

working title Compatibility system and stigma size of pollen recipient as main predictors of heterospecific pollen effect

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Pollinator sharing can have negative consequences for species fitness with the arrival of foreign pollen. However, the costs of heterospecific pollen are not yet well understood. For this reason, we have conducted a glasshouse experiment where we try to understand how phylogenetic relatedness and the different traits of these species are involved in this process. We experimentally crossed 10 species belonging to three different families: Brassicaceae, Solanaceae and Convolvulaceae. Overall, more than 4000 crosses were done and seed set and pollen tubes were considered as proxy of effect. We found that for all species foreign pollen (50% or less) reduced seed set. Moreover, the seed set reduction is not dependent on the degree of relatedness of the pollen donor. However, the effect is governed by the degree of relatedness and the traits of the species recipient. Our results show that the outcome of heterospecific pollen deposition is determined in greater degree by the traits of the pollen recipient than the pollen donor and that certain traits such as compatibility system are crucial to understand the costs of heterospecific pollen.

Keywords: heterospecific pollen, plant reproduction, fitness, interspecific competition, phylogenetic distance.

INTRODUCTION

Paragraph 1 General idea to our concept

In natural systems plant species normally coexist and share their floral visitors with other species Bascompte et al. (2003). This pollinator sharing from the plant perspective at the pre-pollination stage can be negative due to competition Pauw (2013) or positive due to facilitation Carvalheiro et al. (2014). Once the floral visitor has arrived to the flower, pollen deposition on the stigma can take place and hence ovule fertilization. An increasing number of visits generally correlates with higher chances of

35 fertilization Engel and Irwin (2003). However this is not always the case, among these possible flower
36 visitors we find also nectar robbers and pollen thieves Inouye (1980) and the quality of pollen that is
37 deposit on the stigma is also highly relevant to the pollination succes Aizen and Harder (2007).
38 Moreover, other less study issues in the pollination process are conspecific pollen loss and the arrival of
39 foreign pollen which can have important detrimental effects on species fitness Morales and Traveset
40 (2008) Ashman and Arceo-Gómez (2013).

41 **Paragraph 2** Introducing topic and knowledge gap

42 Recent studies have advanced in the ecological understanding of heterospecific pollen effect Morales and
43 Traveset (2008) Ashman and Arceo-Gómez (2013) Arceo-Gómez and Ashman (2016). A general
44 overview of foreign pollen arrival is that it can play an important role on species fitness but seems to be
45 context dependent and not always produce a decrease in fitness Morales and Traveset (2008). Part of
46 this unpredictability is due to the enormous variability of foreing pollen transferred in nature, where
47 levels between 0 and 75 percent are seen, but most commonly values ranges between 0 and 20 percent
48 of the total pollen load Bartomeus et al. (2008) Montgomery and Rathcke (2012) Ashman and
49 Arceo-Gómez (2013) Fang and Huang (2013), being the generalist species the ones that receive greater
50 loads of heterospecific pollen Fang and Huang (2013). Surprisingly, this low ranges of heterospecific
51 pollen have been shown to decrease fitness greatly Thomson et al. (1982). Although heterospecific
52 pollen quantity is fundamental to understand the outcome of the interaction so is the different traits of
53 both pollen donor and recipient. Ashman and Arceo-Gómez (2013) postulated the first predictive
54 framework for traits of heterospecific pollen effect, where different traits such as compatibility system
55 and pollen size among others seems to be crucial to understand foreing pollen effect. Moreover, in Tong
56 and Huang (2016) an assymetric effect was shown in a crossing experiment between 6 species of the
57 genus *Pedicularis* where the pollen of long styled species was able to grow the full length of the style on
58 short styled species but not viceversa. Despite these recent caveats, we still lack empirical evidence to
59 affirm what are the main traits that drive heterospecific pollen effect for both pollen donor and recipient
60 at seed production level. Interestingly, to comprehend how these traits interact is also crucial to look at
61 the phylogenetic relatedness of the species. There is a considerable amount of literature of crosses
62 between close related species Brown and Mitchell (2001) Arceo-Gómez et al. (2016) Tong and Huang
63 (2016) but few works focused on heterospecific pollen of far related species Thomson et al. (1982)

64 Galen and Gregory (1989) Neiland and Wilcock (1999) which also show a noteworthy fitness decrease.
65 Although the effect of close related species is predicted to be greater Ashman and Arceo-Gómez (2013)
66 the presence of pollen of non related species on multiple species Arceo-Gómez and Ashman (2016) and
67 the higher chances to coexist with a species that has less niche overlap (Ref) make foreign pollen from
68 far related species also an important subject of study in order to understand the importance of
69 heterospecific pollen in natural systems. Notwithstanding, the effect of heterospecific pollen of far and
70 close related species at community level remains to be explored beyond single pairwise interactions.

71 **Paragraph 3** Expanding ideas with examples

72 Interestingly, incompatibility system seems to play an important role in foreign pollen effect where
73 species that are self incompatible would have stronger barriers towards heterospecific pollen than self
74 compatible species Ashman and Arceo-Gómez (2013). The type of incompatibility, sporophytic or
75 gametophytic is related with the place of pollen recognition where the former take place at the stigma
76 level and the latter occurs within the style, this last late acting pollen recognition mechanism is
77 associated with greater negative effect Barrett (1988). Remarkably, there is a great variability in
78 mating systems across populations Whitehead et al. (2018) and therefore predict an effect of foreign
79 pollen is a bit obscured by the variability within species, however species that are strong selfers or
80 strong outcrossers have less variability in mating systems and predictions of effect could be more
81 realistic (see figure 1 from Whitehead et al. (2018)). Moreover, other traits such as number of pollen
82 grains per flower and number of ovules have been traditionally associated with the type of
83 incompatibility system where species with higher pollen ovule ratios are predicted to be xenogamous
84 and species with low pollen ovule ratios autogamous (REF). Selfer species would have a reduction of
85 herkogamy (REF), less pollen production per ovule (REF) and therefore less likely to contribute in
86 exporting pollen in the community. Other morphological traits, like stigma size can be determinant for
87 the total pollen quantity that a stigma can receive and therefore related to do that pollen size would also
88 play an important role. Example with pollen here.

89 **Paragraph 4** Introducing our experiment

90 The great environmental variability in natural systems and complexity of floral structures make
91 heterospecific pollination studies a daunting task. Moreover, variation in sampling effort have been

shown to be determinant to characterize pollen transfer interactions Arceo-Gómez et al. (2018). Although plant-pollinator network and pollen network studies can give a first picture of the importance of foreign pollen is necessary to address how its effect is shaped with both traits and relatedness of the species. For this reason, in this study we have created an artificial co-flowering community with 10 species belonging to three different families where we try to test the following questions: 1) Does heterospecific pollen reduce seed set, if so, 2) Does heterospecific pollen effect depend on the relatedness of the species, 3) Does heterospecific pollen effect depend on any floral trait?

METHODS

The study was conducted in a glasshouse at University of New England (Armidale, Australia) from November 2017 to March 2018. Rooms were temperature controlled depending on the requirements of the species with day and night temperature differences. The species selected (Table 1) belonged to three different families, Solanaceae, Brassicaceae and Convolvulaceae. The criteria of species/family selection was based on close/distant related species (see phylogenetic tree for relatedness fig 1), heterogeneous traits, low structural flower complexity and fast life cycle. For the purpose of the experiment all the species were considered as pollen recipient and as pollen donor (see interaction matrix, fig 2). Species were watered once or twice per day and fertilized weekly (NPK 23: 3.95: 14).

Table 1

Family	Genus	Species
Brassicaceae	Brassica	Brassica rapa
Brassicaceae	Brassica	Brassica oleracea
Brassicaceae	Eruca	Eruca versicaria
Brassicaceae	Sinapis	Sinapis alba
Convolvulaceae	Ipomoea	Ipomoea aquatica
Convolvulaceae	Ipomoea	Ipomoea purpurea
Solanaceae	Capsicum	Capsicum annuum
Solanaceae	Petunia	Petunia integrifolia

Family	Genus	Species
Solanaceae	Solanum	Solanum lycopersicum
Solanaceae	Solanum	Solanum melongena

109 Hand-pollination

110 Foreign pollen effect was studied through two different treatments, one with 50% conspecific pollen and
111 50% heterospecific pollen and a second one with 100% foreign pollen (N=10). Therefore, 180 different
112 combinations were performed with N=10. Seed set was the proxy of effect for all our treatments.
113 Moreover, hand cross pollination, hand self pollination, apomixis (bagged emasculated flowers) and
114 natural selfing were tested (N=10). Flowers were emasculated the day prior anthesis and hand
115 pollinated next day with a toothpick. Hand-pollination was realized with 3-4 gentle touches on the
116 surface of the stigma. The mixes of pollen were performed on an eppendorf based on the pollen counts
117 made with Neubauer chamber (each anther was counted 4 times for 20 different anthers per species).

118 Traits and evolutive distance

119 The traits measured for each species were pollen per anther, number of ovules, stigma width and length
120 and stigmatic area, style width and length, ovary width and length. Moreover stigma type was tested.
121 Pollen was counted for 20 anthers of each species with 4 replicates per sample with a hemocytometer.
122 Previously anthers were squashed on a known solution with the pipette tip and homogenized with a
123 vortex for 30 seconds. Ovule number was counted with the help of a stereomicroscope and a small
124 grid over a petri dish from 15 randomly selected flowers. The different morphometrical traits were
125 measured with XXXX. Levels of self incompatibility were estimated by dividing the fruit set of
126 hand self pollination by hand cross pollination. Moreover, two types of evolutive distances were
127 calculated with MEGA7 for two kinds of markers: 1) Internal transcribed spacer (ITS) and 2)
128 ribulose-bisphosphate carboxylase (RBCL)

129 Analysis

130 We used the statistical language R (R Core Team 2018) for all our analyses. These were implemented in

dynamic markdown documents using `knitr` (Xie 2014, 2015, 2018) and `rmarkdown` (Allaire et al. 2018) packages. All the multilevel models were fitted with `lme4` (Bates et al. 2015).

RESULTS

Heterospecific pollen produced fitness for xxx cases.

DISCUSSION

Discussion

1. What are the implications of the findings?

CONCLUSIONS

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REFERENCES

- Aizen, M. A., and L. D. Harder. 2007. Expanding the limits of the pollen-limitation concept: Effects of pollen quantity and quality. *Ecology* 88:271–281.
- Allaire, J., Y. Xie, J. McPherson, J. Luraschi, K. Ushey, A. Atkins, H. Wickham, J. Cheng, and W. Chang. 2018. Rmarkdown: Dynamic documents for r.
- Arceo-Gómez, G., C. Alonso, T.-L. Ashman, and V. Parra-Tabla. 2018. Variation in sampling effort affects the observed richness of plant–plant interactions via heterospecific pollen transfer: Implications

for interpretation of pollen transfer networks. *American journal of botany* 105:1601–1608.

Arceo-Gómez, G., and T.-L. Ashman. 2016. Invasion status and phylogenetic relatedness predict cost of heterospecific pollen receipt: Implications for native biodiversity decline. *Journal of Ecology* 104:1003–1008.

Arceo-Gómez, G., R. A. Raguso, and M. A. Geber. 2016. Can plants evolve tolerance mechanisms to heterospecific pollen effects? An experimental test of the adaptive potential in *Clarkia* species. *Oikos* 125:718–725.

Ashman, T.-L., and G. Arceo-Gómez. 2013. Toward a predictive understanding of the fitness costs of heterospecific pollen receipt and its importance in co-flowering communities. *American Journal of Botany* 100:1061–1070.

Barrett, S. C. 1988. The evolution, maintenance, and loss of self-incompatibility systems. *Plant reproductive ecology: patterns and strategies*:98–124.

Bartomeus, I., J. Bosch, and M. Vilà. 2008. High invasive pollen transfer, yet low deposition on native stigmas in a *Carpobrotus*-invaded community. *Annals of Botany* 102:417–424.

Bascompte, J., P. Jordano, C. J. Melián, and J. M. Olesen. 2003. The nested assembly of plant–animal mutualistic networks. *Proceedings of the National Academy of Sciences* 100:9383–9387.

Bates, D., M. Mächler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67:1–48.

Brown, B. J., and R. J. Mitchell. 2001. Competition for pollination: Effects of pollen of an invasive plant on seed set of a native congener. *Oecologia* 129:43–49.

Carvalho, L. G., J. C. Biesmeijer, G. Benadi, J. Fründ, M. Stang, I. Bartomeus, C. N. Kaiser-Bunbury, M. Baude, S. I. Gomes, V. Merckx, and others. 2014. The potential for indirect effects between co-flowering plants via shared pollinators depends on resource abundance, accessibility and relatedness. *Ecology letters* 17:1389–1399.

Engel, E. C., and R. E. Irwin. 2003. Linking pollinator visitation rate and pollen receipt. *American*

Journal of Botany 90:1612–1618.

Fang, Q., and S.-Q. Huang. 2013. A directed network analysis of heterospecific pollen transfer in a biodiverse community. *Ecology* 94:1176–1185.

Galen, C., and T. Gregory. 1989. Interspecific pollen transfer as a mechanism of competition: Consequences of foreign pollen contamination for seed set in the alpine wildflower, *polemonium viscosum*. *Oecologia* 81:120–123.

Inouye, D. W. 1980. The terminology of floral larceny. *Ecology* 61:1251–1253.

Montgomery, B. R., and B. J. Rathcke. 2012. Effects of floral restrictiveness and stigma size on heterospecific pollen receipt in a prairie community. *Oecologia* 168:449–458.

Morales, C. L., and A. Traveset. 2008. Interspecific pollen transfer: Magnitude, prevalence and consequences for plant fitness. *Critical Reviews in Plant Sciences* 27:221–238.

Neiland, M., and C. Wilcock. 1999. The presence of heterospecific pollen on stigmas of nectariferous and nectarless orchids and its consequences for their reproductive success. *Protoplasma* 208:65–75.

Pauw, A. 2013. Can pollination niches facilitate plant coexistence? *Trends in ecology & evolution* 28:30–37.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Thomson, J. D., B. J. Andrews, and R. Plowright. 1982. The effect of a foreign pollen on ovule development in *diervilla lonicera* (caprifoliaceae). *New Phytologist* 90:777–783.

Tong, Z.-Y., and S.-Q. Huang. 2016. Pre-and post-pollination interaction between six co-flowering pedicularis species via heterospecific pollen transfer. *New Phytologist* 211:1452–1461.

Whitehead, M. R., R. Lanfear, R. J. Mitchell, and J. D. Karron. 2018. Plant mating systems often vary widely among populations. *Frontiers in Ecology and Evolution* 6:38.

Xie, Y. 2014. Knitr: A comprehensive tool for reproducible research in R. *in* V. Stodden, F. Leisch,

- 196 and R. D. Peng, editors. Implementing reproducible computational research. Chapman; Hall/CRC.
- 197 Xie, Y. 2015. Dynamic documents with R and knitr. 2nd editions. Chapman; Hall/CRC, Boca Raton,
198 Florida.
- 199 Xie, Y. 2018. Knitr: A general-purpose package for dynamic report generation in r.

