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# Intra-specific body size determines pollination effectiveness

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## Abstract

Pollinators differ in morphological and behavioral traits. The effect of the resulting trait variation on pollination effectiveness at the level of different species has received considerable attention, while the effect of intra-specific trait variation at the population level is largely unexplored. We examined the impact of body size variation in the Red Mason bee *Osmia rufa* on the yield of oilseed rape in a caged field experiment. Crop yield was positively correlated to mean individual body size. Comparison with control plots showed that only large individuals increased yield to a level above pollinator-free variation. Small individuals, in contrast, even decreased yield compared to the variation within controls. Thus, the fitness of pollinator populations significantly affects pollination services, because adult body size is determined by the resource availability at the larval stage. Our results emphasize the need for complementing investigations on pollinator communities by analyses of the individual species involved. We conclude that only the availability of sufficient floral resources enables wild bee foragers to produce large, persistent offspring constituting effective pollinators for sustainable pollination services in the following season.

## Zusammenfassung

Bestäuber unterscheiden sich in ihrer Morphologie und ihrem Verhalten. Die Auswirkungen der daraus resultierenden Variation in Eigenschaften für die Effektivität der Bestäubung sind auf der Gemeinschaftsebene gut untersucht. Die Auswirkungen von intra-spezifischer Variation auf der Ebene von Populationen sind hingegen größtenteils unerforscht. Wir haben den Einfluss von Körpergröße-Variation innerhalb der Roten Mauerbiene *Osmia rufa* auf den Ertrag von Raps in einem Käfig-Experiment untersucht. Der Ertrag war positiv mit der mittleren Körpergröße korreliert. Ein Vergleich mit Kontrollkäfigen ohne Bestäuber hat gezeigt, dass nur große Individuen den Ertrag über die Variation in der Kontrolle steigerten. Kleine Individuen dagegen haben den Ertrag im Vergleich zur Bestäuber-freien Kontrolle sogar gesenkt. Die Fitness innerhalb von Bestäuber-Populationen beeinflusst somit die Bestäuberleistung, da die Körpergröße der adulten Tiere von der Verfügbarkeit von Nahrungsressourcen während der Larvalphase bestimmt wird. Unsere Ergebnisse verdeutlichen die Notwendigkeit, bei Untersuchungen zu Bestäubergemeinschaften den Zustand der beteiligten Populationen mit zu berücksichtigen. Wir schlussfolgern, dass nur die Verfügbarkeit ausreichender Blütenressourcen es Wildbienen ermöglicht, große und ausdauernde Nachkommen für eine nachhaltige Bestäuberleistung in den folgenden Jahren zu produzieren.



***Keywords:*** Body size distribution; Canola; Crop pollination; Inter-tegular distance; Phenotypic plasticity; Wild bees

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## Introduction

Pollination is an important ecosystem process with economic and ecological relevance for arable crops and wild flowers (Klein et al. 2007; Ollerton, Winfree, & Tarrant 2011). Wild bees are generally considered the most important pollinator group in many ecosystems (Free 1993; LaSalle & Gauld 1993). Pollination efficiency differs among flower visitors (Sahli & Conner 2007), with larger species often being more effective (Kandori 2002). However, although body size also varies considerably within species (Goulson et al. 2002; Peat, Darvill, Ellis, & Goulson 2005), the effect of intra-specific trait variation on pollination efficiency at the population level remains largely unexplored. Some studies have shown intra-specific differences in foraging behavior related to body size for social bumblebees, a group known for considerable size variation in the worker class (Peat, Tucker, & Goulson 2005; Willmer & Finlayson 2014). Here, we examine the effect of individual body size of a solitary wild bee on yield in the mass-flowering crop oilseed rape.

Body size variation within wild bee species is predominantly determined by trophic and not by genetic factors (Tepedino, Thompson, & Torchio 1984; Couvillon & Dornhaus 2009). Large females provide more food to their offspring than smaller ones (Roulston & Cane 2009), thereby producing larger females in the following generation. This may have far-reaching ecological consequences, since larger individuals are more robust against habitat fragmentation, owing to the fact that individual body size is positively related to dispersal capacity (Warzecha, Diekötter, Wolters, & Jauker in press). Accordingly, the loss of flower resources and reduced availability of forage in agroecosystems increase the extinction risk at the community level (Müller et al. 2006; Memmot, Craze, Waser, & Price 2007; Goulson, Nicholls, Botías, & Rotheray 2015). At the same time, isolation of foraging habitats shifts body size distributions in local populations toward larger individuals, followed by a reduction in the number of plant species visited (Warzecha et al. in press). It is yet unknown whether the performance of individual pollinators within populations for specific plant species is similarly affected by body size.

Reduction in pollination service caused by intra-specific trait variability poses a considerable threat to both wild flowers (Biesmeijer et al. 2006) and an increasingly pollinator-dependent agriculture (Aizen, Garibaldi, Cunningham, & Klein 2008). Here, we were interested in whether intra-specific pollinator body size variation affects the pollination service provided to mass-flowering crops. We used oilseed rape (*Brassica napus*), one of the most common energy crops in the EU (van der Velde, Bouraoui, & Aloe 2009; FAO, 2015) to test pollination success of the Red Mason Bee *Osmia rufa* (L.), synonym *O. bicornis*, an efficient pollinator of this crop (Jauker, Bondarenko, Becker, & Steffan-Dewenter 2012). We hypothesize that larger individuals have a higher pollination efficiency and increase the yield parameters of oilseed rape.

## Materials and methods

### Experimental design

The study was carried out at the research station Weilburger Grenze of the Justus Liebig University Giessen, Germany. The experimental design was implemented on an approx. 1.5 ha winter-sown oilseed rape field (hybrid MAXIMUS PR44D06; Pioneer hi-bred Northern Europe division GmbH, Buxtehude, Germany) on allochthone Vega soil. Standard soil preparation and sowing was conducted on August 29 and 30, 2014. Field management included regular fertilizer application (calcium ammonium nitrate: 40 kg/ha on September 29, 2014, 90 kg/ha on March 18, 2015; boron: 2.0 l/ha on October 15, 2014; nitrogen: 63 kg/ha and sulphur: 72 kg/ha, both on February 2, 2015) and pest management (herbicides: Fuego Top, 2.0 l/ha, and Agil-S, 0.5 l/ha, on September 25, 2014; Cohort, 1.25 l/ha on March 19, 2015; insecticides: Bulldock, 0.3 l/ha on September 25, 2014; Trebon 30, 0.2 l/ha on March 19, 2015; fungicides: Ampera, 1.5 l/ha on October 15, 2014; Orius P, 1.0 l/ha on April 10, 2015).

The experimental design comprised 5 × 4 plots ($N = 20$, 148.5 $m^2$ total area) approx. 10 m from the northern edge of the field, established by mechanically removing oilseed rape plants from 1-m corridors and resulting in a plot area of 1.5 × 1.5 m each. Pollinator treatments were established in a pseudo latin square, including four closed control plots (no bees). All plots were caged with iron frames covered with fine mesh plastic gauze (cage length 1.5 m, width 1.5 m, height 2 m; cage area 2.25 $m^2$; mesh size *c.* 1 mm). With the exception of the four closed controls, plots were equipped with a trap nest consisting of approximately 150 internodes of Common Reed *Phragmites australis* (Cav.) in a plastic tube of 10.5 cm diameter on April 21, 2015 to stimulate nest building and foraging. Flowering at the field started on April 25, 2015.

### Pollinator treatment

A total stock of 290 red mason bee cocoons (WAB-Mauerbienenzucht, Konstanz, Germany) was individually weighed (139 female, 151 male). Individuals were ranked according to weight, and sixteen weight categories were defined evenly along the gradient, separately for females and males. From each category, five females and two males closest to the median of the category were chosen for the experiment ($N = 80$ females and 32 males), i.e. seven individuals per cage. The 112 bees from the 16 body size categories were introduced into the flight cages by individually attaching open plastic tubes with the cocoons to the trap nests on May 2, 2015. Unhatched cocoons were manually opened on May 8, 2015 and dead individuals were replaced with manually opened ones from the same size category (20 females and 19 males), previously stored at 4 °C. The mean weights