



Too sticky to steal: species-specific influence of seed mucilage on ant-mediated dispersal

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Received: 15 October 2025 / Accepted: 30 January 2026 / Published online: 10 February 2026
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Abstract

Aims Seed mucilage plays a crucial role in plant ecology and survival strategies. The mucilage, which has high adhesive forces, can be very effective as defense mechanism against ant-mediated seed predation. Especially harvester ants are known to collect seeds and therefore influence seed dispersal and seed survival. To get a better understanding in ant-mediated seed predation, this study investigates the protective properties of seed mucilage of *Plantago ovata* and *Ocimum basilicum* seeds as we hypothesized that the composition of this mucilage influences the protection against ant-mediated dispersal.

Methods For this purpose, we performed field experiments with the harvesting ant *Messor wasmanni* and observed seed survival rates of freshly hydrated and dried-in-contact seeds on two different surfaces.

Results The results demonstrate that seeds of *P. ovata* had a higher resistance to removal by ants (with

90% and 75% seeds left at the experimental site) than those of *O. basilicum* (with 5% and 0% left at the experimental site) on solid substrates (concrete and stones, respectively) and an overall faster removal of *O. basilicum* seeds. These findings indicate a better protection of *P. ovata* seeds against ant-mediated dispersal than of *O. basilicum* seeds.

Conclusions This study provides an insight into species-specific adaptations to seed defense. This can contribute to understand the importance of seed differences and mucilage compositions on seed ecology and plant defense mechanisms with potential implications for plant population dynamics, evolution and industrial and agricultural applications for seed protection.

Keywords Granivory · Insect-plant-interaction · Myxodiaspory · Seed defense · Harvester ants

Introduction

Myxodiaspory is a widespread property in diaspores like plant seeds, fruits or anthocarps (hereafter only ‘seeds’ for simplification) that involves the excretion of a sticky mucilaginous coating from the seed coat when the seeds come into contact with water (Grubert 1974; Western 2012). This phenomenon is observed in various plant families and serves multiple ecological functions, including seed dispersal, support in germination and protection against predators

Responsible Editor: Hans Lambers.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11104-026-08359-0>.

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(Grubert 1974, 1980; Howe and Smallwood 1982; Kreitschitz 2009). In detail, defending seeds against granivory, especially by ants, is one of the primary benefits of myxodiaspory (Forget et al. 2005; Janzen 1971). Granivory, the consumption of seeds, can significantly impact plant reproductive success and population dynamics. Therefore, e.g. harvester ants, being very efficient seed consumers, are a particular threat to many plant species (Gutterman & Shem-Tov 1997; Yang et al. 2012). For this case, the mucilage produced by myxodiasporous seeds acts as a physical barrier, making it difficult for ants to remove the seeds from surfaces and transport them to their nests (LoPresti et al. 2019, 2023). When hydrated, the mucilage swells and becomes sticky, adhering the seeds to substrates. While drying, the seeds become even more sticky and are then finally strongly attached in contact to the substrate as soon as they are dried (Kreitschitz et al. 2015, 2021). This adhesion mechanism can effectively prevent ants from carrying the seeds away (Pan et al. 2021; Yang et al. 2013).

Seed mucilage consists of pectins, hemicelluloses and cellulose fibers, which can be divided into three types, depending on the detailed mucilage composition: 1. ‘true slime’ with pectic mucilage, 2. hemicellulosic mucilage and 3. cellulosic mucilage with cellulose fibers additionally to pectins and hemicelluloses, which stabilize the mucilage (Fahn 1988; Harpaz-Saad et al. 2011; Kreitschitz 2009). Here, pectins are important for water absorption and storage, as well as mucilage adhesion by attached xylan chains (Kreitschitz and Gorb 2018; Phan & Burton 2018; Ralet et al. 2016; Vaclavik & Christian 2008). Additionally, hemicelluloses contribute to surface adhesion and mucilage viscosity (Naran et al. 2008; Zhou et al. 2022). Cellulose fibers function as a ‘skeleton’ by being organized in long, radially stretched fiber bundles, anchored to the seed coat by hemicelluloses (Schaber et al. 2018; Zhou et al. 2022). In some cases, starch granules embedded within the fiber bundles can enhance adhesive properties (Kreitschitz et al. 2021; Tosif et al. 2021). These varying compositions result in varying adhesive forces across the plant species.

Adhesive forces of mucilaginous dried-in-contact seeds can vary from 9.8 mN in the cellulosic mucilage of *Artemisia dracunculus* to 4.9 N in the pectic mucilage of *Linum usitatissimum* (Pan et al. 2022). *Plantago ovata* (psyllium) is known for producing a

high amount of hemicellulosic mucilage with a minor pectin component and other sugars (Phan et al. 2020; Yu et al. 2017). When wetted, its seeds form a thick, gel-like coating. This mucilage has strong adhesive properties, allowing the seeds to strongly adhere to various surfaces. Its adhesive strength (adhesive force in relation to the contact area of mucilage and substrate) is due to the complex polysaccharide composition of the mucilage, which includes arabinoxylans and rhamnogalacturonans, but is lacking cellulose fibers (Kreitschitz et al. 2021; Phan et al. 2020). Cellulosic *Ocimum basilicum* (basil) seeds also produce a high amount of mucilage, though generally in smaller quantities compared to psyllium. The mucilage of basil seeds contains primarily glucomannans (43%) and xylans as well as cellulose fibers and smaller amounts of pectins and small starch granules, which contribute to its adhesive properties (Gorges et al. 2024; Kreitschitz et al. 2021; Phan & Burton 2018; Tantiwatcharothai & Prachayawarakorn 2019).

The adhesive strength of seed mucilage can vary depending on factors, such as: (1) mucilage composition, when different ratios of polysaccharides affect adhesive properties (Kreitschitz 2009; Western 2012), (2) environmental conditions, when temperature and humidity influence mucilage viscosity and adhesiveness (Teixeira et al. 2020; Zare et al. 2023), and (3) surface characteristics, when the texture and chemical composition of the adhering surface impact the adhesive strength. For the latter, wet seeds sticking to smooth surfaces such as glass, have smaller adhesive forces than seeds sticking to more rough surfaces, such as filter paper (Pan et al. 2022). All those conditions can influence the protection against granivorous animals, such as harvester ants.

Harvester ants, with more than 150 species worldwide, are social insects known for their unique behaviors and ecological roles in Mediterranean grasslands and scrublands (Azcarate & Peco 2003; Hölldobler & Wilson 1990; Taber 1998). Highly specialized seed-eating harvester ants belong to the genera *Pogonomyrmex*, *Pheidole* and *Messor* (*Veromessor*) in North America and the *New World* (Brown et al. 1979; MacMahon et al. 2000) and *Messor* in the *Old World* (De Almeida et al. 2020; Johnson 2001). Harvester ants, e.g. *Messor wasmanni* or *Pogonomyrmex barbatus*, live in complex colonies with a highly organized social structure and in some cases even foraging behavior (El Boukhrissi et al. 2023; Harkness &

Isham 1983; Johnson 2001; Luna et al. 2018). Their nests are typically underground, consisting of intricate networks of chambers and tunnels (Arnan et al. 2010). These colonies can house thousands of individuals, each with specific roles and responsibilities (El Boukhrissi et al. 2023). Many harvester ants, including *M. wasmanni* are granivores primarily feeding on seeds, with foraging columns or trunk trails as foraging strategy (Plowes et al. 2013; Solida et al. 2010; Traxler 2018). Additionally, by collecting and storing seeds, some seeds get lost on the way to the nest or are discarded at ‘trash’ piles, potentially germinating in new locations (Taber 1998). Thereby, harvester ants have an important role in seed dispersal.

Understanding the complex interactions between myxodiasporous seeds and granivorous ants is crucial for understanding plant–insect interactions, seed dispersal ecology, and the evolution of plant defense mechanisms. As the composition of seed mucilage is important for adhesion to substrates, we hypothesized that the mucilage type and composition is crucial for the protection of seeds against ant-mediated dispersal. Therefore, we performed field experiments with *Messor wasmanni* ants and two mucilaginous plant seed species, to compare the efficiency of *Ocimum basilicum* and *Plantago ovata* seeds against harvesting ant approaches on two different substrates. We expected different seed performances due to the mucilage composition. Our findings can have implications for conservation efforts and agricultural practices, particularly in ecosystems where ant-mediated seed predation is a significant factor. Furthermore, the results can help in a better understanding of food preferences of ants and environmental adaptations of species-specific seed mucilage properties.

Materials & methods

We experimentally tested seed removal by ants and how the hydration state of the seeds affected the removal on two different substrates. For this purpose, we chose two species of mucilaginous plant seeds that are also widespread in the Mediterranean region: *Ocimum basilicum* L. seeds with cellulosic mucilage (obtained from Covered Marked, Wrocław, Poland) and *Plantago ovata* L. seeds with high amounts of hemicelluloses within the mucilage (obtained from Alnatura, Darmstadt, Germany). The experiment

site was in close proximity to harvester ant nests in Alaçatı near Çeşme/İzmir (Turkey, 38°19'37.8"N 26°20'25.2"E, Fig. 1A–C) in September 2023 (no rain, average temperature: 22.8 °C) (Fig. 1D). In this area, the grain harvesting ant *Messor wasmanni*, known as a generalist which collect a huge variety of food sources, is found (Fig. 1E–F), which, in our case, built their nests underneath and next to a concrete footpath close to a stony beach. No other harvesting ants are recorded or known for this region, as well as no other seed collecting insects. For the experiments, we placed a high number of seeds (> 100, approx. 200 mg of *O. basilicum* and 350 mg of *P. ovata*) close to nest entrances and hydrated the seeds by gently pouring water over the seeds until they were soaking wet and released mucilage (Fig. 1G–H,K). The seeds then dried relatively fast by the sun within 1–2 h. We then documented the number of dried-in-contact and attached seeds left at this place by taking photos daily (Fig. 1I,K). We checked the study site every 2–3 h during daytime (between 8 am until 8 pm). For better comparison, we placed *O. basilicum* seeds next to *P. ovata* seeds, to exclude site-specific preferences of the ants. Additionally, we chose two different types of substrate to perform the experiments: concrete and pebble stones to see whether the harvesting of the seeds is different on undergrounds with a different roughness. In total, we performed two complete trials on concrete with the two plant species *O. basilicum* and *P. ovata* seeds as well as two trials with *P. ovata* and three trials with *O. basilicum* seeds on pebble stones. As control experiments, we placed the same amount of loose dry seeds next to ant nests to confirm the ants' interest in the two species (Fig. 1J). We placed dry seeds without hydrating the seeds next to ant nest entrances and observed the ants' interest in the seeds (foraging behavior and overall detailed examination of the seeds by ants). In all control experiments (two trials per species, one on stones and one on concrete), all seeds were taken by the ants within 24 h. All experiments were conducted at different, randomly chosen ant nest entrances to avoid site or nest specific preferences. In total, seven ant nest entrances of two nests were used.

For the evaluation and statistical analysis, we counted the seeds on each photo with the image software ImageJ (ImageJ2, V: 2.14.0/1.54f) and calculated the survival rates after each day by dividing the number we counted for each day by the total

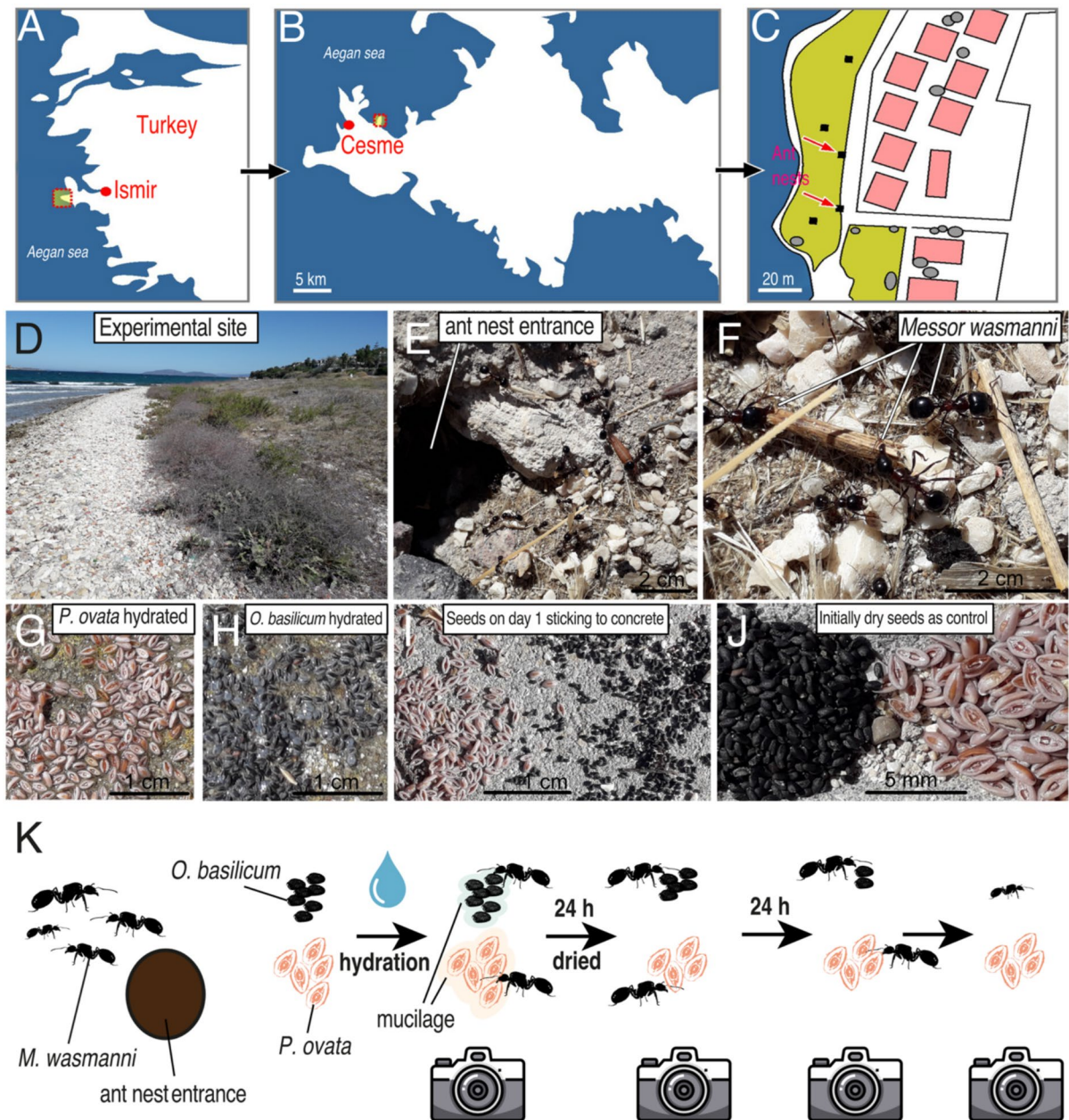


Fig. 1 Experimental site and setup. West coast of Turkey (A). Cesme area (B). Study site map (C), green colour indicates meadows at the seashore, where numerous ant nests are situated (black rectangles). Red arrows indicate two target nests, where experiments and observations were carried out. Experimental site in Alaçati near Çeşme/İzmir (Turkey) (D) with ant nest entrances (E) of *Messor wasmanni* colonies (F). *P. ovata* (G) and *O. basilicum* (H) seeds on concrete in a hydrated

state. Previously hydrated seeds after 1 day of dehydration on concrete (I) and seed piles in an initial dry state (J). Experimental setup: seeds in a dry state placed next to an ant nest entrance, then hydrated to force mucilage extrusion (K). Photos were taken of seeds in hydrated state and then every 24 h after hydration until no seeds were left or nothing changed for several days. Scale bars: B: 5 km; C: 20 m; E, F: 2 cm; G–I: 1 cm; J: 5 mm

seed number. All statistical tests and plotting were performed using R Statistical Software (v4.4.1;

2024 The R Foundation for Statistical Computing Platform; with RStudio (version 2024.09.0 + 375)).

We performed a Kaplan–Meier analysis with a Cox model and Hazard ratio for the seed survival rate. For the percentage of seeds left at the end, we performed a Shapiro–Wilk normality test, and a Two-Way ANOVA followed by a Tukey’s Test with a significance level of 0.05 to compare the plant species on each substrate.

Results

The control with dry seeds showed high acceptance by ants for seeds of both species, with the complete harvesting of those seeds within 1 day. Also, observations showed the interest of the ants on hydrated and also on dried-in-contact and attached seeds

(Supplementary Video S1-S3/Supplementary Figs. S1-S2). The trials on concrete showed strong differences between the detachment of *O. basilicum* and *P. ovata* seeds by the ants. In both trials, a high amount of *P. ovata* seeds were still left, while almost all *O. basilicum* seeds were removed (Fig. 2A–C, Fig. 3A). After 1 day, the number of *O. basilicum* seeds was already reduced, while the number of *P. ovata* seeds almost remained the same. Within several days after the hydration, the ants removed the *O. basilicum* seeds, while they did not remove the same amount of *P. ovata* seeds. On stone, the removal of seeds of both species was slightly higher than on concrete, but did not show any statistically significant differences. Still, about 75% of *P. ovata* seeds were left, while no *O. basilicum* seed was left at the end of both trials

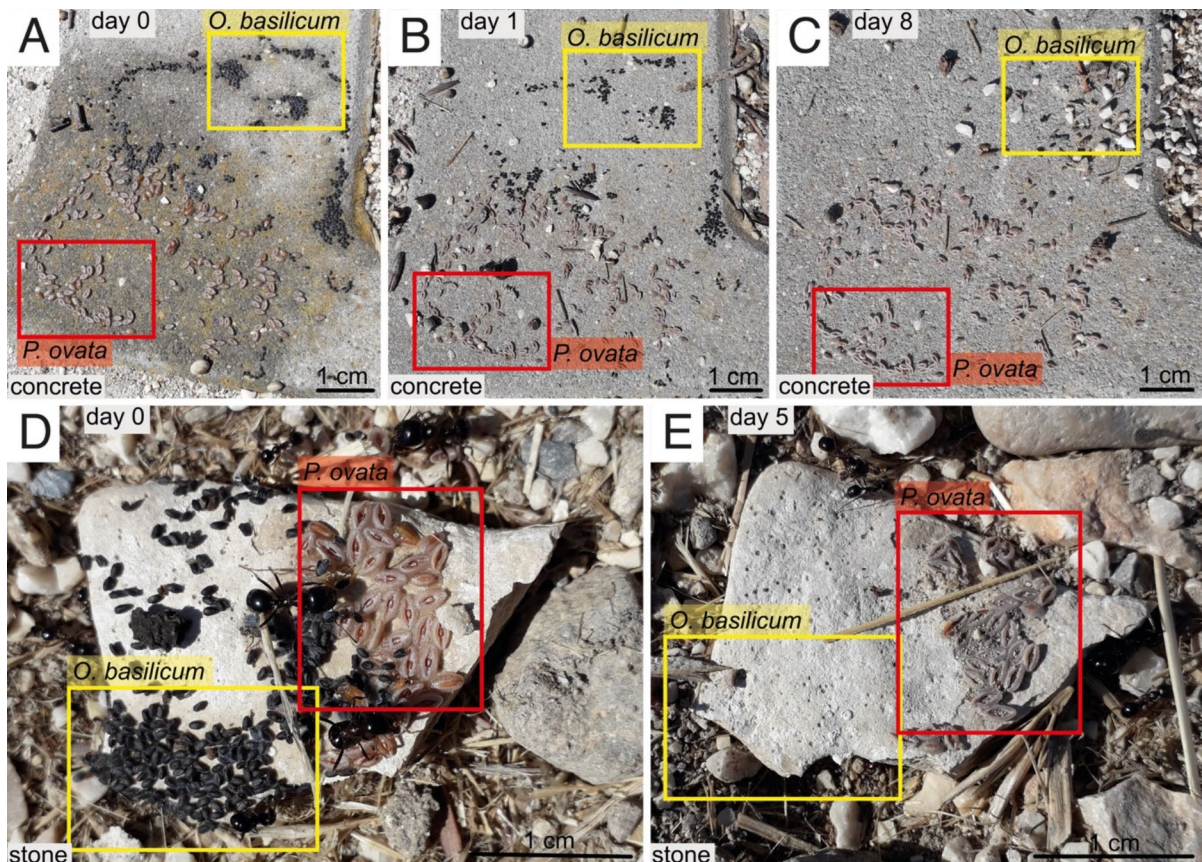


Fig. 2 Trials on concrete and pebble stone. One trial on concrete (A–C) with hydrated (A) *O. basilicum* (e.g. yellow box) and *P. ovata* (e.g. red box). Seeds after 24 h of drying, reduced amounts of the seeds of both species (B) and seeds on day 8 with almost no *O. basilicum* left, but still high amount of *P.*

ovata (C). Trial on pebble stone (D–E) with hydrated seeds (D) and already interest of *M. wasmanni* on the seeds (red box: *P. ovata*, yellow box: *O. basilicum*). Seeds on day 5 (E) with only *P. ovata* left, all *O. basilicum* seeds were completely removed by the ants. Scale bars all 1 cm

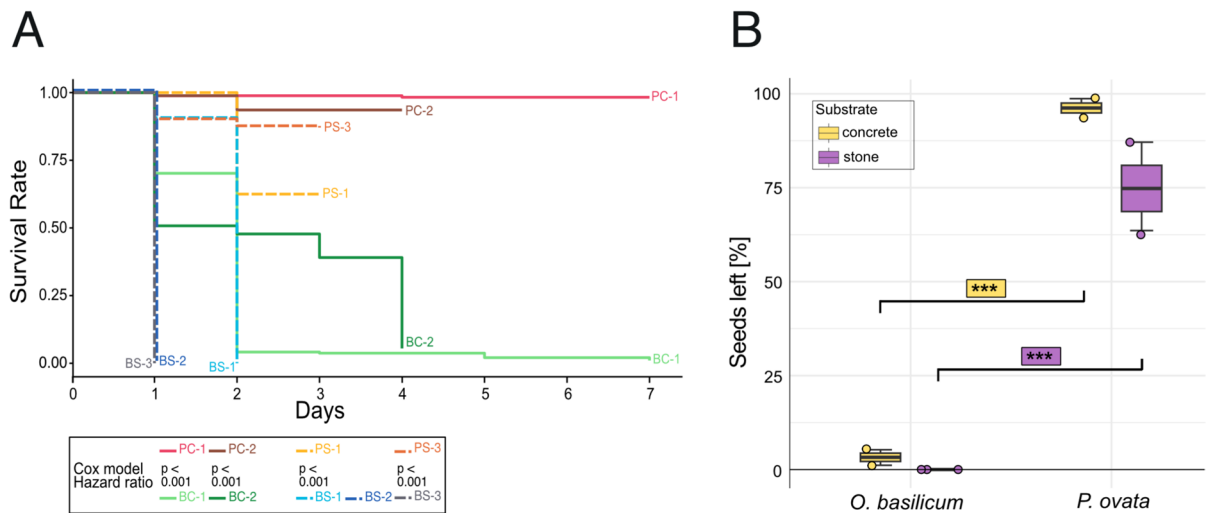


Fig. 3 Survival rate of the seeds per day and percentage of seeds left at the end. Survival rates in a Kaplan–Meier curve of the seeds (A). BC = basil concrete, BS = basil stone, PC = plantago concrete, PS = plantago stone. Cox model with a pairwise comparison as Hazard ratio showed statistically significant differences between the seeds of both species ($p < 0.001$). Experiments stopped at day 3–4 when either the seeds were all removed or nothing changed after 2 days. Boxplot of the

overall percentage of seeds which were left after the end of the experiments (B) with each data point depicted, with 25th and 75th percentiles as bottom and top of the boxes and the median; the whiskers are the 10th and 90th percentiles. Two-Way ANOVA with Tukey’s Test between the species on each substrate showed statistically significant differences (***: $p < 0.001$)

(Fig. 2D–E, Fig. 3B). Another observation showed, that *P. ovata* seeds were only removed within the first 3 days on both substrates, while *O. basilicum* seeds were still removed after 6 days on concrete. However, ants still showed interest in *P. ovata* seeds during the whole trials, e.g. at day 5 after hydration, by examination of the seeds (see Supplementary Fig. 2). The comparison of survival rates of the seeds in each trial (e.g. plantago concrete 1 (PC1) compared to basil concrete 1 (BC1)) between the two species always showed a statistically significant difference, with a Hazard ratio of $p < 0.001$ for each trial (Cox model, Fig. 3A).

Discussion

This study provides insight into the effectiveness of seed mucilage as a defense mechanism against ant-mediated seed predation of two plant species: *O. basilicum* and *P. ovata*. Different plant species have evolved varying levels of mucilage production and resulting adhesive strength, likely in response to specific ecological pressures and ant species in

their native habitats (Grubert 1974). It is specifically known, that mucilage producing seeds show higher resistance to ant predation than those without mucilage (Engelbrecht & García-Fayos 2012).

In their habitats, harvester ants play a crucial role in seed dispersal and soil modification. As they collect and store seeds, some seeds get lost on the way to the nest or are discarded at ‘trash’ piles, potentially germinating in new locations (Taber 1998). This behavior contributes to plant distribution and ecosystem dynamics. Another notable aspect is their seed storage behavior. They create specialized chambers within their nests to store collected seeds, effectively creating a granary (Taber 1998), which allows the colony to survive during periods of food scarcity. Harvester ants are capable of carrying seeds much larger than their body size (Detrain et al. 2000), showing a strong relation of head size and dry food mass (Solida et al. 2007), but workers chose relatively small seeds when provided with seeds of various sizes (Heredia & Detrain 2005; Martyn et al. 2023). Additionally, these ants have evolved specialized mandibles for efficiently collecting, carrying and processing seeds. Bite forces of harvesting ants range between 0.06 N in

Messor barbarus, 0.09 N in *Pheidole noda* and 0.32 N in *Carebara sp.* (Rühr et al. 2024).

Different survival rates of the seeds of two plant species

Our results demonstrate that *P. ovata* seeds were more resistant to ant removal compared to *O. basilicum* seeds. This difference was consistent across both concrete and pebble stone substrates. Interestingly *O. basilicum* seeds seemed to be easier removable and more attractive for ants, even though they showed higher adhesive forces (approx. 4.44 N) and adhesive strength (1.55 N/mm^2) than *P. ovata* seeds (adhesion force: 3.15 N, adhesion strength: 0.94 N/mm^2) in previous laboratory experiments on a glass surface (Kreitschitz et al. 2021) and should also show higher resistance to adhesive failure of the mucilage at the contact area. Still, the adhesive force and strength might vary in our experiments due to the substrates they are sticking to. As the adhesion strength also depends on the internal structure of the mucilage, the adhesive strain energy density of the mucilage can be important for preventing a cohesive failure of the mucilage. For *P. ovata*, the adhesive strain energy density is relatively low (approx. 2.74 mJ/m^2) (Kreitschitz et al. 2021), and therefore might prevent cohesive failure of the mucilage. In this study, we cannot determine if the main reason for detachment of the seeds was adhesive or cohesive failure, but we did not observe remaining mucilage residues at the substrates. Therefore, we assume an adhesive failure of the mucilage to the substrate. In other studies, ants could detach seeds by pulling them with their mandibles or by clipping the mucilage strands (Pan et al. 2021). According to the seed sizes, the ants were able to even grip the bigger *P. ovata* seeds with their mandibles and detach them by only pulling them off the surface in a not completely dry state of the seeds (see Supplementary Videos 1–3). Still, the ants took longer to detach the seeds as they were almost completely dried compared to seeds in a more hydrated state. In a completely dried-in-contact state, it might have been easier for the ants to grip *O. basilicum* seeds with their mandibles, as they are (1) smaller and easier to clamp between the mandibles and (2) might provide more grip by having a fibrous mucilage. In other studies, ants were

observed to prefer the transportation of seeds with structures they can easily grip, for example seeds with elaiosomes which fit their maximal mandible span (Gorb & Gorb 2003). In general, fibrous materials allow stronger interlocking of gripping devices, such as mandibles or insect claws (Gorb 2008). Therefore, we conclude that it was easier for the ants to grip the fibrous mucilage of *O. basilicum* seeds with their mandibles, compared to the mucilage of *P. ovata*, which does not contain cellulose fibers.

One reason for the high attraction for ants could be found in the mucilage composition. *Ocimum basilicum* seed mucilage is composed mainly of hemicelluloses, supported by cellulose fibers and pectins, while *P. ovata* seed mucilage lacks cellulose and is mainly composed of hemicelluloses and pectins (Kreitschitz et al. 2021). Seed-borne chemicals play an important role in seed acceptance as food source by the ants and protection of the seeds against ants, but as other ants of the genus *Messor* are known to collect plantago seeds (Steinberger et al. 1991; Azcárate et al. 2005;), we expected a seed acceptance of *P. ovata* seeds. In addition, our results showed high seed acceptance (by high removal percentages) by the ants for *O. basilicum* seeds. Also, the seed mass and size might play an important role, as ants need higher forces to remove heavier seeds (Pan et al. 2021) and prefer to remove smaller sized items (Heredia & Detrain 2005; Martyn et al. 2023). *Ocimum basilicum* seeds weigh between 1.5–2 mg and are 1–2 mm in diameter, while *P. ovata* seeds weigh approximately 3–3.5 mg and are 2–3 mm in diameter. Another factor for a challenging removal of larger seeds might be the contact area of the dried mucilage to the substrate. In the case of *P. ovata* and *O. basilicum*, the contact area is similar (*P. ovata*: mean 3.35 mm^2 , *O. basilicum*: mean 3.22 mm^2) (Kreitschitz et al. 2021) and might not be the decisive factor for differing seed survival rates. As shown in other studies, ants prefer to only pick up a smaller seed compared to clipping off larger seeds with their mandibles (Pan et al. 2021). In general, the seeds of both species seemed to be easier to remove in an initial hydrated state (Supplementary Videos). At least *P. ovata* seeds were mainly removed when freshly hydrated, as a large proportion of the seeds were removed between hydration and 1 day after hydration (Fig. 2A–B, Fig. 3A).

Substrate characteristics play a role in seed removal

There was not only an influence of the seeds of both species on the percentage of removal, but also of the substrates the seeds were attached to. Granular substrates, such as soil do not considerably improve protection of dry or hydrated seeds, but the situation is different with solid substrates. It is already known that seed mucilage bound to solid substrates can reduce the predation by ants and rodents, as it was shown on sand-coated seeds (LoPresti et al. 2019). Previously hydrated and then dried seeds on smooth surfaces, such as glass, show higher adhesive forces than seeds attached to increasingly finer grit sandpaper, while seeds attached to finer grit sandpaper showed smaller dislodgement forces than those on coarser grit (Pan et al. 2022; Stessman et al. 2023). In contrast, wet seeds show higher adhesive forces on filter paper compared to smooth glass surfaces (Pan et al. 2022; Gorges et al. 2024;). In this study, seed removal percentages were slightly higher on pebble stones compared to concrete, but did not show a statistical difference (Fig. 3B). This observation suggests that substrate characteristics play a role in the effectiveness of mucilage-based seed defense. The rough texture of pebble stones and concrete may provide traction for ants and smaller adhesion forces through smaller contact areas of seeds, allowing the ants to overcome the adhesive properties of the mucilage more easily compared to previously hydrated and then dried seeds on smooth substrates like glass. Nevertheless, the adhesive forces of *P. ovata* seeds were high enough to even provide strong adhesion on both surfaces to protect the seeds from being easily removed, as 90% of *P. ovata* seeds remained on concrete and 75% on stones.

Faster and continuous removal of *O. basilicum* seeds

Not only the percentage of removed seeds differed on the two solid substrates, but also the time the ants took to remove the seeds. On both substrates, *P. ovata* seeds were only removed within the first 3 days, while *O. basilicum* seeds continued to be removed even after 6 days on concrete and were completely removed within 4 days on pebble stone (Fig. 3A). Additionally, temporal changes in mucilage properties and viscoelasticity during drying may play a role in the fast removal on the first day. During drying, the

viscoelasticity and other mechanical properties show small adhesive forces and small Elastic Moduli when still hydrated (Gorges et al. 2024, 2025; Kreitschitz et al. 2015). Over the period of drying, the seeds increase their adhesion, while the Elastic Modulus increases and the mucilage hardens. This temporal pattern might suggest that the adhesive properties of *P. ovata* mucilage may become more effective over time. Still, as there were warm temperatures and sun during our experiments, the seeds dried relatively fast within less than 2 h, which only left a small time frame of the seeds having small adhesive forces and a small E-Modulus. These temporal changes of mucilage properties might explain the seed removal within the first day, as almost 30% and 50% of basil seeds were removed in both trials on concrete, respectively, and we did observe ants removing the seeds while still hydrated. Nevertheless, the ants still showed a high interest in those seeds after some time. Conversely, the continued removal of *O. basilicum* seeds might indicate that the mucilage may not provide long-lasting protection against ant predation. Also, observed persistent interest and examination of the ants on the seeds suggests that the mucilage does not act as a deterrent to ant attraction, but rather as a physical barrier to seed removal.

Limitations and outlook

While this study provides trends of seed removal by ants, it is important to note some limitations. The experiments were conducted in a specific geographical location with a single harvester ant species (*M. wasmanni*) and the experimental site was not constantly monitored. Therefore, we cannot fully exclude the influence of rodents or birds on seed removal, because the experiments were not in a fully monitored and protected environment. As other granivores had access to the experimental site, there could have been the possibility of unrecorded removal by non-ant granivores. However, we did not observe other animals approaching the experimental site. Furthermore, the steady numbers of seeds after some days might indicate that no other granivores took the chance to remove the remaining seeds. Another limitation of this study was the small number of nests and a possibility of pseudoreplication. With only two nests, we should be careful in concluding our findings and putting them in a general context. As the ants of those

two nests might act similar but different than other ants of this species, or have local preferences and behaviors, further studies with more nests in more and differing locations should be considered. Future studies could expand on our findings as follows: 1. Investigating a wider range of plant species with different mucilage compositions. 2. Conducting longer-term studies with a more detailed monitoring to assess potential trade-offs between ant-mediated dispersal and predation for myxodiasporic seeds. 3. Repeat the experiments in well controlled lab environments, with different challenges and different objects with varying mucilage concentrations and compositions, to see an effect of varying mucilage.

Conclusions

In conclusion, this study demonstrates the complex nature of plant-ant interactions mediated by seed mucilage and seed characteristics. On one hand, the size of the seeds might influence the predation by ants, on the other hand, mucilage composition might be important in protecting seeds from ant-mediated dispersal. The findings highlight the importance of considering species-specific adaptations, especially seed characteristics, environmental context, site and substrate wise and temporal dynamics, when evaluating the effectiveness of plant defense mechanisms. This research can contribute to our understanding of seed ecology and species-specific defense success and may have an implication for conservation strategies and agricultural practices in ecosystems, where ant-mediated seed predation is a significant factor.

Acknowledgements We would like to thank Valentin Birkenfeld, Thies Büscher and Simon Züger for advices and support during this study.

Author contributions S.N.G., H.G. – Conceptualization; S.N.G. – Data curation; H.G., S.N.G. – Data analysis; H.G., S.N.G. – Methodology; S.N.G. – Investigation; H.G. – Visualization; H.G. – Writing – original draft; S.N.G. – Writing – review & editing; S.N.G. – Funding acquisition.

Funding Open Access funding enabled and organized by Projekt DEAL. This work was supported by funding to S.N.G. by the grant GO 995/43–1 from German Science Foundation (DFG). The funders took no part in the study design, data

collection and analysis, decision of publishing or any preparation of the manuscript.

Data availability The data that supports these findings can be requested from the authors upon a reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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