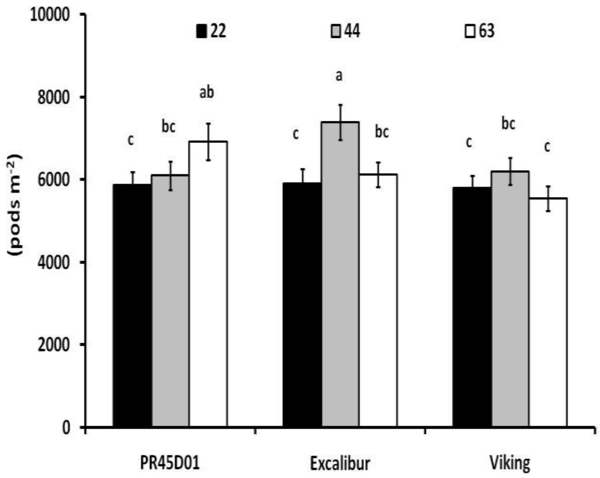

Fig. 4. Number of pods (n m^{-2}) of PR45D01, Excalibur and Viking sown at 22, 44 and 63 seeds m^{-2}. Mean of two years. Letters: statistically different values (LSD test, P≤0.05). Vertical bars: standard error.

PR45D01 showed improved yield as sowing density increased (maximum: 3.6 t ha^{-1} DM at 63 seeds m^{-2}).

Correlation analysis - only hybrid types were examined - revealed that, among morphological parameters, spring biomass (29 and 35 BBCH, i.e., beginning and full stem elongation) and stem weight at seed filling were significantly, but moderately, linked to final seed yield (R^2= 0.24, 0.23 and 0.36 respectively, P≤0.05). Multiple regression analysis confirmed these findings, showing that OSR seed yield was significantly influenced by the DM accumulated until 29 BBCH, (DM 29 BBCH), the weight of stems (STM) and the number of ramifications (NRMF). The three variables retained by the model accounted for 62% of variability, 11% by DM 29 BBCH, 36% by STM and 15% by NRMF, as follows:

OSR yield = 2.43 + 0.004*NRMF + 0.004*DM 29 BBCH + 0.003*STM

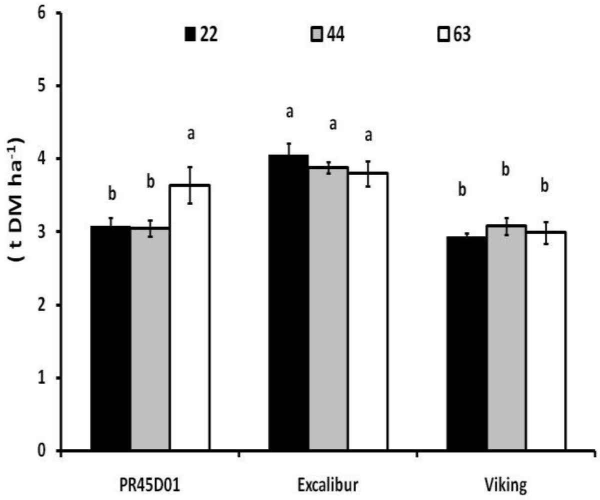

Fig. 5. Seed yield (t DM ha^{-1}) of PR45D01, Excalibur and Viking sown at 22, 44 and 63 seeds m^{-2}. Mean of two years. Letters: statistically different values (LSD test, P≤0.05). Vertical bars: standard error.

In Excalibur, seed yield was significantly positively correlated to DM produced at 29 BBCH (R^2= 0.26, P≤0.05); the yield of the semi-dwarf was linked to that accumulated at 80 BBCH (R^2= 0.26, P≤0.05). The more vigorous conventional hybrid probably reached the quantity of biomass and assimilates necessary to support pod and seed development earlier.

Conclusions

In the environment of NE Italy, the quantity of DM produced until spring and stem weight at seed filling may provide useful indications for OSR final yield prediction. In particular, the yield of conventional hybrids may be better predicted by early spring DM production than that of semi-dwarf ones. In order to achieve equally high productive performance in semi-dwarf genotypes, it appears necessary to compensate for their lower vegetative growth by increasing sowing density.

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