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A new device to autonomously feed individualized mantids on extended periods of time

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ABSTRACT

Mantises can live for many months, are naturally voracious, and feed invariably on live prey. Many species have a propensity for cannibalism and cannot be kept together for most of their life cycle, which makes large-scale rearing typically time-consuming, thus easily becoming prohibitive. This is particularly true for early instars, because they are the most abundant stage of a developmental cohort. Such limitation hinders research on Mantodea which depend on live individuals, such as behavior, physiology, ontogeny, and others. In this work, a simple, low-maintenance "self-service" device is described, which is greatly effective in reducing the time needed for keeping live, individual, small to medium-sized mantises. Trial and error usage and modifications along eight years lead to many improvements, resulting in a nearly optimal device for its target purpose. The final model allows rearing large numbers of mantises while demanding only a fraction of the time demanded by conventional rearing techniques. Key advantages include prevention of cannibalism, the possibility of monitoring mantises individually, and full functioning autonomy of up to several weeks. The new device has ample potential in stimulating and supporting Mantodea research on diverse areas.

Introduction

Rearing individuals is a common practice in Mantodea research. It is vital for studies on ethology (e.g., Balderrama and Maldonado, 1973; Prete et al., 1992; Maxwell, 1998; Hurd et al., 2004; Holwell, 2008), physiology (e.g., Yager, 2005; Prete et al., 2013; Schirmer et al., 2014; Nityananda et al., 2016; Oufiero et al., 2016; Sutton et al., 2016), ontogeny (e.g., Heitzmann, 1960; Terra, 1980; Yager, 1996; Avendaño and Sarmiento, 2011), bionomy (e.g., Travassos Filho and Heitzmann, 1960; Urban, 1964; Matsura et al., 1984; Kaltenpoth, 2005; Ariza, 2011; Maxwell, 2014; Raut and Gaikwad, 2016), or even systematics (e.g., Rivera and Svenson, 2016).

The traditional, standard rearing method was first proposed by Travassos Filho (1945) and improved by Travassos Filho and Heitzmann (1960) but was apparently independently developed by Robinson and Robinson (1978) into the model now widely adopted. It consists in isolating each individual in a disposable plastic recipient, to avoid cannibalism. Gravels or plastic nets are provided as a perch during ecdysis. The lid is partially or completely replaced with fabric to allow for gas exchanges while avoiding prey, nymphs or adults to escape. If humidity is low, water sprays or wet cotton balls must be used. Since mantises do not eat dead specimens, each container must be opened every two or three days to be provisioned with live prey, which must be captured, reared, or purchased from specialized providers. The most used prey is the common fruit fly (*Drosophila* Fallén, 1832), crickets, cockroaches, moths, and butterflies. Mantid hatchlings can be kept collectively in the same container but must be individualized after the first or second ecdysis.

Several adaptations have been informally proposed (e.g., among praying mantis' enthusiasts) to help this general rearing method to become more agile or practical. It is reasonably popular, for example, the use of brachypterous drosophila flies, which minimizes losses when providing specimens to the mantises. It is also common the use of a hole in the container, closed with a piece of foam, to facilitate the process of inserting new prey. An alternative setup was formally proposed by Fye and Carranza (1979) to simplify the process of prey delivery for a large number of rearing cages at the same time. Even so, the available procedures are still time-consuming, discouraging or preventing rearing of large number of mantises (Rivera, 2010).

Prete and Mahaffey (1993) proposed a 51.0 cm × 41.0 cm × 22.0 cm polycarbonate and Lucite chamber for mass hatching and early rearing of mantises. It is sealed once eggs are introduced.

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An aquarium pump forces fresh air through a water bottle within the chamber. The introduction of prey, prey food, and water occur through holes that are plugged with foam rubber. *Drosophila* and, for later stages, crickets, are provided as prey, and kept alive inside the chamber with commercial *Drosophila* food or slices of vegetables. Many mantises can be reared together this way but must be removed and isolated after the fifth or sixth instar. Prete and Mahaffey's device was an important improvement, but rearing mantises in a single chamber makes it difficult or impossible to uniquely identify each individual, a drawback for many studies. For example, individual variations in the number and duration of instars would not be easily assessed. Temporary removal of individuals, e.g. for measurements or photos, would also be almost unattainable. Furthermore, cannibalism remains an issue, even if abundant prey items are provided (Prete et al., 1999).

The present work was completed without the knowledge that Suckling (1984) fed nymphs of *Orthodera ministralis* (Fabricius, 1775) (Mantidae) in "cellophane-covered Dixie cups (size 104w) with perforated bottoms, mounted into the top of a cardboard box", inside of which "bottles of emerging *Drosophila melanogaster* were placed". This matches the main idea proposed herein, but Suckling provides no further details about it.

This work started purely out of necessity, namely, to get fair numbers of ecdyses of all developmental instars of a host of Mantodea species. None of the known devices at the time proved viable for the task. After several trials, the end result showed clear potential for generalized use, justifying the chief aim of this work: to describe a new, low-maintenance, semi-automatic device to simultaneously feed considerable numbers of small to medium-sized, individualized Mantodea, from juveniles into adults.

Material and methods

Material and tools

The following quantities and material is necessary to build the Model A of the autofeeder (Fig. 1); dimensions are abbreviated as *H* (height), *W* (width), *L* (length), and dia (diameter): 24 disposable, translucid plastic cups (145 ml, 7.5 cm dia, H 5.0 cm), with lid; one piece of rectangular polyvinyl chloride (PVC) pipe (HWL 6.54 cm × 10.0 cm × 100.0 cm); two translucent plastic sheets (LW 10.0 cm × 6.54 cm), cut from regular plastic folders found in general office stores; 12 square, 3.5 cm pieces of Tulle fabric of mesh size 0.3 mm; 12 round, 5.0 cm dia pieces of Tulle fabric of mesh size 2.0 mm; one 75 g tube of plastic adhesive for PVC; three glue sticks (thermoplastic adhesive). The following tools were used: knife for paper; glue gun; electric drill and hole saw of 4.0 cm dia and 6.0 cm dia. For Model B, 36 plastic cups are needed, along with 24 cm × 3.5 cm and 5.0 cm pieces of Tulle.

Assembling

An assembling schema is presented in Fig. 2 (Model A). There are three main compartments which must be interconnected and communicating: (1) A central circulation chamber for the prey, composed by the rectangular PVC pipe (Fig. 2, CII); (2) the attached rearing cups for the prey, connected to the central chamber from below (Fig. 2, CIII); and (3) the attached rearing cups for the mantises, connected to the central chamber from above (Fig. 2, CI). The rearing cups for the prey open freely into the central chamber; the bottom of the rearing cups for the mantises are also open into the central chamber, but separated from it by a 5.0 cm piece of Tulle fabric of 2.0 mm mesh size, which is just narrow enough to avoid young mantises to escape into the central chamber, but large enough to allow small prey items to enter.

The first step is to drill the connecting holes (Figs. 1, 2, numbers 1 and 2) on the rectangular PVC pipe (Figs. 1, 2, piece **e**). Twelve holes need to be made on one of the 10.0 cm sides, using the hole saw of 4.0 cm dia, and another 12 holes are made on the opposite side with the 6.0 cm dia hole saw. The openings of both sides must be vertically aligned, and horizontally equidistant from one another by 8.2 cm from their center (Figs. 1, 2, numbers 1 and 2). The lids of the bottom (prey) cups are then cut with the knife to open a 6.0 cm dia hole on the center (Figs. 1, 2, number 3). Each lid is then fixed with PVC adhesive, and sealed with thermoplastic adhesive, aligned to one of the 6.0 cm dia holes on the PVC pipe. The bottom cups are filled with about 30 ml of a food mix for *Drosophila* and snapped into place by pressing against their respective lids, now fixed on the PVC pipe. A 4.0 cm circular hole is next cut on the bottom of the 12 top cups (mantises' cups). Each of the 5.0 cm pieces of Tulle fabric of mesh size 2.0 mm are then positioned over one of the 4.0 cm dia holes on the PVC pipe; each cup is then aligned by its hole with the equivalent holes on the PVC pipe, over the Tule, and the whole set is glued in place with PVC adhesive and sealed with the thermoplastic adhesive. A 2.0 cm square hole is then cut on the center of the 12 remaining lids. The holes must be fully covered with the 3.5 cm pieces of 0.3 mm mesh Tulle, glued externally. These lids will close the mantises' cups. The open ends of the PVC pipe are sealed by the 10.0 cm × 6.54 cm plastic sheets.

In such configuration, the autofeeder can keep up to 12 individualized mantises simultaneously. Each specimen can be easily labeled or annotated by attaching an external tag to the cups. It is important to note that the hole on the lids of the top cups are the only ventilation openings of the system. The objective of the fine mesh here is twofold; firstly, it prevents that both young mantises and small prey escape, and then it also works as a foothold for the mantids to hang during ecdysis. The clear plastic sheets on the sides of the PVC pipe make it easy to inspect this area, e.g., when checking for population density of prey in the course of lengthened usage.

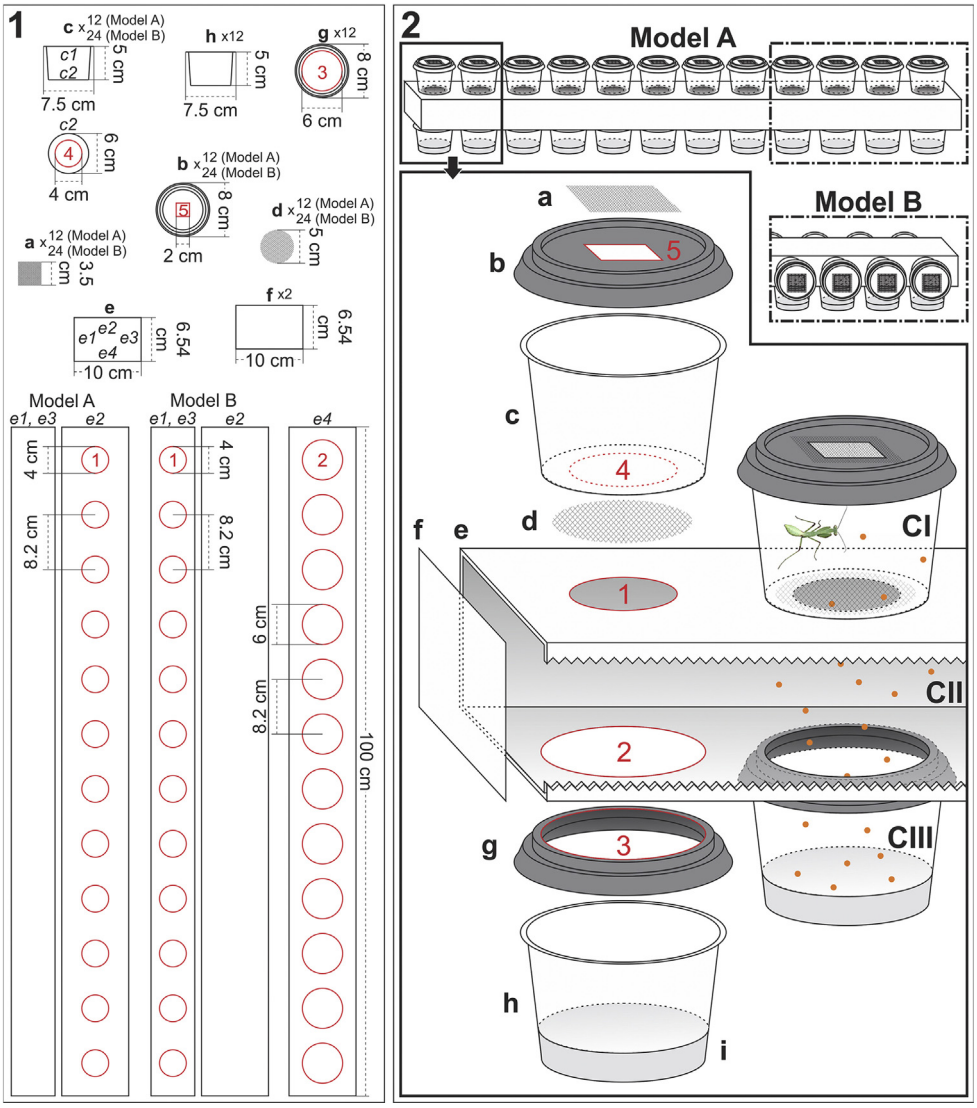
An expanded autofeeder model, with 24 mantises' cups, 12 on each of the 6.54 cm sides of the PVC pipe, was also built and tested (Fig. 2, Model B). Differences in the operation between the two models were registered and discussed.

Experiments were conducted in a tropical area (21–29 °C average monthly temperature, 70–83% relative humidity), so there was no need to regulate humidity. If humidity is an issue, the solution by Prete and Mahaffey (1993) could be used but was not tested here.

Operation

Before any praying mantis can be transferred into an autofeeder, a *Drosophila* culture must be established on the prey cups. At this stage, the bottom of the mantises' cups must be covered with a 5.8 cm dia cardboard disk, to avoid the entrance of *Drosophila* specimens. The flies can be captured with the same 145 ml cups, and then immobilized with 8 s in a freezer. The same cups are then attached to the bottom of the autofeeder; once the flies reanimate, they will fly into the central chamber, and the capture cup can be replaced with a cup with the culture medium. Some 10–20 flies take about two and a half weeks to colonize all cups, generating enough specimens to autonomously maintain 12 praying mantises for several weeks.

The culture medium for the flies can be pure ripe banana puree, but a more efficient formula is achieved by enriching it with cornmeal – one teaspoon for each medium-size banana (about 100 g) makes one portion. The mix was protected with a quarter teaspoon of the fungicide methylparaben (Nipagin®) per portion. Commercial or other formulas were not tested. Labeling the prey cups with the date of production of the culture medium was quite useful in monitoring the quality of the medium.



Figs. 1 and 2. Building schemes for the autofeeders. **1**. Used material, measurements and quantities. **2**. Assembling. Bottom panel corresponds to an exploded view drawing of the Model A, with mantises' cups on the top. The top right detail is for Model B, with mantises' cups installed laterally, thus holding twice as many cups. CI, first compartment, the rearing chamber, showing a 4th instar, 2.0 cm long *Photina* sp. (to scale); CII, central or circulation compartment; CIII, third compartment, the prey cup; a, square piece of Tulle fabric with mesh size of 0.3 mm; b, Lid with a square hole (5) in the center; c, translucent mantis cup, with circular hole (4) on the bottom; d, circular piece of Tulle fabric with mesh size of 2.0 mm; e, rectangular PVC pipe with circular holes on the top side (1) and bottom side (2) [serrations on the side is only an effect to show inside the pipe, and is not meant to be carved on pipe!]; f, translucent plastic sheet; g, lid with circular hole (3) on center; h, translucent prey cup; i, culture medium for *Drosophila* Fallén, 1832. The connections between components a+ b, c+ d+ e, e+ f and e+ g are fixed with PVC adhesive and sealed with thermoplastic adhesive (glue gun). The small orange dots represent drosophila flies, indicating that they must circulate freely between CI, CII and CIII.

Mantises were captured in the wild or reared from the egg cases produced by the captured or reared specimens. Each specimen was placed in a single cup, from which the protecting cardboard disk was removed moments before, allowing the flies to enter. Actual autofeeders and some details of its operation are pictured in Fig. 3.

Results and discussion

The autofeeders were operated for over eight years, supporting the development of various projects. The number of autofeeders being operated simultaneously varied from 1 to 5, according to necessity. A total of 381 specimens were reared: 4 *Acanthops falcataria* (Goeze, 1778), 45 *Acontista* sp., 4 *Bantia* sp., 73 *Cardioptera brachyptera* Burmeister, 1838, 2 *Eumusonia* sp., 40 *Miobantia aptera* Giglio-Tos, 1917, 85 *Miobantia fuscata* (Giglio-Tos, 1915), 64 *Fuga fluminensis* (Piza, 1965), 4 *Hicetia* sp., 1 *Parastagmatoptera* sp., 6 *Photina* sp., 25 *Pseudovates* sp., and 28 *Thesprotia* sp. As expected, the flies circulated and mated freely in the PVC chamber and in the prey cups. The amount of light projected inside the PVC chamber from the bottom opening of the mantises' cups was also just enough to regularly attract some, but not all flies. Once in the mantises' cup, the flies rarely returned to the PVC chamber, because it is much darker and because they try to escape flying upwards. The number of flies captured by the mantises was generally efficiently counterbalanced by the continuous production of new flies in the prey cups.

Each prey cup lasted for up two months efficiently producing adult flies. Once the culture medium was consumed, some of the prey cups were replaced by new ones, with fresh, uncolonized culture medium. Not more than two cups could be replaced per week. Such precaution is important because even though new cups are almost immediately colonized, the eggs they receive took time to

Fig. 3. Model B autofeeder in operation. (A) Overall view; empty rearing chambers have a cardboard disk blocking the entrance of flies. (B) Four 4th and 5th instar *M. aptera* Giglio-Tos, 1917 in the rearing cups along with some *Drosophila* Fallén, 1832 flies. (C) Front view of one end of the equipment, showing the prey cup with culture medium, and *Drosophila* larvae and flies; note central compartment with prey freely circulating, and the rearing cup with a 4th instar *M. aptera* hanging in the Tulle fabric. (D) Rearing cup seen through its cover lid, with a 4th instar *M. aptera* and some prey. (E) Side view of the rearing cup, with a 5th instar *M. aptera* feeding on a freshly caught *Drosophila* fly.

develop and produce the first batch of adults. In the meantime, the population density of flies is safely maintained by the cyclic production of adults in the remaining cups.

Adjusting for prey availability

Even in spite of regular replacements of food in the prey cups, the population density of flies sometimes became quite low. Such episodes were more frequent when the autofeeders were used in their maximum capacity, housing large individuals, and for extended periods of time. The adopted solution was to have a number of extra autofeeders in operation. When the number of flies became low in one autofeeder, some of its mantises were transferred to a vacant autofeeder and maintained there until the original fly population was reestablished. An equivalent strategy was employed for autofeeders with high densities of flies, that is, these devices would receive more mantis specimens. Such management was more effective with the Model B autofeeder, since the higher number of mantises it can hold allows for a finer tuning. On both models, the need for managing mantises between devices was easily assessed by checking the number of flies inside the mantises' cups. Moreover, changing mantises between autofeeders creates the opportunity to remove feces and prey debris from the chambers. Once this dynamic was observed, problems with shortage or excess of flies were consistently avoided. Typically, however, the autofeeders run autonomously for several weeks, without any intervention.

Models

Generally, Models A and B were similarly efficient for semi-autonomous and simultaneous rearing of mantises. The used material, sizes and proportions were adjusted empirically through the years, and can be safely changed according to necessity (e.g., larger cups or chambers, different materials), provided that the three intercommunicating chambers (Fig. 2, CI, CII, CIII) are maintained.

Model A, with the mantises' cups on the top, accumulates less feces and prey debris, because the remains pass through the mesh on the bottom and fell in the prey cups. Accumulation of debris in

the prey cups was negligible and did not produce any noticeable effect on growth and reproduction of the flies. In Model B, however, the remains quickly accumulate on the lateral wall of the cup, requiring them to be cleaned more often than cups of Model A.

Regardless of the model, the number of flies in the central compartment, and therefore in the mantises' cups, was proportional to the number of rearing chambers in use. Model A is however prone to accumulation of live flies if their availability is not monitored. The flies always seek to escape flying toward light, and upwards, and therefore will not get back to the dark circulation chamber below. In such cases, the cup had to be slightly opened and the flies released. The excessive number of flies can distress the mantises, particularly small nymphs, and all stages of development of *F. fluminensis*. It also can spread microorganisms, which colonize the walls of the cup, requiring them to be cleaned with cotton soaked in 92.8% ethanol. In Model B, mantises' cups are less likely to accumulate flies, because they can easily return to the circulation chamber, which is positioned laterally.

Rearing success

The autofeeder was developed, and used, exclusively as a solution for one specific problem (see Introduction). The results on rearing success provided below are, therefore, available only for the specific cases where the device was used. It is not the aim of this work to present a full-blown test on the overall efficiency of the autofeeder. The provided data, however, offers an informative report of 8 years of annotated results and observations.

Specimens of *Acontista* sp. were reared from hatching up to the end of adult life in the autofeeder (maximum body length ~20 mm). Nymphs of *A. falcataria*, *C. brachyptera*, *Hicetia* sp., *Parastagmatoptera* sp., *Photina* sp., *Pseudovates* sp., and *Thesprotia* sp. were efficiently reared up to the last or penultimate instar (~35 mm). At this point the available space was inadequate for a normal ecdysis, and the specimens had to be transferred to larger containers under the traditional rearing method. Even so, adults of *Hicetia* sp., *Photina* sp., and *Thesprotia* sp. were successfully returned and reared in the autofeeders after ecdysis (~65 mm). Adults of *Bantia* sp. and *Eumusonia* sp. were also efficiently reared (~43 mm).

Specimens of first instar of *Miobantia* spp. would not take *D. melanogaster*. This might be related to their small size, near 2.5 mm (Scherrer, 2014), not much larger than the flies. Yager (1999) reported the same rejection by very small first instar nymphs of some Amelinae, Oligonicinae, and Thespinae. The only available solution is to rear the first instars of these taxa in chambers containing established cultures of Collembola, as proposed by Urban and Travassos Filho (1954). Second stage nymphs of *Miobantia* spp. were successfully reared in the autofeeders until the adult stage.

Specimens of *F. fluminensis* lived the least in the autofeeder. Seventeen of the nymphs collected on the field lived long enough to undergo one or a few ecdyses. One of these nymphs completed six ecdyses and reached adulthood. Other collected nymphs, all the nymphs hatched on laboratory, and all the adults lasted only a few days. This however does not seem to be an inherent limitation of the device, since reduced longevity was also the outcome when we tried to keep *F. fluminensis* using the traditional method. This might simply mean that *F. fluminensis* is difficult to rear. Indeed, they are, most of the time, notoriously agitated in the containers, a behavior which does not correspond to what is observed in natural condition.

Adults of *A. falcataria*, *C. brachyptera* and *Parastagmatoptera* sp. (body length ~40–50 mm) are not adequately fed with *D. melanogaster* and therefore could not be maintained in the autofeeders as designed. Adults of *Pseudovates* sp. (body length ~70 mm) also could not be maintained in it due to space limitations of the rearing chambers. This should obviously also be the case for adults or late instars of other similar or larger sized mantises (e.g., *Stagmatoptera* Saussure, 1871, *Macromantis* Saussure, 1871, and *Angela* Serville, 1839). This was however a planned limitation, in favor of saving space and because of the focus on rearing juveniles. This is relevant because, in Mantodea, it is the early stages of development which are often numerous, and therefore difficult to rear one by one. Adults are much less of a problem in what regards maintenance for scientific purposes.

Adapting the autofeeders for large individuals would be relatively easy, e.g., by replacing one or more of the original cups with larger ones. For large specimens, however, larger food items would also be required. Supplying the prey cups with cultures of the common house fly, or any of the moth species which infest stored grains (Pyralidae), along with a larger mesh size Tulle, could be a viable alternative, but this was not tested.

The use of the device for rearing animals other than praying mantises was not tested, but it clearly has potential for rearing other predatory arthropods such as spiders, earwigs, some beetles, bugs, lacewings, and others.

Advantages

Table I summarizes the main differences between the traditional rearing method, the Prete and Mahaffey's mass hatching chamber, and the new device. Building an autofeeder consumes clearly more time than assembling a traditional cage. However, this is quickly paid-off by the fact that the demanding, highly repetitive and time-consuming procedure of transferring food items into individual rearing chambers is fully avoided with the autofeeder. The more mantises reared simultaneously, and the longer the colonies last, the more time-rewarding the use of the autofeeder will be. If freedom to do other things is an issue, the autofeeder might still be the best choice, even if a single mantis is to be reared.

By definition, an autonomous feeding mechanism does not allow precise control over how many prey items the mantises will take. Unless rigorous control of the diet of each mantis is required, such monitoring can be performed, for example, by observing the degree of abdominal swelling of the specimens (usually quite conspicuous in Mantodea), or by observing how much prey is left in the central chamber.

The mass-hatching chamber proposed by Prete and Mahaffey (1993), as well as other methods of rearing mantises communally (Prete et al., 1999), will, generally, generate similar results. The key advantages of the new device, however, lay on the fact that it is designed for mass-rearing of individualized mantids, preventing predation/cannibalism, and allowing for safe and simultaneous rearing of different or incompatible species. Tagging is also easy, promoting the precise follow-up of each individual.

Final comments

The described device is not intended as a substitute for previous methods. Instead, it presents a unique, and finely tuned set of features that makes it a potentially advantageous alternative for mass-rearing of individualized mantises. The specimens can be left fully unattended for extended periods of time, freeing the researcher for other activities. It has a solid potential for supporting Mantodea research on areas such as behavior, physiology, ontogeny, biological cycles, immature stages, taxonomy, and any other investigation which depend on rearing or maintaining live Mantodea individuals, especially during its early stages of development.

Table I
Differences between the new device, the mass hatching chamber (Prete and Mahaffey, 1993), and the traditional rearing method (e.g., Robinson and Robinson, 1978). Typical autonomy and typical setup time data are for rearing 12 mantises.

Method	Typical autonomy	Typical setup time	Prey consumption monitoring	Cannibalism prevention	Individual monitoring
Autofeeder	1–3 weeks	4–5 h	Subjective	Total	Possible
Mass-hatching chamber	Weeks[a]	Hours[a]	Subjective	Partial	Impossible
Traditional	2–4 days	<30 min	Objective	Total	Possible

[a] No precise data available in the literature.

Conflicts of interest

The authors declare no conflicts of interest.

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