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SHORT COMMUNICATION

The domestic goat as a potential seed disperser of *Mimosa luisana* (Leguminosae, Mimosoideae) in the Tehuacán-Cuicatlán Valley, Mexico

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Abstract: *Mimosa luisana* is functionally important in the Tehuacán-Cuicatlán Valley, Mexico, since it is able to create favourable microsites for the establishment of other plant species. The endozoochory of *M. luisana* seeds by goats was evaluated in terms of excrement deposition pattern, seed survival and germination. The excrement deposition pattern was evaluated by collecting pellets in four plots of 25 × 2 m randomly placed in a grazing area and recording the microhabitat where pellets were found. Seed survival and germination were evaluated by feeding the goats with seeds and collecting dung pellets at 8-h intervals for 80 h. Seeds from goat pellets (treatment) and seeds collected from pods (control) were placed in a germination chamber for 24 d. Goats mainly deposited *M. luisana* seeds in viable sites (open areas) for growth. *Mimosa luisana* seeds survived the goat digestive treatment (5.91% ± 2.86%) and most of them (67% ± 25.9%) were recovered 8–32 h after ingestion. Goat gut treatment increased *M. luisana* final germination (47.5% ingested, 5.83% control) and shortened initial and mean time of germination. Our results indicate that goats may be an efficient disperser of *M. luisana* seeds.

Key Words: drylands, endozoochory, germination, long-distance seed dispersal, plant-animal interactions, ruminants, seed dispersal, seed predation

Domestic herbivores can have an important ecological role by acting as agents of plant dissemination (Baraza & Fernández-Osores 2013, Sánchez de la Vega & Godínez-Álvarez 2010). In the Tehuacán-Cuicatlán Valley, Mexico, which is one of the semi-arid zones of greatest biological diversity in the world (Dávila *et al.* 2002), goats were introduced during the colonial period and extensive herding has since then become the most important resource for the local population. Baraza & Valiente-Banuet (2008) reported the presence of viable cactus and legume seeds in domestic goat faeces, indicating their potential role as plant dispersers. *Mimosa luisana* Brandegee is a legume species with an important functional role in the study area, since it is able to create favourable soil and shade conditions for the establishment of other plant species (Camargo-Ricalde *et al.* 2010). In this study, we evaluated if the domestic goat (*Capra hircus* L.) is a legitimate (i.e. has the potential for seeds to pass the goat digestive system without damage; Herrera 1989) and efficient (i.e. deposits seeds in suitable sites for germination; Reid 1989) disperser of *M. luisana* seeds. Gut treatment on seeds was assessed since it is strongly linked with legitimacy, as the digestion process could destroy seeds or alter the speed of their germination, thus modifying germination patterns (Schupp 1993). We also evaluated the retention time of *M. luisana* seeds since it is highly connected with the distance that seeds are dispersed (Or & Ward 2003).

The study was conducted in the Tehuacán-Cuicatlán Valley, Puebla, Mexico located at 17°20′–18°53′N and 96°55′–97°44′W. Fieldwork was conducted within the municipality of Zapotitlán Salinas, at the altitudinal range of 1700–2000 m asl. The mean annual precipitation (mainly occurring from July to August) and temperature is 400 mm and 21 °C, respectively (Dávila *et al.* 2002). The vegetation is classified as xeric shrubland (Rzedowski 1978) and characterized by the presence of columnar cacti. *Mimosa luisana*, is a thorny shrub or tree, flowering from April to November and fruiting from September to

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December (Camargo-Ricalde *et al.* 2004) and it is endemic to Mexico (Martínez-Bernal & Grether 2006). The fruit is a dry one-carpel pod, with each pod containing two to eight seeds. Seeds are small (2.7–3.5 mm long, 2.4–2.6 mm wide and 2.0–2.7 mm high), shiny dark brown and characterized by a lentil form (Martínez-Bernal & Grether 2006) with hard seed coats that impose seed dormancy; consequently, scarification is needed to break seed dormancy (Camargo-Ricalde *et al.* 2004).

To evaluate deposition patterns, goat pellets were collected in four rectangular transects of 25 × 2 m randomly located in a grazing area. The microhabitat (open areas, canopy areas and boulder-dominated areas) of pellet locations were recorded. Pellet collection was repeated three times in October and November 2007 and the first collection also included old pellets already present in the transects. All goat pellets were analysed for the presence of *M. luisana* seeds. A chi-square test was used to assess whether goat pellet deposition in the microhabitats was independent of collection periods. A Bonferroni z-test method ($P < 0.05$) was used to test goat microhabitat preferences for defecation in relation to habitat occurrence (Neu *et al.* 1974). In total ($n = 1958$ pellets) 77.5% were found in open areas, 19.5% in canopy areas and 3% in boulder-dominated areas. The distribution of goat pellets in the three microhabitats was independent of collection period ($\chi^2 = 8.96$; df = 4; $P = 0.06$) but differed among microhabitats ($\chi^2 = 459$; df = 2; $P < 0.01$), with pellet density higher than expected in open areas. Only one *M. luisana* seed was found within the transect survey.

To assess seed retention time and presence of viable seeds in goat pellets, six pregnant goats (26.8 ± 1.8 kg) randomly selected from the same local herd, were penned individually and fed with 3000 *M. luisana* seeds mixed with alfalfa and corn stubble. The goats finished the batch in about 1 h and were then fed with alfalfa and corn stubble during the whole length of the experiment. All pellets produced by each goat were collected every 8 h over a period of 80 h (0–8, 8–16, 16–24, 24–32, etc. h after seed ingestion). A subsample of 20 g of faeces dried in thermostatic chamber (50 °C) was taken from each collection for each goat and analysed for presence of *M. luisana* seeds. Seeds that appeared intact under a stereomicroscope were considered as potentially dispersed. In contrast, seeds that were cracked or showed signs of digestion were considered predated and unable to germinate. Of the ingested seeds, 5.9% ± 2.86% (mean ± SD) survived the goat digestive treatment. Two seeds were found at the 0–8 h interval, 67% ± 25.9% were found 8–32 h after ingestion, and two seeds were recorded as much as 72 h after ingestion (Figure 1). Similarly to what Or & Ward (2003) reported for *Acacia* sp., bruchids such as *Acanthoschelides mexicanus* Sharp and *Acanthochselides chiricahuae* Fall, can negatively influence the resistance of seeds to mastication and digestive acids. Consequently, seeds used to feed the goats were checked for infestation by bruchids and an infestation curve was built, resulting in an estimate of 44.8% seed infestation. Among recovered ingested seeds, none showed any signs of bruchid infestation.

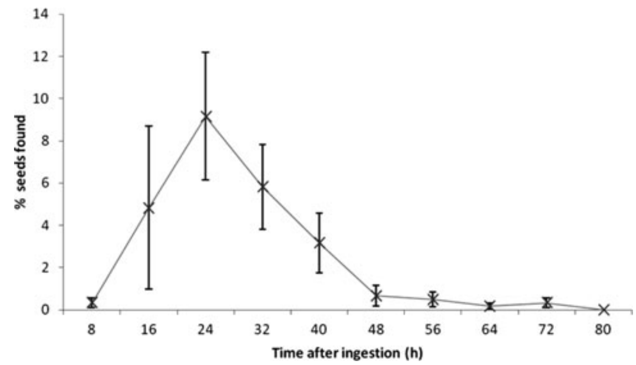

Figure 1. Per cent (mean ± SE) of seeds of *Mimosa luisana* found in domestic goat ($n = 6$) faeces as a function of time since seeds were ingested, Tehuacán-Cuicatlán Valley, Mexico. Goats were fed with 3000 *M. luisana* seeds mixed with alfalfa and corn stubble and then fed with alfalfa and corn stubble during the whole length of the experiment. Goat pellets were collected every 8 h over a period of 80 h.

To evaluate the effects of endozoochory on seed germination, we established a germination experiment with 120 ingested and 120 control seeds collected from the same mother plants and in the same day. Cracked seeds, seeds that floated in water or showed any signs of bruchid infestation were discarded. The ingested seeds sample included seeds recovered at all retention times and reflected the retention time curve. Seeds were washed with a 3% detergent and disinfected with a 5% chlorine solution for 5 s (Camargo-Ricalde *et al.* 2004). Twenty-four Petri dishes containing five seeds each were set up for ingested and control seeds and randomly placed in a germination chamber set at a constant 25 °C and with a 12-h photoperiod for 24 d. Germination (i.e. radicle reached 1 mm in length) functions were built for each treatment by using the Kaplan–Meier estimators and compared by means of non-parametric generalized log-rank and Wilcoxon tests (McNair *et al.* 2012). Germination of ingested seeds was higher than control seeds (log-rank test, $\chi^2 = 51.9$; df = 1; $P < 0.001$) (Figure 2). Passage through the digestive also shortened the mean germination time, which was 23.0 ± 0.39 d for control seeds and 14.9 ± 0.94 d for ingested seeds. Goat gut passage shortened the initial time of germination ($\chi^2 = 52.1$; df = 1; $P < 0.001$).

This study shows that free-ranging goats could act both as legitimate and efficient dispersers of *M. luisana* seeds, although the percentage of seeds able to survive the gut passage is small. Low seed survival following ungulate digestion has been found in several studies (Grande *et al.*

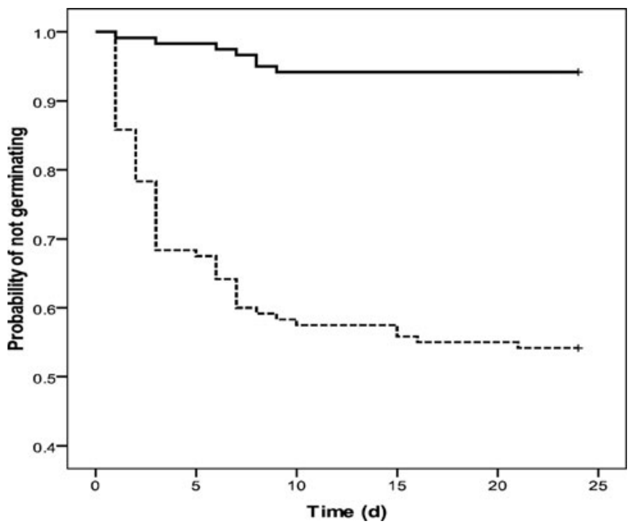

Figure 2. Probability of not germinating of ingested (stippled line) and control (solid line) *Mimosa luisana* seeds, based on Kaplan–Meier estimates, Tehuacán-Cuicatlán Valley, Mexico. The final crosses represent censored observation. Differences in germination curves are significant (log-rank test, $P < 0.001$; Wilcoxon test, $P < 0.001$). The germination chamber was set at a constant 25 °C and with a 12-h photoperiod for 24 d. Germination was defined as when the radicle reached 1 mm in length.

2013, Mancilla-Leytón *et al.* 2011) and the percentage of *M. luisana* seeds that we retrieved intact after the gut passage (5.91%) is similar to what observed for other seeds with similar size (Mancilla-Leytón *et al.* 2011). Size was shown to be negatively correlated to seed recovery (Grande *et al*. 2013) primarily due to seed mastication, as was evident by seed fragments found in the faeces. Low seed survival is also caused by high bruchid infestation (Or & Ward 2003). With the estimated bruchid infestation close to 50%, none of the ingested seeds had any sign of infestation. Thus, gut treatment apparently destroyed all bruchid-infested seeds. Accordingly the percentage of *M. luisana* seeds able to survive gut passage could increase in years with few bruchids.

The passage through the goat digestive system enhanced seed germination by increasing the quantity of seeds able to germinate and shortening initial and mean germination time. Since excreted seeds are virtually ready to germinate, they may take advantage of rainfall events, which could improve their seedling development and inter- and intraspecific seedling competition (Izhaki & Safriel 1990).

The spatial distribution of pellets is important to ensure seeds are potentially deposited in suitable sites. In this study, pellet density was higher than expected in open areas and lower than expected under canopy or on boulder-dominated areas. *Mimosa luisana* can act as a pioneer species (Badano *et al*. 2009) and it is common in abandoned fields (Camargo-Ricalde *et al*. 2002). Since abandoned fields are used as pasture by local shepherds (pers. obs.), goats may facilitate its migration from the mother plant to open areas. The functional importance of goats is enhanced by the fact that wild large herbivores, notably the native deer, *Odoicoleucus virginianus*, are essentially extinct from this area (Dávila *et al.* 2002).

Although only one seed was found in the pellets collected in the wild, it is important to note that this survey covered only 200 m^2. Assuming a constant seed rain estimate of 1 seed per 200 m^2, this would determine a deposition of 5000 seeds km^{-2}, which could increase in years with little bruchid infestation. Considering that goats graze over an area of hundreds of km^2, the total quantity of seeds they are able to deposit may, therefore, be important. Studies on long-distance dispersal have stressed that even a very small amount of seed present in the faeces can be of great significance for vegetation dynamics and population genetic structure and rare long-distance dispersal seems to be crucial for invasion dynamics and vegetation response to changes in land use (Myers *et al*. 2004). In addition, low seedling density allows seeds to escape from high competition environments and can be an advantage for seed and seedling survival from predators (Wang & Smith 2002).

In the study area, goats are released from corrals on a regular basis (pers. obs.). Seeds excreted 24 h after ingestion were more likely to be deposited outside the corral, while those excreted before 16 h or after 32 h were more likely to be deposited inside the corral. Similarly to Baraza & Fernández-Osores (2013), we found that more than half of the seeds (67%) were excreted between 8 and 32 h after ingestion and the curve peaked 24 h after ingestion, increasing the probability of seeds to be dispersed in favourable habitats.

We conclude that goats may function as legitimate and efficient dispersers of *M. luisana* seeds and facilitate re-colonization in abandoned agricultural fields and in degraded areas.

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LITERATURE CITED

BADANO, E. I., PÉREZ, D. & VERGARA, C. H. 2009. Love of nurse plant is not enough for restoring oak forests in a seasonally dry tropical environment. *Restoration Ecology* 17:571–576.

BARAZA, E. & FERNÁNDEZ-OSORES, S. 2013. The role of domestic goats in the conservation of four endangered species of cactus: between dispersers and predators. *Applied Vegetation Science* 16:561–570.

BARAZA, E. & VALIENTE-BANUET, A. 2008. Seed dispersal by domestic goats in a semiarid thorn shrub of Mexico. *Journal of Arid Environments* 72:1973–1976.

CAMARGO-RICALDE, S. L., DHILLON, S. S. & GRETHER, R. 2002. Community structure of endemic *Mimosa* species and environmental heterogeneity in a semi-arid Mexican valley. *Journal of Vegetation Science* 13:697–704.

CAMARGO-RICALDE, S. L., DHILLION, S. S. & GARCÍA-GARCÍA, V. 2004. Phenology, seed production and germination of seven *Mimosa* species (Fabaceae-Mimosoideae) from the Tehuacán-Cuicatlán Valley, Mexico. *Journal of Arid Environments* 58:423–437.

CAMARGO-RICALDE, S. L., REYES-JARAMILLO, I. & MONTAÑO, N. M. 2010. Forestry insularity effect of four *Mimosa* L. species (Leguminosae-Mimosoideae) on soil nutrients in a Mexican semiarid ecosystem. *Agroforestry Systems* 80:385–397.

DÁVILA, P., ARIZMENDI, M., VALIENTE-BANUET, A., VILLASEÑOR, J. L., CASAS, A. & LIRA, R. 2002. Biological diversity in the Tehuacán-Cuicatlán Valley, México. *Biodiversity and Conservation* 11:421–442.

GRANDE, D., MANCILLA-LEYTÓN, J. M., DELGADO-PERTIÑEZ, M. & MARTÍN-VICENTE, A. 2013. Endozoochorous seed dispersal by goats: recovery, germinability and emergence of five Mediterranean shrub species. *Spanish Journal of Agricultural Research* 11:347–355.

HERRERA, C. M. 1989. Frugivory and seed dispersal by carnivorous mammals and associated fruit characteristics in undisturbed Mediterranean habitats. *Oikos* 55:250–262.

IZHAKI, I. & SAFRIEL, U. N. 1990. The effect of some Mediterranean scrubland frugivores upon germination patterns. *Journal of Ecology* 78:56–65.

MANCILLA-LEYTÓN, J. M., FERNANDÉZ-ALÉS, R. & MARTÍN VICENTE, A. 2011. Plant–ungulate interaction: goat gut passage effect on survival and germination of Mediterranean shrub seeds. *Journal of Vegetation Science* 22:1031–1037.

MARTÍNEZ-BERNAL, A. & GRETHER, R. 2006. Mimosa. Pp. 1–108 in Novelo, A. & Medina-Lemus, R. (eds.). *Flora del Valle de Tehuacán-Cuicatlán*. Fascículo 44. Instituto de Biología, Universidad Nacional Autónoma de México, Mexico City.

MCNAIR, J., SUNKARA, A. & FORBISH, D. 2012. How to analyse seed germination data using statistical time-to-event analysis: non-parametric and semi-parametric methods. *Seed Science Research* 22:77–95.

MYERS, J. A., VELLEND, M., GARDESCU, S. & MARKS, P. L. 2004. Seed dispersal by white-tailed deer: implications for long-distance dispersal, invasion, and migration of plants in eastern North America. *Oecologia* 139:35–44.

NEU, C. W., BYERS, C. R. & PEEK, J. M. 1974. A technique for analysis of utilization-availability data. *Journal of Wildlife Management* 38:541–545.

OR, K. & WARD, D. 2003. Three way interaction between *Acacia*, large mammalian herbivore and bruchid beetles. *African Journal of Ecology* 41:257–265.

REID, N. 1989. Dispersal of mistletoes by honeyeaters and flowerpeckers: component of seeds dispersal quality. *Ecology* 70:135–137.

RZEDOWSKI, J. 1978. *Vegetación de México*. Limusa, Mexico City. 432 pp.

SÁNCHEZ DE LA VEGA, G. & GODÍNEZ-ÁLVAREZ, H. 2010. Effect of gut passage and dung on seed germination and seedling growth: donkeys and a multipurpose mesquite from a Mexican inter-tropical desert. *Journal of Arid Environment* 74:521–524.

SCHUPP, E. W. 1993. Quality, quantity and effectiveness of seed dispersal by animals. *Vegetatio* 107/108:15–29.

WANG, B. C. & SMITH, T. B. 2002. Closing the seed dispersal loop. *Trends in Ecology & Evolution* 8:379–385.