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RESEARCH PAPER

## Body mass and wing geometric morphology of the codling moth (Lepidoptera: Tortricidae) according to sex, location and host plant in the region of Maule, Chile

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### Abstract

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Codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), is the key pest of apple and walnut production worldwide. Among other variables, successful management of this pest is dependent on adult dispersal at the local scale. Body mass and wing geometric morphology were evaluated on female and male codling moth adults collected from apple and walnut trees in three localities of the Region of Maule. Codling moth adults were obtained by rearing diapausing larvae collected from the field. Newly emerged adults were killed, and the total dry weight, thorax weight and abdomen weight were calculated. The wings were cleared and mounted for morphometric analyses: 15 and 11 characteristics of the fore and hind wings, respectively, were measured, including the meeting points of the veins and attaching points to the margins. In addition, wing length, area, loading, and aspect ratio were evaluated. As previously reported, females showed larger thorax, abdomen and total body mass, with longer, larger, and wider wings than males but with similar wing loading as males. The geometric morphology analysis also confirmed a sexual dimorphism in the fore and hind wings' size and shape. Significant differences in body mass and wing loading were found between localities, with morphological differences detected in the fore and hind wing shape but not in size. Host plant (apple and walnut) did not influence body mass, wing size or shape variables. Potential consequences of body mass and wing morphology differences on the dispersal and management of this major pest are discussed.

**Key words:** Apple, aspect ratio, *Cydia pomonella*, landmark-analysis, MorphoJ, walnut, wing loading

### Introduction

Codling moth, *Cydia pomonella* L. (Lepidoptera: Tortricidae), is the major pest of pome fruits

(apple, pear, and quince) and walnut worldwide (Barnes, 1991). The control of this pest has been based on regular sprays of synthetic insecticides; in some areas, mating disruption and granulovirus applications are also key components of management programs (Witzgall *et al.*, 2008; Weddle *et al.*, 2009). The spatial population dynamics of

the codling moth can affect these control strategies in several ways (Mazzi and Dorn, 2012). Landscape, orchard and tree canopy structure influence codling moth dispersal at the local scale and thus its spatial population dynamics (Stoekli *et al.*, 2008; Ricci *et al.*, 2009, 2011). The selection of insecticide-resistant individuals in orchards under regular insecticide sprays could be reduced by immigration and gene flow of susceptible individuals from unmanaged areas (Basoalto *et al.*, 2010, Fuentes-Contreras *et al.*, 2014). Furthermore, a decrease in mating disruption efficacy is well-documented as a consequence of the immigration of mated females from unmanaged areas, especially in orchard borders, as well as from high density populations or small orchard sizes with high perimeter-area relationship (Witzgall *et al.*, 2008).

Some studies in codling moth have found an association between insecticide resistance, body size, and sexual dimorphism because females have higher levels of resistance compared with males, which usually are of smaller body size (Varela *et al.*, 1993; Sauphanor *et al.*, 2000; Reyes *et al.*, 2004, 2015; Fuentes-Contreras *et al.*, 2007). Body size has also been related to dispersal capability in the codling moth: in the same population, larger females tend to be more fecund, live longer, and disperse less than smaller females (Gu *et al.*, 2006). Flight distance was also negatively correlated with body weight and wing size in the codling moth, suggesting a trade-off between fitness and dispersal for this species (Schumacher *et al.*, 1997a). Sex dimorphism in the codling moth is apparent in the body size, wing size, and wing shape, as detected using wing geometric morphology analyses (Khaghaninia *et al.*, 2011a), and factors such as altitude and geographic origin affect wing morphometrics (Khaghaninia *et al.*, 2011b).

Few other studies suggest the existence of different apple and walnut races of the codling moth (Cisneros and Barnes, 1974; Phillips and Barnes, 1975), although genetic studies have found little

genetic differentiation between apple and walnut populations (Buès *et al.* 1995; Thaler *et al.*, 2008; Franck and Timm, 2010). To our knowledge, no studies on body size or wing morphology have been performed with codling moth from different host plants, although such differences could be important for the insecticide resistance and dispersal capabilities of this pest species.

Our aim was to evaluate whether body size and several wing morphometric variables of codling moth populations differ between sex, locality and host plant in the Region of Maule, Chile. This information could shed light on the patterns of insecticide resistance and codling moth dispersal in central Chile, which could contribute to a more successful management of this pest under rotation of insecticides with different modes of action between codling moth generations.

## Materials and methods

### *Insect sampling and rearing*

Cardboard traps were strapped around trunks in unsprayed backyard apple and walnut trees at the end of the summer in the Region of Maule (February 2013), Chile. Apple and walnut trees, usually growing together, were sampled in each of these three localities: Las Cruces (35°45'43,11''S, 71°62'10,66''W), Orilla de Maule (35°63' 39,70''S, 71°41'89,07''W), and Yerbas Buenas (35°74'64,07''S, 71°58'57,01''W). One apple and one walnut tree were sampled in Orilla de Maule and Yerbas Buenas, whereas six apple and two walnut trees were sampled in Las Cruces. The cardboard traps were removed in autumn (April 2013) and brought back to the laboratory to obtain fifth instar larvae in diapause. A minimum of fifty larvae were sexed and maintained for three months at  $10 \pm 1$  °C and a 12:12 (L:D) photoperiod to complete diapause. Larvae were then transferred to  $24 \pm 1$  °C and a 16:8 (L:D) photoperiod to promote diapause break and to obtain adults. Less than 1-day old adults were killed to prevent wing damage caused by

flight inside small containers and were preserved in 95% ethanol for further analyses. A sample size of ten individuals ( $N = 10$ ) for each sex, location and host plant combination was used for body mass and wing morphometric measurements.

#### *Body mass evaluation and wing mounting*

Adult insects were removed from the alcohol and dried at 45 °C for 48 h to evaluate their total dry mass (m), expressed in mg, using a microbalance (Mettler Toledo XS, Greifensee, Switzerland). After weighing, the fore and hind wings, head, and legs were carefully removed to weigh the thorax (t) and abdomen (a) separately, as described by Norberg and Leimar (2002). The right pair of wings was then transferred to 70% ethanol to induce a partial rehydration for two hours. The wings were placed in a sodium hypochlorite solution (5%) for five minutes, and the scales were removed with a fine brush. The wings were then cleared with a potassium hydroxide solution (5%), and then glacial acetic acid solution (5%) was added to stop the alkaline reaction. The wings were gently washed with eugenol and left in 95% alcohol overnight. Finally, the wings were mounted on a slide/cover slip with Neo-Mount media (Merck Millipore, Darmstadt, Germany).

#### *Wing morphology and geometric morphometric measurements*

Geometric morphometrics of the wings were calculated using landmark analysis (Bookstein, 1986) to address the possible influence of sex, location and host plant on wing size and shape. Fifteen and eleven landmarks were defined for the fore and hind wings, respectively, which correspond to the meeting points of the veins and attaching points of the veins and wing margins (Type I landmarks), as described for this species by Khaghaninia *et al.* (2011a,b). Images with 10X magnification were taken with the software Optika Vision Pro using a stereoscopic microscope with

a digital camera (SMZ 2, Optikam Pro5, Optika, Pontenarica, Italy). Two-dimensional coordinates of the landmarks were obtained with TpsDIG 2 software (Rohlf, 2006). Coordinate data were transformed to shape variables and partial warp scores with MorphoJ 1.03a software (Klingenberg, 2011).

Dry body mass in relation to wing size and area was used to estimate the wing loading and aspect ratio, as defined by Betts and Wootton (1988). Wing morphology measurements were performed as follows: i) wing length (R) was the maximum length (mm) from forewing base to apex, ii) wing area (S) was the total area (mm<sup>2</sup>) of both fore and hind wings, iii) wing loading ( $P_w$ ) was the ratio between total dry mass and wing area mS<sup>-1</sup> (mg mm<sup>-2</sup>), and iv) aspect ratio (AR) was the ratio between four times the square of the wing length and wing area ( $4R^2S^{-1}$ ).

#### *Statistical analyses*

Significant differences between body dry mass (t, a, and m) and wing morphology variables (S, R,  $P_w$  and AR) were performed with a generalized linear model (GLM) using the package glm in R (R Development Core Team, 2014). A gamma error distribution with a logarithmic link function was used. Sex, host plant, location and their interactions were considered as fixed effects. Model selection was performed according to Crawley (2013), using the package car in R. In all cases, we selected the additive model because the interaction model was not significantly better and showed the lowest value of the Akaike information criterion (AIC). Contrasts between pairs of treatments were calculated using the multcomp package in R following Bretz *et al.* (2011).

Procrustes superimposition removed the variation not related to shape, and the residuals were analyzed with ANOVA using MorphoJ 1.03a software (Klingenberg, 2011) to evaluate the decomposition of the geometric morphological

variation between individuals and independent variables (sex, host plant and location). Furthermore, canonical variation and discriminant function analyses were performed with the same software.

## Results

### *Body mass and wing morphology*

Thorax (t), abdomen (a) and total dry body mass (m) showed significant differences between sex (t:  $\chi^2 = 40.4$ , df = 1,  $P \leq 0.001$ ; a:  $\chi^2 = 39.9$ , df = 1,  $P < 0.001$ ; m:  $\chi^2 = 50.0$ , df = 1,  $P \leq 0.001$ ) and locality (t:  $\chi^2 = 6.6$ , df = 2,  $P \leq 0.05$ ; a:  $\chi^2 = 30.4$ , df = 2,  $P \leq 0.001$ ; m:  $\chi^2 = 21.7$ , df = 2,  $P \leq 0.001$ ), but not between host plants (t:  $\chi^2 = 0.2$ , df = 1,  $P = 0.67$ ; a:  $\chi^2 = 0.3$ , df = 1,  $P = 0.56$ ; m:  $\chi^2 = 0.5$ , df = 1,  $P = 0.47$ ) (Table 1). Females had higher t, a and m than males (Table 1). Regardless of host plant and sex, adults from Orilla de Maule has significantly heavier t, a and m than those obtained from Las Cruces and Yervas Buenas (Table 1).

Regardless of locality or host plant, females had significantly larger R and S than males (R:

$\chi^2 = 48.4$ , df = 1,  $P \leq 0.001$ ; S:  $\chi^2 = 59.8$ , df = 1,  $P \leq 0.001$ ) (Table 2). Significant differences in  $P_w$  were found between localities ( $\chi^2 = 41.6$ , df = 2,  $P \leq 0.001$ ), but not between sex ( $\chi^2 = 3.2$ , df = 1,  $P = 0.07$ ) or host plant ( $\chi^2 = 0.04$ , df = 1,  $P = 0.84$ ).  $P_w$  was significantly higher in wings from Orilla de Maule than in wings from Las Cruces and Yervas Buenas (Table 2). Finally, AR was significantly higher in males than in females ( $\chi^2 = 14.9$ , df = 1,  $P \leq 0.001$ ), without significant differences by locality ( $\chi^2 = 0.7$ , df = 2,  $P = 0.72$ ) or host plant ( $\chi^2 = 0.05$ , df = 1,  $P = 0.84$ ).

### *Wing geometric morphology*

Procrustes ANOVA showed significant effects of sex on wing size (fore wings MS = 1273003,  $F_{(1,118)} = 54.7$ ,  $P \leq 0.001$ ; hind wings MS = 983139,  $F_{(1,118)} = 58.8$ ,  $P \leq 0.001$ ) but not for host plant or location. Similarly, significant effects on wing shape were found for sex (fore wings MS = 0.00034,  $F_{(26,3068)} = 3.5$ ,  $P \leq 0.001$ ; hind wings MS = 0.00644,  $F_{(18,2124)} = 23.1$ ,  $P \leq 0.001$ ) and location (fore wings MS = 0.00024,  $F_{(52,3042)} = 2.5$ ,  $P \leq 0.001$ ; hind wings MS = 0.00081,  $F_{(36,2106)} = 2.5$ ,  $P \leq 0.001$ ) but not for host

**Table 1.** Mean  $\pm$  SE dry mass (mg) of adult codling moth thorax (t), abdomen (a) and full body (m) from males and females obtained from different host plants and localities in the Maule Region, Chile.

Locality	Host	Mean $\pm$ SE dry mass (mg) <sup>1</sup>					
		Male			Female		
		t	a	m	t	a	m
Las Cruces	Apple	1.29 $\pm$ 0.08	1.91 $\pm$ 0.10	4.12 $\pm$ 0.22	1.74 $\pm$ 0.12	2.81 $\pm$ 0.30	5.59 $\pm$ 0.49
	Walnut	1.21 $\pm$ 0.03	2.23 $\pm$ 0.15	4.28 $\pm$ 0.18	1.49 $\pm$ 0.14	2.65 $\pm$ 0.21	5.15 $\pm$ 0.43
Mean <sup>2</sup>		1.25 $\pm$ 0.06 b	2.07 $\pm$ 0.13 b	4.20 $\pm$ 0.20 b	1.62 $\pm$ 0.13 b	2.73 $\pm$ 0.25 b	5.37 $\pm$ 0.45 b
Orilla de Maule	Apple	1.34 $\pm$ 0.06	2.72 $\pm$ 0.19	4.88 $\pm$ 0.24	1.82 $\pm$ 0.18	4.06 $\pm$ 0.53	7.0 $\pm$ 0.73
	Walnut	1.45 $\pm$ 0.09	2.90 $\pm$ 0.23	5.23 $\pm$ 0.34	1.90 $\pm$ 0.14	4.13 $\pm$ 0.40	7.55 $\pm$ 0.48
Mean		1.40 $\pm$ 0.08 a	2.81 $\pm$ 0.20 a	5.05 $\pm$ 0.29 a	1.86 $\pm$ 0.16 a	4.09 $\pm$ 0.45 a	7.27 $\pm$ 0.61 a
Yervas Buenas	Apple	1.46 $\pm$ 0.10	2.61 $\pm$ 0.16	4.91 $\pm$ 0.25	1.71 $\pm$ 0.14	3.04 $\pm$ 0.34	5.79 $\pm$ 0.53
	Walnut	1.28 $\pm$ 0.06	2.14 $\pm$ 0.15	4.31 $\pm$ 0.17	1.81 $\pm$ 0.20	3.70 $\pm$ 0.47	6.64 $\pm$ 0.74
Mean		1.37 $\pm$ 0.09 b	2.37 $\pm$ 0.17 b	4.61 $\pm$ 0.23 b	1.76 $\pm$ 0.17 b	3.37 $\pm$ 0.41 b	6.22 $\pm$ 0.64 b
Grand Mean <sup>3</sup>		1.34 $\pm$ 0.08 B	2.42 $\pm$ 0.19 B	4.62 $\pm$ 0.26 B	1.75 $\pm$ 0.15 A	3.40 $\pm$ 0.42 A	6.28 $\pm$ 0.62 A

<sup>1</sup>Sample size N = 10.

<sup>2</sup>Small letters indicate significant differences between localities in each column.

<sup>3</sup>Capital letters indicate significant differences between sex columns.

plant. Canonical variation analysis showed that the first and second canonical variates accounted for 29.3% and 18.8% of the variance in the fore wings, respectively, and 50.0% and 18.5% of the variance in the hind wings, respectively. Discriminant function analysis showed significant differences between sex (fore wings Mahalanobis distance = 2.21,  $t^2 = 146.2$ ,  $P \leq 0.001$ ; hind wings Mahalanobis distance = 2.62,  $t^2 = 205.5$ ,  $P \leq 0.001$ ) and between some locations, as follows: Las Cruces and Orilla de Maule (fore wings Mahalanobis distance = 1.80,  $t^2 = 64.5$ ,  $P = 0.05$ ; hind wings Mahalanobis distance = 0.99,  $t^2 = 19.6$ ,  $P = 0.63$ ), Las Cruces and Yerbas Buenas (fore wings Mahalanobis distance = 1.51,  $t^2 = 45.4$ ,  $P = 0.29$ ; hind wings Mahalanobis distance = 1.74,  $t^2 = 60.7$ ,  $P \leq 0.01$ ), Orilla de Maule and Yerbas Buenas (fore wings Mahalanobis distance = 1.36,  $t^2 = 37.1$ ,  $P = 0.52$ ; hind wings Mahalanobis distance = 1.69,  $t^2 = 57.2$ ,  $P \leq 0.01$ ). Finally, discriminant function analysis showed non-significant differences between host plants (fore wings Mahalanobis distance = 1.33,  $t^2 = 52.7$ ,  $P = 0.06$ ; hind wings Mahalanobis distance = 0.94,  $t^2 = 26.4$ ,  $P = 0.24$ ).

## Discussion

Our results support previous reports of sexual dimorphism in body mass and wing morphology in the codling moth (Schumacher *et al.*, 1997a; Gu *et al.*, 2006), with females showing larger thorax, abdomen and body mass than males. Larger body size is related to higher detoxification capacity, which confers resistance towards insecticides (Reyes *et al.*, 2004, 2015; Fuentes-Contreras *et al.*, 2007). Therefore, females with larger body size have higher levels of insecticide resistance than do males with a smaller body size (Varela *et al.*, 1993; Sauphanor *et al.*, 2000; Reyes *et al.*, 2004, 2015; Fuentes-Contreras *et al.*, 2007).

In our study, codling moth females have longer (higher R), larger (higher S), and wider (lower AR) wings than males. However, heavier females with larger, longer and wider wings have a similar

wing loading ( $P_w$ ) as males. The wing shape of females is associated with slow and agile flight in restricted space and dense vegetation, whereas the smaller and more slender wings of males is related to extensive flight in open spaces (Betts and Wootton, 1998). The similar wing loading between sexes is indicative of similar flight speeds (Betts and Wootton, 1998). Wing geometric morphology analyses consistently detected larger wings for females, with females exhibiting broader wings than males, as previously reported by Khaghaninia *et al.* (2011a,b).

Differences in body mass and wing morphology between sexes are indicative of different dispersal capabilities. Regardless of sex, adult flight in wind-tunnel experiments has shown a negative correlation with body weight (Schumacher *et al.*, 1997a). However, no major differences in flight capacity between males and females were found in another study (Schumacher *et al.*, 1997b). Flight activity was related with the circadian rhythm, age and mating status rather than sex (Schumacher *et al.*, 1997b; Keil *et al.*, 2001; Gu *et al.*, 2006). Additionally, flight activity was higher in mated than virgin females and increased during the egg-laying period; therefore, little dispersal occurs before mating (Schumacher *et al.*, 1997b). Both sexes showed higher activity at dusk, with males reaching flight activity peaks at a younger age than females (Keil *et al.*, 2001). Treatment with the juvenile hormone mimic insecticide fenoxycarb stimulated locomotor activity and provoked a marked activity peak at dawn in both virgin and mated females (Keil *et al.*, 2001). Therefore, morphological traits are important to explain dispersal, and the physiological and life history attributes are of major relevance (Roff and Fairbairn, 2007).

Regardless of sex and host plant, adults from Orilla de Maule were heavier and had higher  $P_w$  than adults from Las Cruces and Yerbas Buenas. However, no differences in R, S or AR were found between locations. The geometric morphology analyses revealed significant differences in the

**Table 2.** Mean  $\pm$  SE wing length (R) (mm), area (S) (mm<sup>2</sup>), loading (P<sub>w</sub>) (mg mm<sup>-2</sup>), and aspect ratio (AR) from males and females obtained from different host plants and localities in the Maule Region, Chile.

Locality	Host	Mean $\pm$ SE wing length, area, loading and aspect ratio <sup>1</sup>							
		Male			Female				
		R (mm)	S (mm <sup>2</sup> )	P <sub>w</sub> (mg mm <sup>-2</sup> )	AR	R (mm)	S (mm <sup>2</sup> )	P <sub>w</sub> (mg mm <sup>-2</sup> )	AR
Las Cruces	Apple	7.3 $\pm$ 0.2	32.0 $\pm$ 1.5	0.129 $\pm$ 0.004	6.67 $\pm$ 0.07	8.0 $\pm$ 0.2	40.9 $\pm$ 2.2	0.135 $\pm$ 0.006	6.37 $\pm$ 0.10
	Walnut	7.3 $\pm$ 0.1	32.5 $\pm$ 0.9	0.133 $\pm$ 0.007	6.56 $\pm$ 0.06	7.6 $\pm$ 0.3	37.4 $\pm$ 2.9	0.138 $\pm$ 0.008	6.35 $\pm$ 0.11
Mean <sup>2</sup>		7.3 $\pm$ 0.2	32.3 $\pm$ 1.2	0.131 $\pm$ 0.006 b	6.62 $\pm$ 0.07	7.8 $\pm$ 0.2 a	39.1 $\pm$ 2.6 a	0.137 $\pm$ 0.007 b	6.36 $\pm$ 0.10 a
Orilla de Maule	Apple	7.0 $\pm$ 0.1	29.5 $\pm$ 1.0	0.167 $\pm$ 0.010	6.58 $\pm$ 0.10	7.8 $\pm$ 0.2	37.6 $\pm$ 2.0	0.188 $\pm$ 0.020	6.50 $\pm$ 0.11
	Walnut	7.1 $\pm$ 0.2	30.5 $\pm$ 1.2	0.173 $\pm$ 0.011	6.59 $\pm$ 0.14	8.1 $\pm$ 0.2	41.0 $\pm$ 2.0	0.183 $\pm$ 0.006	6.45 $\pm$ 0.08
Mean		7.0 $\pm$ 0.1	30.0 $\pm$ 1.1	0.170 $\pm$ 0.010 a	6.59 $\pm$ 0.12	7.9 $\pm$ 0.2	39.3 $\pm$ 2.0	0.186 $\pm$ 0.015 a	6.47 $\pm$ 0.09
Yerbas Buenas	Apple	7.3 $\pm$ 0.2	32.5 $\pm$ 1.8	0.154 $\pm$ 0.009	6.54 $\pm$ 0.09	8.0 $\pm$ 0.2	40.8 $\pm$ 2.4	0.141 $\pm$ 0.09	6.31 $\pm$ 0.07
	Walnut	7.5 $\pm$ 0.1	33.6 $\pm$ 1.6	0.131 $\pm$ 0.009	6.67 $\pm$ 0.09	8.0 $\pm$ 0.2	40.4 $\pm$ 1.9	0.162 $\pm$ 0.014	6.42 $\pm$ 0.07
Mean		7.4 $\pm$ 0.2	33.0 $\pm$ 1.7	0.142 $\pm$ 0.009 b	6.60 $\pm$ 0.09	8.0 $\pm$ 0.2 a	40.6 $\pm$ 2.1 a	0.152 $\pm$ 0.012 b	6.36 $\pm$ 0.07
Grand Mean <sup>3</sup>		7.2 $\pm$ 0.2 B	31.8 $\pm$ 1.4 B	0.148 $\pm$ 0.010	6.60 $\pm$ 0.09 A	7.9 $\pm$ 0.2 A	39.7 $\pm$ 2.2 A	0.158 $\pm$ 0.013	6.40 $\pm$ 0.09 B

<sup>1</sup>Sample size N = 10.

<sup>2</sup>Small letters indicate significant differences between localities in each column.

<sup>3</sup>Capital letters indicate significant differences between sex columns.

shape of the fore and hind wings between locations, which were accounted for by marginal differences in the fore wings between Orilla de Maule and Las Cruces and larger differences in the hind wings from Yervas Buenas in comparison with Las Cruces and Orilla de Maule. Previous studies on wing geometric morphology of codling moth populations from different localities in North-West Iran (Khaghaninia *et al.*, 2011a,b) found that abiotic conditions, such as wind velocity at different altitudes, were associated with significant changes in wing size and shape. Slender and longer wings were found in codling moth adults from higher altitudes (Khaghaninia *et al.*, 2011a,b). All locations included in our study were in the central valley of the Maule River, less than 50 km apart, at altitudes between 100 and 200 masl. At the small geographic scale of our study, it is less likely that abiotic factors explain the differences in body mass or wing shape. We propose that biotic factors, such as host plant condition and codling moth population density, which might vary at smaller spatial scales, explain the changes in body mass and wing size and shape observed between locations. For instance, water availability for home-grown trees could be higher or the codling moth population density lower in Orilla de Maule than in Las Cruces and Yervas Buenas, which could improve the availability of fruits as resources for the development of the codling moth and therefore allow a higher body mass and wing size in adults from this location in relation to others with lower fruit availability or higher codling moth population density (Ferro and Hardwood, 1973; Howell, 1991).

Previous studies detected behavioral differences between codling moth from apple and walnut trees in California (Cisneros and Barnes, 1974; Phillips and Barnes, 1975). Because no influence of the host plant species on body mass or wing morphology was found, our results did not support a phenotypic differentiation between apple

and walnut populations in the Maule Region of central Chile. Walnut is often regarded as a secondary host for codling moth in comparison with apple because of the high content of secondary metabolites (*e.g.*, juglone) that the walnut fruit contains (Piskorski and Dorn, 2011). Effective metabolism of juglone was found in codling moth larvae feeding on walnut, although a longer developmental period and a male biased sex ratio were observed when reared in this host plant (Piskorski and Dorn, 2011). In our study, we used adults obtained from apple and walnut trees; therefore, we selected those individuals who successfully developed on those host plants.

Our results confirm previous studies showing differences in body mass and wing morphology depending on codling moth sex and location but did not find differences between apple and walnut as host plants. Small individuals from home-grown trees should have high insecticide susceptibility and dispersal capabilities. The scenario of insecticide-susceptible adults migrating to managed orchards has been proposed as source-sink population dynamics that could explain the low levels of insecticide resistance found in codling moth in central Chile (Fuentes *et al.*, 2014). Further studies could evaluate whether such differences based on sex and location in body mass and wing morphology could affect the dispersal of this species and subsequently influence its management through the use of insecticides and mating disruption.

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### Resumen

**F. Torres, M.A. Rodríguez, B. Lavandero y E. Fuentes-Contreras. 2015. Tamaño corporal y morfometría geométrica de la polilla de la manzana (Lepidoptera: Tortricidae) según sexo, localidad y planta hospedera en la Región del Maule, Chile. Cien. Inv. Agr. 42(3): 397-406.** La polilla de la manzana, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), es la plaga clave de manzanos y nogales alrededor del mundo. Entre otras variables, el manejo exitoso de esta plaga depende de la dispersión de los adultos en la escala local. Se evaluó el peso corporal y la morfología geométrica de las alas de hembras y machos adultos de la polilla de la manzana, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), provenientes de manzano y nogal en tres localidades de la Región del Maule, Chile. A partir de larvas en diapausa recolectadas en el campo se obtuvieron adultos de la polilla de la manzana en laboratorio. Los adultos recién emergidos fueron muertos y se calculó el peso seco total, peso del tórax y peso del abdomen. Las alas fueron aclaradas y montadas para su análisis morfométrico, el cual incluyó 15 hitos para las alas delanteras y once para las alas posteriores, respectivamente, incluyendo puntos de unión de las venas y puntos de unión vena/margen. Además, se evaluó el largo, área, carga alar y razón de aspecto de las alas. Como se ha reportado previamente, encontramos que las hembras mostraron mayor peso de tórax, abdomen y cuerpo completo, con alas más largas, grandes y anchas que los machos. Sin embargo, tales diferencias no resultaron en diferencias de la carga alar entre sexos. El análisis de morfometría geométrica también confirmó un dimorfismo sexual en el tamaño y forma de las alas anteriores y posteriores. Se encontraron diferencias significativas en el peso corporal y la carga alar entre localidades, con diferencias en la morfología geométrica de la forma, pero no del tamaño en las alas anteriores y posteriores. La planta hospedera (manzano y nogal) no influyó ninguna de las variables de peso corporal, tamaño o forma de las alas analizadas en los adultos de la polilla de la manzana. Se discuten las posibles consecuencias de las diferencias en peso corporal y morfología alar según sexo y localidad sobre la dispersión y manejo de esta plaga primaria.

**Palabras clave:** Carga alar, *Cydia pomonella*, hito, manzano, MorphoJ, nogal, razón de aspecto.

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