Journal of Agricultural Science (2014), **152**, 770–778. © Cambridge University Press 2013
doi:10.1017/S0021859613000440

CROPS AND SOILS RESEARCH PAPER

Cross-pollination benefits differ among oilseed rape varieties

A. HUDEWENZ*, G. PUFAL, A-L. BÖGEHOLZ AND A-M. KLEIN

Institute of Ecology, Ecosystem Functions, Leuphana University of Lüneburg, Scharnhorststr. 1, D-21335 Lüneburg, Germany

(*Received 15 November 2012; revised 17 May 2013; accepted 26 June 2013; first published online 29 July 2013*)

SUMMARY

Winter oilseed rape (*Brassica napus*) is an important crop for human consumption and biofuel production and its production is increasing worldwide. It is generally assumed that cross-pollination by insects increases oilseed rape yield but testing of this has been restricted to a few rapeseed varieties and produced varying results. The present study determines whether cross-pollination benefits a number of oilseed rape varieties by comparing yield in the presence and absence of insects. Four rapeseed varieties (Sherlock, Traviata, Treffer and Visby) were used with ten individuals each in four pollination treatments: (1) supplementary hand-pollination, (2) open pollination with insects able to access the flowers, (3) wind pollination and (4) autonomous self-pollination. Across all four varieties, open and supplementary hand-pollination treatments resulted in higher fruit set, numbers of seeds per pod and seed yield compared with wind and self-pollination. The cross-pollination benefits, however, differed among rapeseed varieties: Treffer and Visby had a higher dependence on open (insects) and supplementary cross-pollination than Sherlock and Traviata. Across all four varieties, seed weight compensated for reduced fruit set and was highest when plants were self-pollinated. The present results highlight the importance of considering varietal differences in crop pollination research. Information on the pollination requirements of crop varieties is required by farmers to optimize management decisions in a world of increasing agropollination deficits.

INTRODUCTION

Winter oilseed rape (also referred to as rapeseed or canola) (*Brassica napus* L.) is one of the world's most important annual oil crop species and is used for human consumption, animal feed and biofuel production (FAO 2012). Production increased 8·8-fold worldwide from 1970 to 2010, with China being the largest producer followed by Canada (FAO 2012). One reason for this increase is the importance of winter oilseed rape as a renewable resource for biofuel production (Van der Velde *et al*. 2008).

Winter oilseed rape is a cross between *Brassica campestris* L. and *Brassica oleracea* L. (Cramer 1990). Oilseed rape is described as a self-pollinated species with similar yield after self- or cross-pollination (Williams *et al*. 1986). Oilseed rape produces sticky pollen which remains adhered to the anthers even under strong wind conditions (Eisikowitch 1981). The sticky pollen, the yellow colour and the bilateral symmetry of rapeseed flowers indicate adaptations for pollen dispersal by insects rather than by wind, although wind pollination is conceivable (Creswell *et al*. 2004). The flower morphology and the mass flowering nature of the crop make rapeseed flowers an attractive pollen and nectar source for insects (Westcott & Nelson 2001). Many studies have shown a higher rapeseed yield (usually measured as total seed weight per plant) when flowers were visited by insects compared with unvisited flowers (Kołtowski 2005; Sabbahi *et al*. 2005; Bommarco *et al*. 2012; Jauker *et al*. 2012). However, Williams *et al*. (1986) did not find that insect pollination increased yield significantly. Similarly, other studies suggest that the resource allocation into fewer, heavier seeds under self-pollination compared with cross-pollination outbalances differences in the actual yield (Westcott & Nelson 2001; Steffan-Dewenter 2003). One potential reason for the observed differences regarding the

* To whom all correspondence should be addressed. Email: hudewenz@leuphana.de

https://doi.org/10.1017/S0021859613000440 Published online by Cambridge University Press

response variables may be the use of different rapeseed varieties in the studies.

Seed companies breed rapeseed varieties with new characteristics continuously. New varieties are bred to be better adapted to specific environmental conditions and to be resistant to pests and diseases. Some characteristics of these new rapeseed varieties are little known, such as whether insect pollination is required for optimum yield. Given the concerns about pollinator decline (Biesmeijer *et al*. 2006; Potts *et al*. 2010), the increasing amount of land cultivated with pollinator-dependent crop species (Aizen *et al*. 2008) and the high annual increase in oilseed rape production (Fig. A.1), rapeseed varieties that do not depend on insect pollination for optimum yield may be economically beneficial for farmers. This information is valuable for farmers in order to choose the rapeseed variety most suitable for their pollinator availability.

In the present study, four aspects of crop yield were compared in relation to different pollination treatments (wind, open, self- and supplementary hand-pollination). It was investigated whether supplementary hand-cross and open pollination increase fruit sets, the number of seeds per pod and yield compared with self- and wind pollination. Furthermore, it was assessed if rapeseed plant individuals receiving less cross-pollen can compensate for a reduced fruit set by increasing the allocation of resources into seed growth and hence increased seed weight. The present study provides important information on whether the impact of insect pollination differs among crop varieties, which is greatly overlooked in the crop pollination literature (Klein *et al*. 2007).

METHODS AND MATERIALS

Rapeseed varieties

Four different winter oilseed rape varieties were selected: Traviata, Sherlock, Treffer (bred by KWS Saat AG, Germany) and Visby (bred by Norddeutsche Pflanzenzucht Hans George Lembke KG, Germany), as they are either commonly grown or were introduced to Germany recently. Rapeseed varieties can be hybrids or 'bred'. A bred variety is the sexually reproduced offspring (through self-fertilization) of one plant individual with desired plant growth and performance traits that are then specifically selected for the breeding process. Hybrids are crosses of two different parental varieties with known characteristics, e.g. high pest or drought resistance. Hybrids are produced by pollination of a sterile plant individual with the help of a fertile individual via hand cross-pollination (Kristen 2008). Sherlock is a bred variety and characterized by early growing, flowering and ripening of fruits and by a high number of branches (KWS 2012). Traviata, Treffer and Visby are hybrid varieties. According to information provided by the seed company Rapool, Visby is particularly stress-resistant and performs well on sandy soils with high yield security. Treffer is a variety for regions with late frost, because it starts growing and flowering later (KWS 2012). Traviata has early ripening fruits and achieves a high yield and oil content (KWS 2012).

Pollination experiment

The present study took place at the experimental field of the Leuphana University in Lüneburg, Germany (53°13′N, 10°24′E, 17 m asl). The four selected winter oilseed rape varieties were sown on the 16 August, 2011 in a field near Reinstorf, a small village east of Lüneburg. In March 2012, 40 individuals per rapeseed variety were removed from the field, potted in plant pots (11 × 11 × 11 cm) using the same commercial soil for all plant individuals and then transported to the experimental field site. At this time the juvenile plants were at BBCH growth stage 23–25 (3–5 side shoots detectable; Lancashire *et al*. 1991), *c*. 20 cm in height and buds had not yet developed. At the beginning of April, the individual plants were transplanted to deeper pots (11 × 11 × 21 cm), using the same soil type for all individuals, to allow sufficient rooting space and placed randomly in the experimental field. Plants were not treated with pesticides or fertilizer during the experiment.

Ten plants of each of the four varieties were used for each of the following pollination treatments:

(1) Self-pollination

Each of the ten plants was completely covered with pollen-proof bags (Crispacs, Baumann Saatzuchtbedarf, Waldenburg, Germany) before flowering. These bags exclude pollinators but allow air exchange through small breathing pores (0·5 mm openings). Pollen of another individual (hereafter cross-pollen) cannot enter the bag and bagged plants are therefore pollinated autonomously.

(2) Wind pollination

Each of the ten plants was completely covered with bags of fine mesh gauze with 0·8 mm

https://doi.org/10.1017/S0021859613000440 Published online by Cambridge University Press

openings (out of Rantai S-48 gauze, Kammlott, Erfurt, Germany). The mesh openings are large enough to enable pollen to pass through the bag but too small for insects to access the flowers (Klein *et al*. 2003), allowing only wind and self-pollination.

(3) Open pollination

Each of the ten plants remained uncovered, so that their flowers could be pollinated either by wind or by insects with self- and cross-pollen. During the whole flowering period, these plants were frequently visited by honey bees, wild bees and syrphid flies.

(4) Supplementary hand-pollination

Each of the ten plants remained uncovered to allow insect- and wind pollination. Every second day, supplementary hand cross-pollination was carried out on all open flowers, using pollen from other plants of the same variety. Pollen was collected shortly before hand pollination and placed on top of the stigma of all open flowers with a brush. This treatment is assumed to serve as a control for optimum pollination (Williams *et al*. 1986).

After four weeks, at the end of flowering, the pollen-proof bags and mesh bags were removed. The plants were harvested in the middle of June when fruiting was complete, but before ripe pods started to split and disperse their seeds.

The aim was to estimate the effect of different pollination treatments on fruit set, number of developed seeds per pod, seed weight and yield (weight of all seeds) per plant individual.

Data collection

After harvesting, the number of flower stalks (virgin flowers of rapeseed not developing pods) and pods produced by each plant individual were counted. The pods were dried in a drying cabinet (Heraeus; Jürgens, Germany) for three days at 45 °C. After drying was completed the seeds were removed from the pods. A seed counter (Contador; Pfeuffer GmbH, Germany) was used for counting the number of seeds per plant. After counting, seeds were dried for two days at 45 °C and then all seeds were weighed to obtain the seed weight per plant in grams (yield).

Four yield variables served as response variables: mean fruit set, mean number of seeds per pod, mean weight of 1000 seeds (g) and the yield (g) per plant. Fruit set was calculated as the proportion of produced pods in relation to the number of produced flowers per plant.

The number of seeds per pod was achieved by dividing the total number of seeds per plant by the number of pods per plant. To calculate the seed weight, the mean weight of one seed per plant was calculated and then multiplied by 1000 to achieve values that are comparable with the literature. The weight of all seeds per plant served as yield per plant.

Statistical analyses

The fruit set, number of seeds per pod, seed weight (g) and yield (g) were used as response variables and the rapeseed variety, pollination treatment and their interaction as categorical explanatory variables in Generalized Linear Models (GLMs).

For fruit set per plant individual, a binomial distribution for proportional data was used. The response variables number of seeds per pod, seed weight (g) and yield (g) were normally distributed. Those models were fitted using a Gaussian distribution.

All statistical analyses were conducted using the software R 2.15.1. for windows (R Development Core Team 2012).

RESULTS

Number of produced flowers and fruit set

The number of produced flowers per plant differed significantly between pollination treatments ($P \leqslant 0{\cdot}001$) and between rapeseed varieties ($P \leqslant 0{\cdot}001$). The highest mean number of flowers was produced by plants under wind pollination (440) followed by open (405), supplementary hand- (353) and self-pollination treatment (351). Traviata plants produced most flowers (464), followed by Treffer (389), Visby (352) and Sherlock plants (340).

Pollination treatment and rapeseed variety as well as their interaction had a significant effect ($P \leqslant 0{\cdot}001$) on the fruit set per plant individual (Table 1). The highest fruit set was achieved when plants received supplementary hand-pollination, followed by open pollination, wind pollination and self-pollination (Fig. 1). Sherlock produced the highest fruit set and varied little among the four pollination treatments (Fig. 1). The fruit set of Visby and Traviata reached intermediate values and both rapeseed varieties showed higher differences among pollination treatments (Fig. 1). Treffer produced the lowest fruit set and differed markedly among pollination treatments (Fig. 1).

https://doi.org/10.1017/S0021859613000440 Published online by Cambridge University Press

Table 1. *Fruit set, number of seeds per pod, seed weight and yield for the different pollination treatments and rapeseed varieties and the interaction between treatment and variety. Results are from generalized linear models*

	Treatment		Rapeseed variety		Treatment × rapeseed variety	
Response variables	*F*	*P*	*F*	*P*	*F*	*P*
Fruit set	56·178	<0·001	7·352	<0·001	2·587	<0·01
Seeds per pod	42·082	<0·001	12·824	<0·001	4·301	<0·001
Seed weight	13·409	<0·001	6·071	<0·001	1·721	NS
Yield	11·315	<0·001	4·099	<0·01	1·200	NS

NS, not significant.

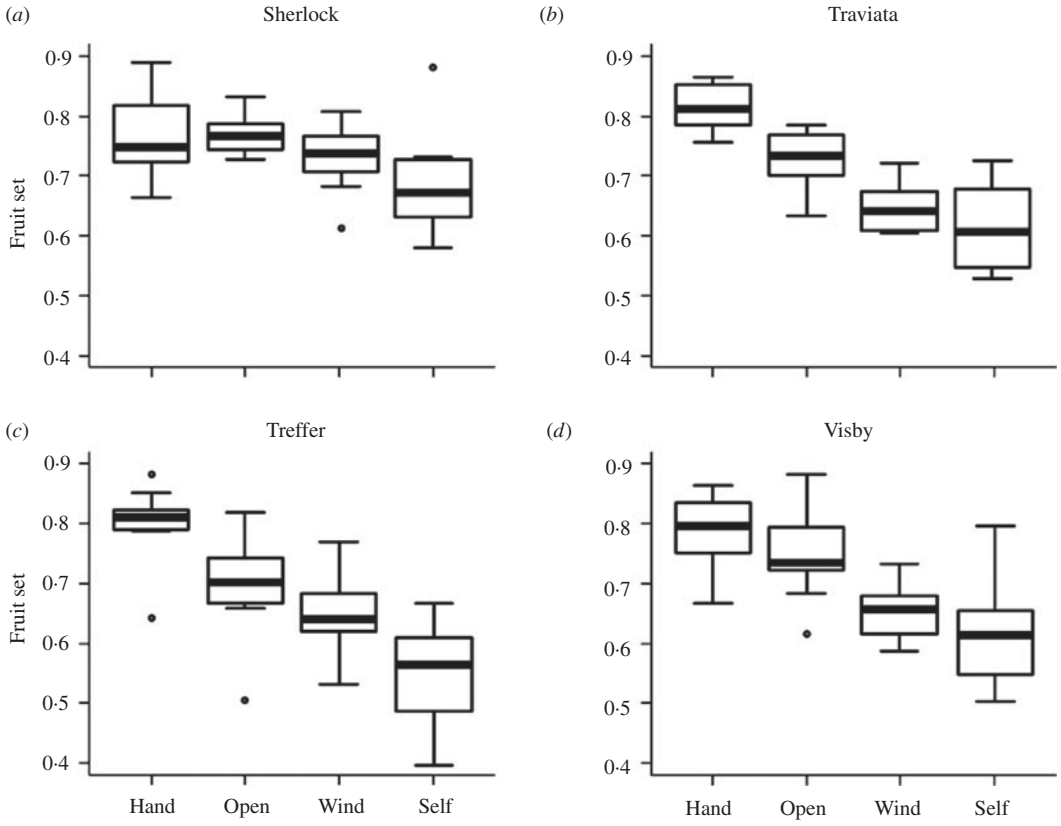


Fig. 1. Boxplot showing the mean fruit set as proportion under different pollination treatments of four tested rapeseed varieties: (*a*) Sherlock, (*b*) Traviata, (*c*) Treffer and (*d*) Visby.

Number of seeds per pod

The pollination treatment, the rapeseed variety and the interaction of both influenced the number of seeds per pod significantly ($P \leqslant 0{\cdot}001$, Table 1). When comparing the number of seeds per pod among the treatments, supplementary hand-pollination and open pollination showed no difference (Fig. 2), but individual plants from the open and supplementary hand-pollination treatments produced more seeds per pod in all rapeseed varieties than those that were wind or self-pollinated (Fig. 2).

Traviata showed the lowest number of seeds per pod and also the lowest differences among pollination treatments (Fig. 2). Sherlock and Visby produced intermediate numbers of seeds per pod and showed higher variation among pollination treatments (Fig. 2). The highest number of seeds per pod and the highest

https://doi.org/10.1017/S0021859613000440 Published online by Cambridge University Press

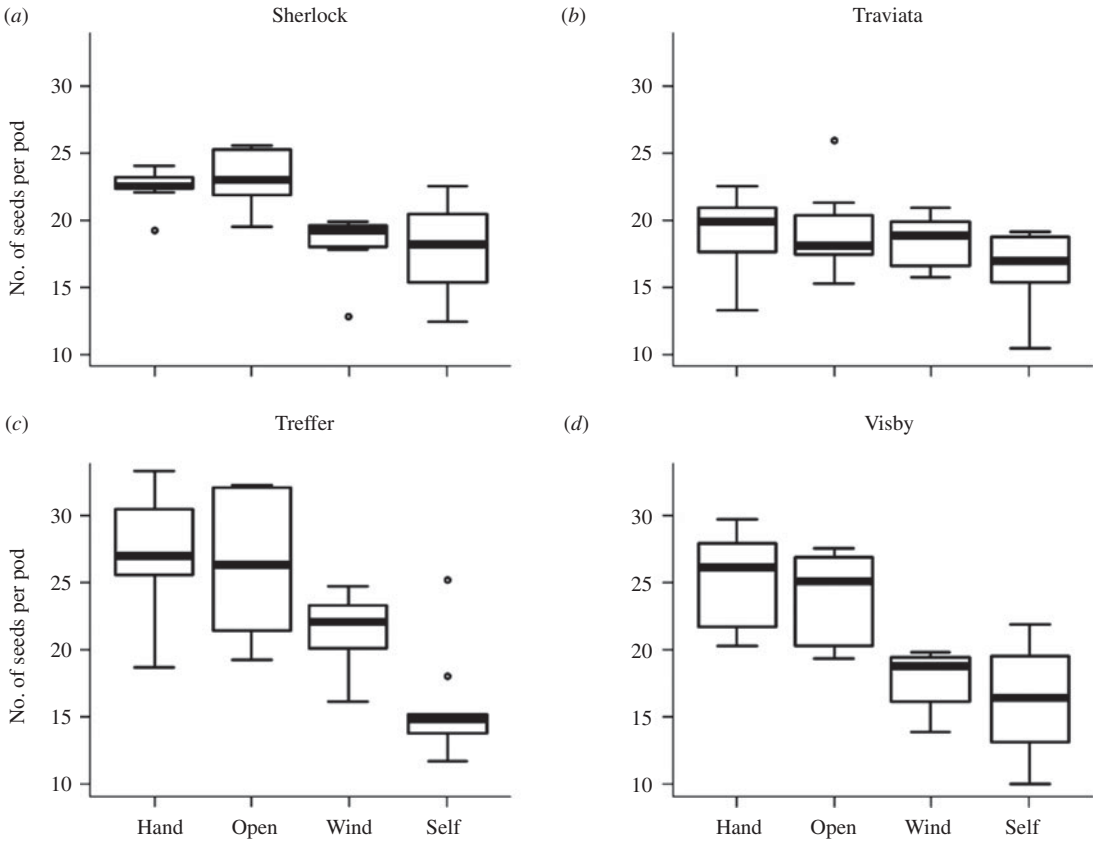


Fig. 2. Boxplot showing the mean number of seeds per pod under different pollination treatments of four tested rapeseed varieties: (*a*) Sherlock, (*b*) Traviata, (*c*) Treffer and (*d*) Visby.

differences among pollination treatments were achieved by the rapeseed variety Treffer (Fig. 2). The number of seeds per pod was correlated with fruit set (Table A.1).

Seed weight

The pollination treatment and the rapeseed variety influenced the seed weight significantly ($P \leqslant 0{\cdot}001$, Table 1). The interaction of pollination treatment and rapeseed variety had no significant influence on seed weight (Table 1). In all rapeseed varieties, seed weight was highest in the self-pollination treatment (Fig. A.2). Comparing rapeseed varieties, Visby had the highest seed weight followed by Sherlock, Traviata and Treffer (Fig. A.2). Seed weight was negatively correlated with the number of produced flowers per plant (Table A.1).

Yield

The pollination treatment ($P<0{\cdot}001$) and the rapeseed variety ($P<0{\cdot}01$) had a significant effect on yield (Table 1, Fig. A.3). Open pollination and supplementary hand-pollination resulted in higher yield than wind and self-pollination (Table 1, Fig. A.3). Yield differed significantly between rapeseed varieties (Table 1, Fig. A.3) with Traviata achieving highest yield followed by Sherlock and Visby and with Treffer achieving lowest yields (Fig. A.3). Yield was significantly correlated with the number of flowers produced per plant ($r=0{\cdot}43$, $P<0{\cdot}001$), fruit set ($r=0{\cdot}46$, $P<0{\cdot}001$), number of seeds per pod ($r=0{\cdot}54$, $P<0{\cdot}001$) and seed weight ($r=0{\cdot}24$, $P<0{\cdot}01$, Table A.1).

DISCUSSION

The present study shows that all yield variables of different rapeseed varieties were significantly affected by pollination treatment. Plants in supplementary hand- or in open-pollination treatments showed higher fruit set and number of seeds per pod compared with wind and self-pollinated plants. The degree of these differences was dependent on the tested rapeseed variety. In contrast, the weight of seeds was highest in the self-pollination treatment independent of the tested

https://doi.org/10.1017/S0021859613000440 Published online by Cambridge University Press

rapeseed variety. However, plants from the open and supplementary hand-pollination treatments generally achieved higher yields compared with self-pollinated plants, indicating that insects increase the yield of the tested rapeseed varieties; although the cross- and open-pollination benefits are more obvious in Treffer (50·9% compared with autonomous self-pollination) and Visby (42·7%) compared with Sherlock (13·7%) and Traviata (21·8%). Most previous studies on pollination of rapeseed confirm that insect pollination increases fruit set (Williams *et al*. 1986; Sabbahi *et al*. 2005; Munawar *et al*. 2009; Jauker *et al*. 2012), the number of seeds per pod (Steffan-Dewenter 2003; Kołtowski 2005; Sabbahi *et al*. 2005; Kristen 2008; Munawar *et al*. 2009) and yield (Kołtowski 2005; Sabbahi *et al*. 2005; Bommarco *et al*. 2012). Sabbahi *et al*. (2005) found that pollination by insects can increase yield by 46%, whereas Bommarco *et al*. (2012) concluded that insect pollination contributes an increase of 18% to the yield of oilseed rape. Williams *et al*. (1986) show contrasting results, finding no differences in the yield of self-pollinated or cross-pollinated individuals.

Contrary to fruit set, number of seeds per pod and yield, the seed weight was highest when plants were self-pollinated. Additionally, seed weight was negatively correlated with the number of flowers. This observation may be explained by the compensatory capacity of the plant for low fruit and seed setting, which implies that a pollination deficit can be compensated by the development of larger and heavier seeds (Westcott & Nelson 2001; Steffan-Dewenter 2003; Durán *et al*. 2010). One reason might be resource allocation; when a plant produces less seeds, more resources can be allocated to each individual seed and this may increase their weight significantly. However, in the studies by Jauker *et al*. (2012) and Kołtowski (2005), differences in seed weights among pollination treatments were not observed. These contrasting results might be explained by the use of different rapeseed varieties.

The varieties Treffer and Visby depended more on pollination by insects. This indicates that the pollinator dependency of a rapeseed variety is not determined by the heritage of the variety (hybrid or bred variety). Rather, it is a varietal-specific characteristic.

Comparing the tested rapeseed varieties, Sherlock showed a lower variance of the different response variables among the different pollination treatments. In contrast to Sherlock, which is a bred variety, Traviata, Treffer and Visby are hybrids. Hybrids are known to sometimes have a reduced pollen supply and may therefore be more dependent on pollinators than bred varieties (Kristen 2008). This is supported by the significant difference found between the supplementary hand- and open-pollination treatments compared with the self-pollination treatment in Treffer and Visby.

Yield was positively correlated with the number of produced flowers, fruit set, number of seeds per pod and seed weight showing that these variables directly or indirectly influenced yield. Yield differed among rapeseed varieties, corresponding to differences in fruit set. The different rapeseed varieties showed distinct responses to different pollination treatments regarding their dependence of the different plant sexual reproduction variables on supplementary hand- and insect pollination. For example, Traviata showed the lowest number of seeds per pod, but this was compensated by a high number of flowers produced and a higher fruit set, leading to highest yield compared with the other rapeseed varieties tested. Furthermore, Traviata showed a high pollinator dependence regarding fruit set. Treffer produced the lowest fruit set, seed weight and yield and intermediate numbers of flowers but also displayed the highest dependence on insect pollination. The seeds of Visby had the highest weight, while the other yield variables and the number of produced flowers achieved intermediate values. The pollinator dependence of Visby was generally high. Sherlock had the highest fruit set of all varieties but only intermediate numbers of seeds per pod, seed weight and yield and the lowest number of produced flowers. The dependence on pollination treatment was low in Sherlock plants.

SUMMARY AND CONCLUSION

Providing farmers with information about the pollinator dependence of the different varieties will aid their decision to cultivate certain rapeseed varieties that are best suited for their local conditions without compromising on yield. The present study demonstrates that insect pollination increases yield of the tested rapeseed varieties differently. The results suggest that experiments to investigate the dependence on insects of certain varieties are important for general information on rapeseed varieties. This will help farmers in their decision whether or not to invest in pollination management to maximize yield.

We acknowledge Heinrich Lübbecke for providing the rapeseed plants. We thank all people from the Institute

https://doi.org/10.1017/S0021859613000440 Published online by Cambridge University Press

of Ecology of the Leuphana University of Lüneburg who helped with pod opening and sorting. Claire Brittain and two anonymous reviewers are gratefully acknowledged for valuable comments. A. H. is financed by the Deutsche Bundesstiftung Umwelt (DBU) and G. P. by the Pro Science programme of the Leuphana University.

REFERENCES

Aizen, M. A., Garibaldi, L. A., Cunningham, S. A. & Klein, A. M. (2008). Long-term global trends in crop yield and production reveal no current pollination shortage but increasing pollinator dependency. *Current Biology* **18**, 1572–1575.

Biesmeijer, J. C., Roberts, S. P. M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A. P., Potts, S. G., Kleukers, R., Thomas, C. D., Settele, J. & Kunin, W. E. (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science* **313**, 351–354.

Bommarco, R., Marini, L. & Vaissière, B. E. (2012). Insect pollination enhances seed yield, quality, and market value in oilseed rape. *Oecologia* **169**, 1025–1032.

Cramer, N. (1990). *Raps: Anbau und Verwertung*. Stuttgart: Ulmer.

Cresswell, J. E., Davies, T. W., Patrick, M. A., Russell, F., Pennel, C., Vicot, M. & Lahoubi, M. (2004). Aerodynamics of wind pollination in a zoophilous flower, *Brassica napus*. *Functional Ecology* **18**, 861–866.

Durán, X. A., Ulloa, R. B., Carrillo, J. A., Contreras, J. L. & Bastidas, M. T. (2010). Evaluation of yield component traits of honeybee pollinated (*Apis mellifera* L.) Rapeseed canola (*Brassica napus* L.). *Chilean Journal of Agricultural Research* **70**, 309–314.

Eisikowitch, D. (1981). Some aspects of pollination of oil-seed rape (*Brassica napus* L.). *Journal of Agricultural Science, Cambridge* **96**, 321–326.

FAOSTAT (2012). *FAOSTAT*. Available from: http://faostat.fao.org/site/567/default.aspx (verified 5 June 2013).

Jauker, F., Bondarenko, B., Becker, H. C. & Steffan-Dewenter, I. (2012). Pollination efficiency of wild bees and hoverflies provided to oilseed rape. *Agricultural and Forest Entomology* **14**, 81–87.

Klein, A. M., Steffan-Dewenter, I. & Tscharntke, T. (2003). Bee pollination and fruit set of *Coffea arabica* and *C. canephora* (Rubiaceae). *American Journal of Botany* **90**, 153–157.

Klein, A. M., Vaissiere, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C. & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences* **274**, 303–313.

Kołtowski, Z. (2005). The effect of pollinating insects on the yield of winter rapeseed (*Brassica napus L. var. napus f. biennis*) cultivars. *Journal of Apicultural Science* **49**, 29–41.

Kristen, R. (2008). *Entomofauna an Raps: Verteilung, Bestäubung und ökologische Bedeutung in der Kulturlandschaft*. Gießen, Germany: Justus-Liebig-Universität Gießen.

KWS (2012). *Rapssorten von KWS*. Einbeck, Germany: KWS. Available from: http://www.kws.de/aw/KWS/germany/Produkte/Oelfruechte/~dbor/Sortenuebersicht/ (verified 5 June 2013).

Lancashire, P. D., Bleiholder, H., Boom, T. V. D., Langelüddeke, P., Stauss, R., Weber, E. & Witzenberger, A. (1991). A uniform decimal code for growth stages of crops and weeds. *Annals of Applied Biology* **119**, 561–601.

Munawar, M. S., Raja, S., Siddique, M., Niaz, S. & Amjad, M. (2009). The pollination by honeybee (*Apis mellifera* L.) increases yield of canola (*Brassica napus* L.). *Pakistan Entomologist* **31**, 103–106.

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O. & Kunin, W. E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology and Evolution* **25**, 345–353.

R Development Core Team (2012). *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing.

Sabbahi, R., De Oliveira, D. & Marceau, J. (2005). Influence of honey bee (Hymenoptera: Apidae) density on the production of canola (Crucifera: Brassicacae). *Journal of Economic Entomology* **98**, 367–372.

Steffan-Dewenter, I. (2003). Seed set of male-sterile and male-fertile oilseed rape (*Brassica napus*) in relation to pollinator density. *Apidologie* **34**, 227–235.

Van der Velde, M., Bouraoui, F. & Aloe, A. (2008). Pan-European regional-scale modelling of water and N efficiencies of rapeseed cultivation for biodiesel production. *Global Change Biology* **15**, 24–37.

Westcott, L. & Nelson, D. (2001). Canola pollination: an update. *Bee World* **82**, 115–129.

Williams, I. H., Martin, A. P. & White, R. P. (1986). The pollination requirements of oil-seed rape (*Brassica napus* L.). *Journal of Agricultural Science, Cambridge* **106**, 27–30.

https://doi.org/10.1017/S0021859613000440 Published online by Cambridge University Press

APPENDIX A

Table A. 1 *Correlation matrix of all response variables and additionally of the number of produced flowers. Correlation coefficients (ρ) and their significance (in parentheses) are presented.*

	Seeds per pod	Seed weight	Yield	No. of flowers
Fruit set	0·48 (<0·001)	–0·11	0·46 (<0·001)	–0·08
Seeds per pod	–	–0·15	0·54 (<0·001)	–0·05
Seed weight	–	–	0·24 (<0·01)	–0·23 (<0·01)
Yield	–	–	–	0·43 (<0·001)

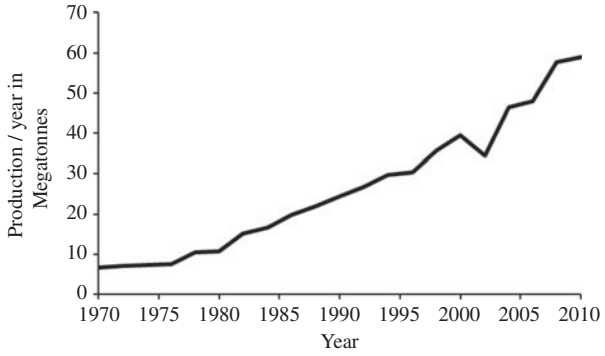


Fig. A1. Global production of oilseed rape per year from 1970 to 2010 (FAO 2012).

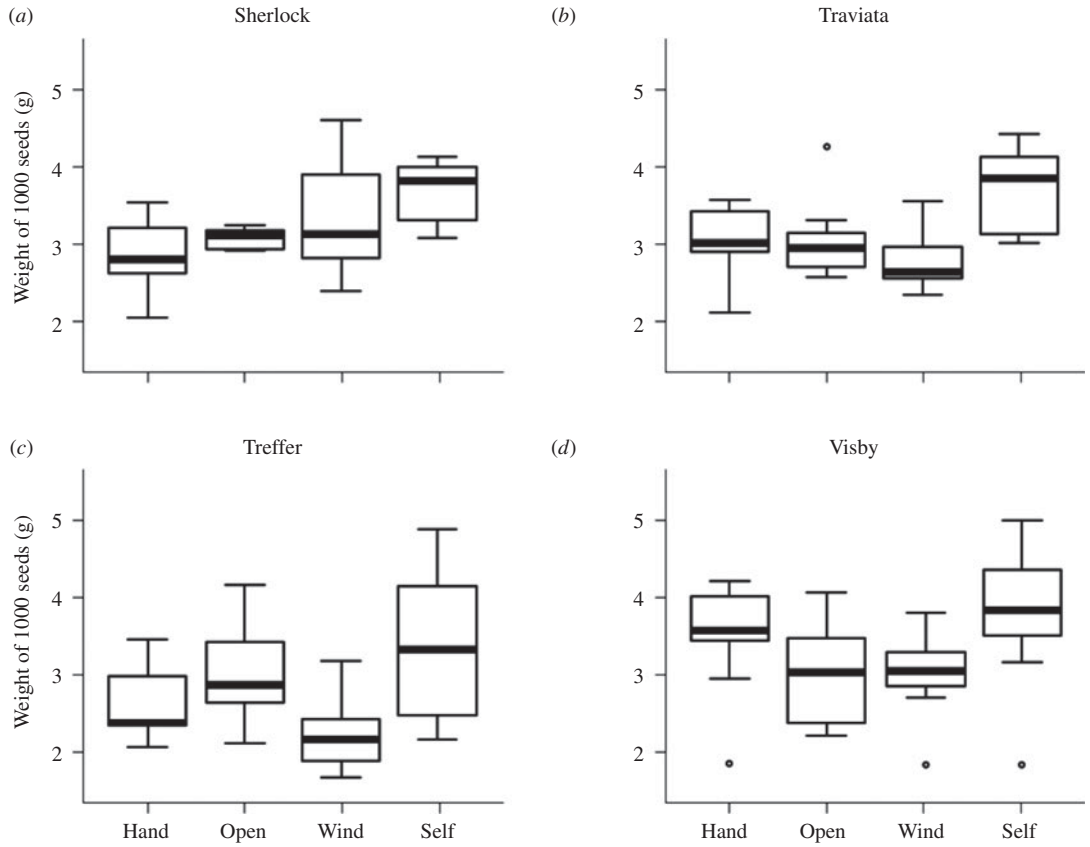


Fig. A2. Boxplot showing the seed weight in grams under different pollination treatments of four tested rapeseed varieties: (*a*) Sherlock, (*b*) Traviata, (*c*) Treffer and (*d*) Visby.

https://doi.org/10.1017/S0021859613000440 Published online by Cambridge University Press

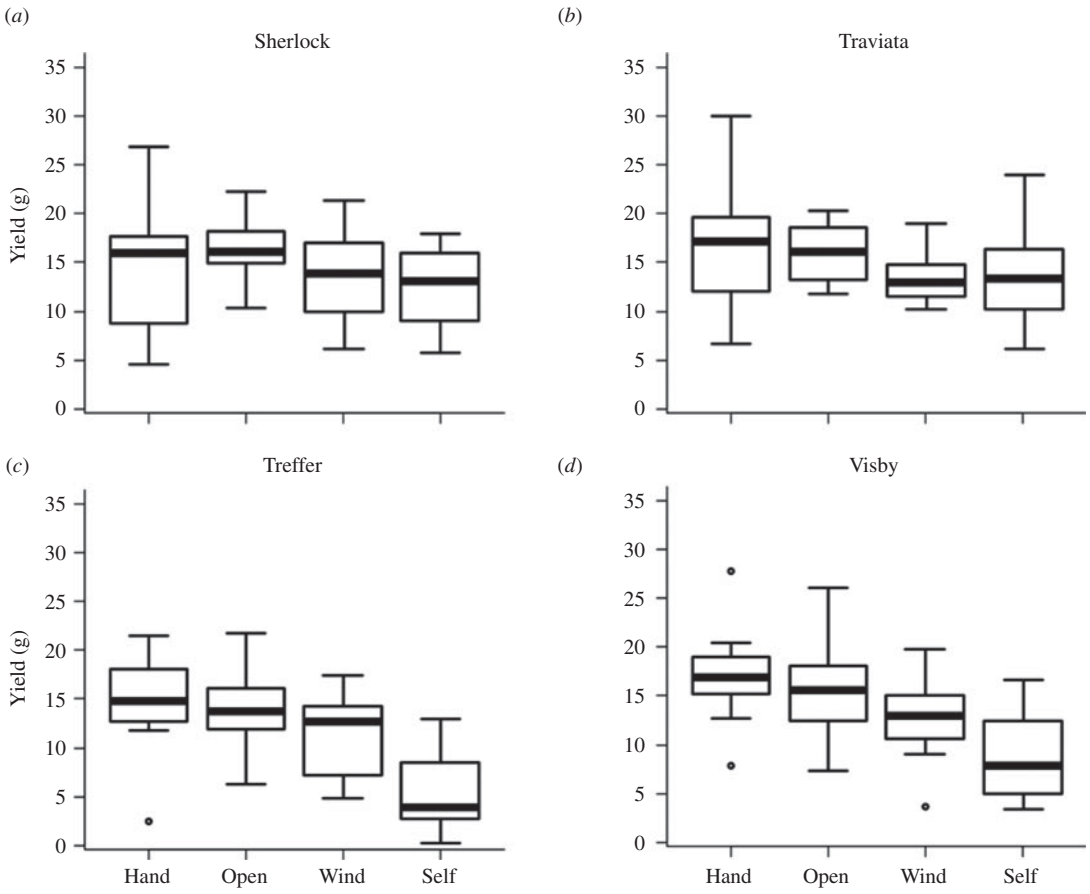


Fig. A3. Boxplot showing the yield in grams under different pollination treatments of four tested rapeseed varieties: (*a*) Sherlock, (*b*) Traviata, (*c*) Treffer and (*d*) Visby.

https://doi.org/10.1017/S0021859613000440 Published online by Cambridge University Press