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1 The potential of mass rearing of *Monoska dorsiplana* (Pteromalidae) a native
2 gregarious ectoparasitoid of *Pseudopachymeria spinipes* (Bruchidae) in South
3 America.

4
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26 **Abstract**

27 In Chile and Uruguay, the gregarious Pteromalidae (*Monoska dorsiplana*) has been
28 discovered emerging from seeds of the persistent pods of *Acacia caven* attacked by the
29 univoltin bruchid *Pseudopachymeria spinipes*. We investigated the potential for mass rearing
30 of this gregarious ectoparasitoid on an alternative bruchid host, *Callosobruchus maculatus*, to
31 use it against the bruchidae of native and cultured species of Leguminosea seeds in South
32 America.

33 The mass rearing of *M. dorsiplana* was carried out in a population cage where the density
34 of egg-laying females per infested seed was increased from 1:1 on the first day to 5:1 on the
35 last (fifth) day. Under these experimental conditions egg-clutch size per host increased, and at
36 the same time the mortality of eggs laid also increased. The density of egg-laying females
37 influenced the sex ratio which tended towards a balance of sons and daughters, in contrast to
38 the sex ratio of a single egg-laying female per host (1 son to 7 daughters). The mean weight of
39 adults emerging from a parasitized host was negatively correlated with the egg-clutch size, i.e.
40 as egg-clutch size increased, adult weight decreased.

41 All these results show that mass rearing of the gregarious ectoparasitoid *M. dorsiplana* was
42 possible under laboratory conditions on an alternative bruchid host *C. maculatus*. As *M.*
43 *dorsiplana* is a natural enemy of larval and pupal stages of bruchidae, the next step was to
44 investigate whether the biological control of bruchid *C. maculatus* was possible in an
45 experimental structure of stored beans.

46

47 **Key words.** Gregarious parasitoid, egg-clutch size, theoretical offspring, observed
48 offspring, sex ratio, bruchid host, *Callosobruchus maculatus*

49

50

51 **1. Introduction**

52

53 Bruchids constitute the largest single problem for native and cultured species of
54 Leguminosea seeds in Latin America, attacking a number of economically important plant
55 species. The common bean weevil *Acanthoscelides obtectus* (Say) and the Mexican bean
56 weevil *Zabrotes subfasciatus* (Boh) are the main post-harvest pests of dry beans and currently
57 constitute a major problem in the management of bean stocks in storage sites (Schmale *et al.*,
58 2001; Alvarez *et al.*, 2005). In the last 30 years, these two bruchid species have also been
59 recorded on new host plant species, such as *Cajanus indicus*, *Pisum sativum*, *Vicia faba*, and
60 *Vigna unguiculata* (Jarry and Bonet, 1982; Johnson, 1983, 1990). This expansion of host
61 range requires new integrated pest management strategies based on natural resources,
62 including parasitoids. In South America, as in traditional storage systems in the African
63 tropical belt, the parasitoid *Dinarmus basalis* (Ashm.) is currently the main candidate for the
64 biological control of bruchids in stored beans (Schmale *et al.*, 2001; Sanon *et al.*, 1998; Dorn
65 *et al.*, 2005).

66 The challenge now is to find one or more appropriate biological control agents which are
67 native to Latin America. Two native Trichogrammatidae have recently been found as
68 oophagous parasitoids of bruchid beetle eggs: *Uscana chiliensis* (Pintureau and Gering) on
69 *Bruchus pisorum*, and *Uscana espiniae* (Pintureau and Gering) on *Pseudopachymeria spinipes*
70 (Er.), (Pintureau *et al.*, 1999). In addition, one Pteromalidae (*Monoska dorsiplana*, Boucek)
71 and two Eulophidae (*Horismenus spp.*) have been found emerging from seeds of the persistent
72 pods of *Acacia caven* (Mol.) contaminated by the univoltin bruchid *P. spinipes* (Rojas-Rousse,
73 2006). These persistent pods provide a natural reserve of parasitoids which are a potential
74 resource for the biological control of Bruchidae. Previous investigations have shown that
75 *Dinarmus vagabundus* and *Dinarmus basalis* (Pteromalidae), parasitoids of larval and pupal

76 stages of bruchids, can be mass-reared on a substitution bruchid host, *Callosobruchus*
77 *maculatus* (Rojas-Rousse *et al.*, 1983; Rojas-Rousse *et al.*, 1988). Some life history traits of
78 *M. dorsiplana* have been investigated under laboratory conditions using the substitution
79 bruchid host *Callosobruchus maculatus*, and it was observed that with a low density of *M.*
80 *dorsiplana* females per host, i.e. 1:1, the female laid one clutch of eggs during one oviposition,
81 the parasitoid larvae developed gregariously, and the most common patriline was 1 male and
82 7 females (Rojas-Rousse, 2006).

83 The aim of the present study was to test how egg-clutch size changed in a population
84 cage when the density of females per host was increased from 1:1 to 5:1 over 5 consecutive
85 days. Under these controlled conditions, mass production of *M. dorsiplana* on the alternative
86 host *C. maculatus* could be investigated. The egg and offspring clutch sizes were compared
87 and the trade-off between egg and offspring clutch sizes was studied through experimental
88 manipulation of the egg-clutch size.

89

90 **2. Materials and Methods**

91

92 *2.1. Biological material.*

93

94 Host and parasitoid strains were mass-reared in a climatic chamber under conditions
95 close to those of their zone of origin, with synchronous photo and thermo-periods: 30° / 20°C,
96 12h / 12h L:D, and 70% RH.

97 The bruchid host *C. maculatus* was mass reared in the laboratory on *Vigna radiata* (L.)
98 Wilszek seeds. After egg-laying, the bruchid females were removed and the seeds stored until
99 the larvae inside the seed reached the final larval or pupal stage.

100 Host size, determined by its developmental stage, is one of the main factors contributing
101 to variations in egg-clutch size, and therefore only the largest *C. maculatus* hosts were

102 presented to the egg-laying *M. dorsiplana* females (Terrasse *et al.*, 1996; Pexton and Mayhew,
103 2002; Pexton and Mayhew, 2005). For this, the seeds were examined under a microscope lens
104 and only seeds with 1 to 3 hosts, i.e. the fourth-instar larvae, prepupae and pupae, were
105 offered to the parasitoid females. Because *C.maculatus* larvae were not directly accessible to
106 parasitoids, the female parasitoid generally introduced her ovipositor through the hole drilled
107 by the neonatal host larvae (van Alebeek *et al.*, 1993). The parasitoid females located these
108 holes from the egg shells remaining on the seed tegument (personal observations).

109

110 2.2. Parasitization of the substitution bruchid host *C. maculatus* in a population cage.

111

112 The experiments were conducted in a special ‘altuglass’ population-rearing cage
113 (40x30x25 cm) simulating a ventilated storage structure. In this cage, 120 *V. radiata* seeds
114 with one, two or three hosts were introduced every day with 120 newly mated *M. dorsiplana*
115 females (mating occurred immediately after emergence of females). The bruchid-infested
116 seeds were exposed for 24h to the parasitoids and renewed daily on 5 consecutive days, unlike
117 parasitoid females which were not removed. In this way, theoretically the density of females
118 per seed increased from 1:1 on the first day (120 females for 120 infested seeds) to 5:1 on the
119 last (fifth) day (120x5 females for 120 infested seeds). The seeds removed every day were
120 divided into two sets, one with 40 and the other with 80 seeds. All the seeds in the first set
121 were opened to investigate the parasitism of each host, and the second set was used as a
122 control.

123

124 2.3. Analysis of egg-clutch size, theoretical offspring, and relative mortality

125

126 The data recorded for each opened seed included the number and developmental stage
127 of hosts, whether the host was parasitized or not, and if so, the egg-clutch size. Each
128 parasitized host was incubated individually in a small plastic tube (30° / 20°C, 12h / 12h L:D,
129 and 70% RH) to identify the developmental stage of the parasitoids, the weight of each
130 parasitoid pupa before the moult, and the number and sex of the emerging adults.

131

132 *2.4. Observed offspring*

133

134 All the seeds of the control set were incubated individually in a small plastic tube (30° /
135 20°C, 12h / 12h L:D, and 70% RH). This control set was used to determine the number and
136 sex of parasitoid adults emerging from each parasitized seed without experimental
137 manipulation.

138

139 *2.5. Data analysis*

140

141 For each set of seeds, the various parameters were analysed for the 5 days of activity of
142 the parasitoid females. Seeds with one or two parasitical hosts were analysed separately.
143 These two sets were compared with regard to the distribution of egg-clutch sizes, the
144 offspring observed per parasitized host, the development time of each sex and the dry weights
145 of emerging male and female parasitoids. An ANOVA was performed (XLStats 6 for
146 Windows) to assess the intra- and inter-variability of the sets. If the variances were
147 statistically different, the Student-t test was performed. The Chi-square test was used to
148 evaluate the of distribution of egg-clutch sizes between the hosts in the seeds. The influence
149 of egg-clutch size on the parasitoid adult weight was tested by a simple linear regression
150 (XLStats 6 for Windows).

151

152 **3. Results**

153

154 *3.1 Parasitized hosts*

155

156 In the 200 opened seeds (40 seeds per day for 5 days), there were 323 hosts. Of these
157 seeds, 45.5% (91/200) contained one host, 47.5% (95/200) two hosts, and 7% (14/200) three
158 hosts. Only 67% of the hosts (216/323) were actually parasitized, i.e. contained egg clutches
159 (Table 1). The seeds with a single parasitological host per seed were 100% attacked (Table 1).
160 Those with two hosts were attacked less, with 59.47% of hosts parasitized (113/190), and
161 when there were three hosts, only 28.57% of the hosts (12/42) were parasitized (Table 1).

162 Because 3 hosts per seed were rarely observed, our analysis was restricted to a
163 comparison of seeds enclosing one and two hosts. The percentage of parasitized hosts was
164 significantly greater among seeds enclosing only one host (t-test for percentage comparison t
165 = 6.95; at the level of significance $\alpha = 0.05$ $t_{[.05]} \infty = 1.96$).

166

167 *3.2. Distribution of egg-clutch size with one parasitized host per seed*

168

169 The distribution of egg-clutch size observed per parasitized host varied from 1 to 29
170 eggs with the modal class from 9 to 10 eggs (Figure 1). With one host enclosed per seed, the
171 average clutch size was 9.37 ± 1.12 eggs, and with two hosts per seed it was 8.48 ± 0.97
172 (mean \pm standard error of the mean). The distribution of egg-clutch sizes showed no
173 significant difference from the normal distribution and the difference between the two means
174 was not significantly different [Kolmogorov-Smirnov test: 1 host per seed, $N(6.07; 37.35)$,

175 $D=0.176 < D_{0.05} = 0.338$; 2 hosts per seed $N(5.13; 32.83)$, $D=0.241 < D_{0.05} = 0.338$,
176 (Student test: $t=1.07$ at the level of significance $\alpha = 0.05$ $t_{[.05]}_{\infty} = 1.96$).

177

178 *3.3 Distribution of egg-clutch size with two hosts per seed*

179

180 With two hosts per seed, the females could parasitize only one of the two hosts (Figure
181 1). When both hosts were parasitized, the modal class (1-2 eggs per parasitized host)
182 corresponded to the smallest egg clutch size (Figure 1). The modal class was larger (9-10 eggs
183 per clutch) when one of the two hosts was parasitized (Figure 1). There was a significant
184 difference in the mean clutch size when both hosts were parasitized, 4.17 ± 1.06 (mean \pm
185 standard error of the mean), and when one of the two hosts was parasitized: 9.37 ± 1.12 eggs
186 (Student-t test: $t=5.3$ at the level of significance $\alpha = 0.05$ $t_{[.05]}_{\infty} = 1.96$). This difference
187 was confirmed by an irregular distribution of the observed frequencies, ranging from 1-2 to
188 13-14 eggs per host (Chi-square test using Yates correction: $\chi^2_{\text{calculated}} = 27.25$: $\alpha =$
189 0.05 , $\chi^2_{\text{ddl } 6} = 12.59$).

190

191 *3.4 Theoretical offspring and sex-ratio of observed offspring with one parasitized host per* 192 *seed*

193

194 As each parasitized host was incubated individually up to the adult stage, it was
195 possible to calculate the relative mortality: number of eggs– number of emerged adults /
196 number of eggs. The correlation between egg-clutch size and relative mortality was strong:

197 R=0.99, P <0.0001, with mortality rising as egg-clutch size increased, i.e. not all the eggs of
198 one clutch would reach adulthood.

199 On average, 4.12 ± 0.39 males and 3.84 ± 0.28 females emerged from one parasitized
200 host (mean \pm standard error of the mean). As the variances of emerged males and females
201 were equal, the difference observed between their means was not statistically different
202 [ANOVA: $F_{(0.05), 1, 427}$ calculated =1.245 with P= 0.265: $F_{\text{critical value}} = 3.86$].

203

204 *3.5 Development time*

205

206 Observations indicated that in each clutch the male(s) emerged first while the
207 emergence of females was spread over time. The shortest time (19 days) was for males with an
208 average of 20.88 ± 0.15 days, and the longest (30 days) for females with an average of 21.06
209 ± 0.19 days (mean \pm standard error of the mean). Analysis of the total development time from
210 egg to adulthood (male or female), showed that the difference observed between the means
211 did not significantly differ [ANOVA: $F_{(0.05), 1, 378}$ calculated =1.912 with P= 0.168: F_{critical}
212 $\text{value} = 3.86$].

213

214 *3.6. Dry weights of males and females in each clutch*

215

216 Dry weight distribution indicated that the lowest values (from 0.1mg to 0.9 mg) were for
217 males and the highest (up to 1.6 mg) for females. The mean dry weight of females ($0.717 \pm$
218 0.05) was double that of males 0.391 ± 0.02 (mean \pm standard error of the mean). The
219 variances of these dry weights being statistically different, the difference between the mean
220 weights of emerged females and males was statistically different [ANOVA: $F_{(0.05), 1, 378}$

221 calculated =151.58 with $P = 0.0001$: $F_{\text{critical value}} = 3.02$, Student-t test: $t = 11.7$ at the level
222 of significance $\alpha = 0.05$ $t_{[.05] \infty} = 1.96$]. For each sex and clutch, mean adult weight and
223 egg-clutch size were negatively correlated (Figure 2A, B). This negative correlation indicated
224 that the mean adult weight decreased as the egg-clutch size increased.

225

226 4. Discussion

227

228 In this study, *M. dorsiplana* was successfully mass-reared in a population cage. With both
229 one and two parasitological hosts per seed but only a single host actually parasitized, the most
230 frequent egg-clutch size was 9 to 10 eggs and the largest was 29 eggs. With a density of one
231 to five females and one parasitological host per seed, a modal class of egg-clutch size close to
232 that observed with one egg-laying female per host was produced (Rojas-Rousse, 2006). The
233 smallest egg-clutch size (1 or 2 eggs) was observed when two parasitological hosts per seed
234 were parasitized. In this situation, egg-laying was disturbed by numerous contacts between
235 the females (personal observations).

236 In theory, the number of eggs laid on a host's body corresponds to the number of
237 offspring. However, this theoretical offspring clutch size differed significantly from the actual
238 offspring numbers emerging from parasitized hosts in the control group, indicating that not all
239 the eggs reached the adult stage. The correlation between egg-clutch size and relative
240 mortality was high ($R=0.99$, $P < 0.0001$), with mortality rising as the egg-clutch size increased.
241 This could be the outcome of a scramble competition between gregarious larvae to share
242 resources (Godfray, 1994). The possibility of aggressive behaviour by the first-instar larvae of
243 a gregarious species could explain why egg clutches were larger than the number of offspring
244 in mass rearing of *M. dorsiplana*. In fact, when the parasitized hosts are superparasitized,
245 aggressive encounters between the pteromalid first-instar larvae of *M. dorsiplana* are likely

246 due to their great mobility and well-developed mandibles. In the following phase, although
247 the larvae are immobile and unarmed (personal observations), it is also possible that some
248 brood reduction could occur in hosts containing a large number of gregarious larvae due to
249 over-crowding (Pexton and Mayhew, 2001, Pexton et al., 2003).

250 In a rearing population cage of *M. dorsiplana* with a density of 1 to 5 females per seed,
251 when one host was parasitized per seed, the sex ratio tended towards a balance of sons ($4.12 \pm$
252 0.39) and daughters (3.84 ± 0.28), in contrast to the ratio observed with a density of one egg-
253 laying female per host (1 son and 7 daughters) (Rojas-Rousse, 2006). This increase of sons
254 has also been observed in previous experiments with two or three egg-laying *M. dorsiplana*
255 females per host, where the distribution of the associations of 1, 2, 3 or X sons with 1, 2, 3 or
256 X daughters indicates that the common patriline is 2 sons and 8 daughters (Rojas-Rousse,
257 2006; Stevoux, 1997). The same pattern has been observed among the gregarious pteromalid
258 *Dinarmus vagabundus*, a parasitoid of *C. maculatus*: increasing the density of egg-laying
259 females from one to three per host leads to a greater increase of sons than daughters, the sex
260 ratio ($\frac{\text{♂}}{\text{♀}}$) increasing from 0.33 to 1 (Rojas-Rousse et al., 1983). Different models have
261 shown the influence of parasitoid density on host-parasitoid population dynamics through
262 local mating competition (LMC) (Hamilton, 1967), the number of female offspring per host
263 being influenced by the density of ovipositing females (Hardy and Ode, 2006). The
264 constraints of mass rearing *M. dorsiplana* in a population cage might prevent the precise
265 application of Hamilton's LMC theory. Some of these constraints need to be tested to
266 understand better the observed fluctuations of the sex ratio of *M. dorsiplana*. For example,
267 asymmetrical mate competition between the broods of different females could occur in a
268 mass-rearing population cage, and females might visit and lay eggs sequentially on different
269 hosts, producing different sex ratios in a patch (Shuker and West, 2004; Shuker et al., 2005).
270 The dispersion of *M. dorsiplana* males from their natal patch before mating has frequently

271 been observed due to the gregarious nature of the hosts in a patch (Jervis and Copland, 1996;
272 Gu and Dorn, 2003), which raises the likelihood of a partial local mating competition in this
273 species.

274 Studies of the nutritional balance during the development of the gregarious
275 ectoparasitoid *D. vagabundus* have shown that the mean weight of both sexes decreases
276 significantly at higher larval densities (Rojas-Rousse et al., 1988). In a population rearing
277 cage with a high level of ovipositing *M. dorsiplana* females per host, the mean weights of
278 adults emerging from a parasitized host were negatively correlated with egg-clutch size, the
279 larger the egg clutch, the lower the weight. As in other parasitoid species, the different egg-
280 clutch sizes laid by *M. dorsiplana* females might have a considerable impact on offspring
281 fitness (Bezemer et al., 2005; Elzinga et al., 2005; Milonas, 2005; Traynor and Mayhew,
282 2005 a and b).

283 Overall, this biological information about the newly discovered pteromalid *Monoska*
284 *dorsiplana* in Latin America indicates that this native gregarious parasitoid could be a
285 promising resource for the biological control of bruchid beetles. When climatic conditions
286 become favourable, the *C. maculatus* bruchid population in storage structures increases
287 rapidly over successive generations (Ouedraogo et al., 1996). To determine whether
288 *M.dorsiplana* could be used as a natural enemy to control this increase in storage systems, its
289 action during regular intervals of introduction need to be analysed after ascertaining that it can
290 move around inside experimental storage systems and locate its hosts, even when these are
291 scarce.

292
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298 **References**

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Table 1. Distribution of parasitized and non-parasitized hosts in a global set of 200 seeds (40 seeds per day for 5 days). Each seed was opened to observe whether the host was parasitized or not.

	Total seeds	Presented hosts	Parasitized hosts	Non-parasitized hosts
1 host per seed	91	91	N=91 91/91= 1	0
2 hosts per seed	95	190	N=113 113/190= 0.59	77
3 hosts per seed	14	42	N=12 12/42 = 0.28	30
Total	200	323	216	107

Observed Frequencies



