Calibration of a probabilistic model of oilseed rape fertility to analyze the inter-variety variability in number of seeds

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Abstract

With the objective of using plant models as predictive tools scaling from genotype to phenotype, model parameters should have a strong genetic determinant. For this purpose, the modeling process involves assessing the differences in model parameters between varieties. In this study, a model of flower fertility is used to explain the observed behaviors and to identify the variety related parameters relevant to seed production. The model simulates the steps of seed production: ovule formation, landing of pollen grains on a flower, fertilization of ovule by pollen grains, possible abortion of the fertilized ovules. The aims of this study are to assess the differences of estimated parameters and identify the factors that can explain observed differences among varieties in the number of seeds per pod.

Four varieties of oilseed rape (Mendel, Gamin, Exocet and Pollen) were grown at the experimental station of Grignon, France. Ten plants were marked and 15 pods from rank 11 to 40 (to eliminate the effect of position) on the main stem were collected on each plant for each variety. The numbers of seeds and aborted seeds were recorded. The total seed dry weight for each plant was measured.

The maximum number of ovules per flower is different among the four varieties with the range of 36-45. The landing of pollen grains on a flower was significantly different among the varieties, although they were grown in the same field. The estimation result of model allows us to conclude that pollination and resource competition have the similar impact on the ovule and seed abortion. However, for the variety Gamin, the probability of fertilized ovules to abort was quite large in agreement with the smaller number of seeds measured but mean seed weight was higher than others ($P<0.001$, ANOVA). The data analysis indicated that the small number of seeds per pod was compensated by a higher seed weight.

The abortion of seeds could result from insufficient pollination and resource competition. Current work aims at quantifying more precisely the roles of these factors and investigating other ones. We intend to use the model to distinguish the effects of different factors on seed production, such as the plant architecture. One way is to compare the behaviors of the main stem, the ramifications and the plants.

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Introduction

We use a probabilistic model to represent the processes of flower fertility on winter oilseed rape. The model is calibrated on experimental data using Generalized Least Square Method. The modeling process involves assessing the differences in model parameters between different varieties. The model can help us to explain the differences measured in number of seeds per pod.

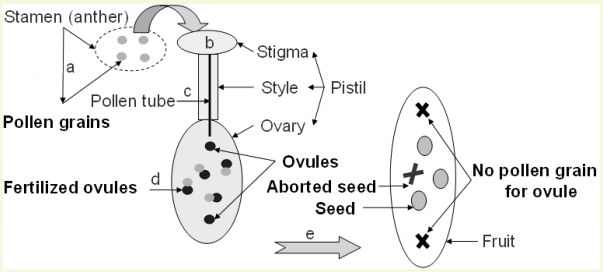
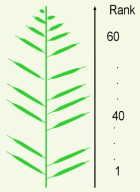


Figure 1. Schematic presentation of the events of seed development. Seed production involves several processes and floral components: pollen production by the anther, deposition of pollen grains (a) on the stigma (b), pollen germination and growth of the pollen tube (c), fertilization (d) and development of embryo and seed (e).

Field experiment

Varieties: Mendel, Gamin, Exocet, Pollen
Time: Sep, 2008 to July, 2009.
Measurements:
15 pods (rank 11-40) to eliminate the effect of position) on the main stem were collected on each plant.

- The number of seeds and that of aborted seeds were recorded.
- The total seed dry weight of all the pods for each plant was measured.



Model description

- Number of ovules per ovary (*Y*)- Binomial distribution

$$P(Y=y)=C_N^y b^y (1-b)^{N-y} \quad (1)$$

N is the maximum number of ovules; *b* is the probability of survival of ovule).

- Number of effective pollen grains (*X*)- Lognormal distribution

$$f(x)=\frac{e^{\frac{(\ln(x)-m)^2}{2s^2}}}{xs\sqrt{2\pi}} \quad (2)$$

m, s are the parameters of probability;

- Number of fertilized ovules (*Z*)- *Z=min(X,Y)*; $P(Z=y)=P(X=y)P(Y>y)+P(Y=y)P(X\geq y)$ (3)
- Seed viability that a fertilized ovule develop into a seed (*S*) - Bernoulli process

$$P(S=i)=\sum_{y=0}^{N} C_y^i p^i (1-p)^{y-i} P(Y=y)P(X\geq y)+\sum_{y=0}^{N}\sum_{k=i}^{y-1} C_k^i p^i (1-p)^{k-i} P(X=k)P(Y=y) \quad (4)$$

p is the probability of a fertilized ovule to form a seed.

Results

Table 1. Parameter values of different steps for each variety.

	Variety	Exocet	Gamin	Pollen	Mendel
Ovule distribution	*N*	45	44	39	36
	b	0.834	0.746	0.788	0.825
Seed viability	*p*	0.834	0.573	0.916	0.887
Pollen distribution	*m*	3.584	3.154	3.593	3.646
	s	0.199	0.434	0.304	0.466
Ratio of fertilized ovules to ovules (F/O)		0.929	0.823	0.931	0.888
Ratio of seeds to fertilized ovules (S/F)		0.821	0.519	0.938	0.936

The maximum number of ovules (N) varies in the range of 36-45.

The parameter of seed viability (p) was quite small (0.573) for the variety Gamin in agreement with the smaller number of seeds measured on this variety

The ratio of the number of seeds to fertilized ovules (S/F) was significant difference for Gamin (0.519) for the four varieties.

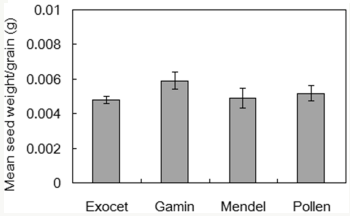


Figure 4. Mean seed weight on the main stem for the four cultivars. The short lines represent the error bounds. The mean seed weight for the variety Gamin being higher than others (P<0.001, ANOVA).

For the variety Gamin:

Large number of ovules per flowers; Small number of seeds per pod; The small number of seeds per pod was compensated by a higher seed weight (Fig. 2)

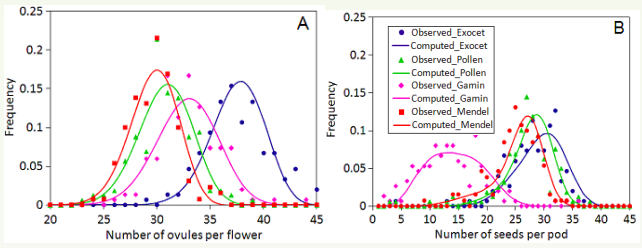


Figure 2. The results and adjustments on measurement for distribution of number of ovules per flower (A), number of seeds per pod (B) on the main stem for the four varieties.

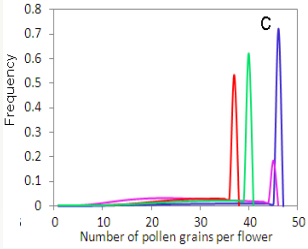


Figure 3. Different distributions of pollen grains deduced by our model between the four varieties. The peak values are the cumulated probability in which the number of pollen grains is larger than the number of ovules.

Conclusion

The parameters of the model were estimated for four contrasting varieties, and it allows distinguishing different causes of seed abortion, including pollination and resource competition. F/O shows that the loss of seeds due to pollination was about 10% for the four varieties, with a maximum value of 18% in the case of the variety Gamin; S/F shows the proportion of aborted ovules. Except for Gamin, their values were quite close to that the ratios F/O, which indicates that pollination and resource competition have the similar impact on the ovule and seed abortion. These factors have different impacts on the yield of each variety. Current work aims at quantifying more precisely the roles of these factors and investigating other ones. One way is to compare the behaviors of the main stem, the ramifications and the plants.

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