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Adult feeding by the rice water weevil *Lissorhoptrus oryzophilus* on different host plants

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Abstract

Laboratory assays to determine the leaf consumption rates of adult rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera Erirhinidae), were conducted under no-choice conditions. Adults were individually reared on excised leaves of *Heteranthera reniformis* Ruiz et Pavon, *Echinochloa crus-galli* (L.) P. Beauv., *Leersia oryzoides* L., *Schoenoplectus mucronatus* L., *Bolboschoenus maritimus* L., and *Alisma* spp. Their consumption was at first compared at 28 °C. Results showed that *E. crus-galli* was the most preferred host. No consumption was detected on *S. mucronatus* and *Alisma* spp. Further trials were conducted between 10-50 °C on *E. crus-galli*, *L. oryzoides* and *B. maritimus*. Feeding activity was recorded from 14 °C to 48 °C. Scars were not detected at 10 °C, 12 °C and 50 °C for all the weeds. All the analyzed parameters resulted influenced by weed species and temperature.

Key words: alien species, laboratory assay, *Oryza sativa*, host plant, leaf area, image processing, feeding preference.

Introduction

The rice water weevil (RWW), *Lissorhoptrus oryzophilus* Kuschel (Coleoptera Erirhinidae), is native to the United States, where the beetle originally fed on gramineous and cyperaceous weeds (Webb, 1914; Tindall and Stout, 2003). When rice was introduced in the United States, the RWW became one of the most destructive pests of this crop. RWW remained confined in North America until 1976 when it spread to Japan (Saito *et al*., 2005). Thereafter it was detected in China (Chen *et al*., 2004) in Korea (Lee and Uhm, 1993), in India (Hix *et al*., 2000), and in Europe (Caldara *et al*., 2004). The insect is now considered one of the most important phytophagous pests of rice in the world.

The detection in Europe is important because the insect was detected in Italy, the largest rice producing country in the European Union with 1,493,200 t of rice produced in 2007 on 232,500 ha (IRRI, 2008; Ente Nazionale Risi, 2008).

Damage is caused by larvae, which are aquatic root herbivores: the newly hatched larva feeds within the sheath for a short time, then moves to the mud and feeds within and upon rice roots (Zou *et al*., 2004). Root pruning results in a reduced plant height, a slight delay in maturation, and a reduced yield. In extreme cases, wind may cause the plant to dislodge and float (Wu and Wilson, 1997). Adults are semiaquatic foliage feeders leaving longitudinal scars on leaves; their feeding is usually of little economic importance, but can be an indicator of the magnitude of subsequent larval infestation and damage (Way and Wallace, 1992).

The RWW is a polyphagous pest, feeding on rice and many weeds coexisting with rice in the agroecosystem. Studies carried out in the United States (Tindall and Stout, 2003) and China (Chen *et al*., 2004) established that the host range of the insect primarily consists of monocotyledonous plants (Poaceae and Cyperaceae). According to these authors, RWW can also feed on dicotyledonous plants (Onagraceae, Amaranthaceae, Fabaceae, Euphorbiaceae, Asteraceae, and Convolvulaceae).

Weeds are not equally suitable for RWW. Some weeds support only adult feeding but are indispensable in spring, when the adults emerge from overwintering sites to replenish energy reserves and to develop flight muscles and ovaries (Nilakhe, 1977; Muda *et al*., 1981; Matsui, 1985; Palrang *et al*., 1994; Shi *et al*., 2007). Others can support both adult and larval development (Tindall and Stout, 2003; Lupi *et al*., 2007a). These plants possess aerenchyma, which is necessary for larvae to acquire oxygen from roots. Larvae have respiratory hooks from the second to the seventh abdominal segment, and they insert them into roots to obtain oxygen (Isely and Schwardt, 1930).

While many and detailed are the lists of host plants in various countries (Tindall and Stout, 2003; Chen *et al*., 2004; Lupi *et al*., 2007b; 2008; Shih and Cheng, 1992) (table 1), little information is available about the adult behaviour and feeding on these hosts.

The present study aimed to evaluate the ability of the insect to feed on the most common weeds of rice paddies in Italy and to establish the influence of temperature on leaf consumption by adults using no choice tests.

Materials and methods

A laboratory assay was carried out to assess the suitability of different spontaneous plants as hosts for *L. oryzophilus* and the consumption rate in relation to temperature. Six monocotyledonous species, common in Northern Italian rice fields, were used to establish the susceptibility to RWW. Barnyardgrass, *Echinochloa crus-galli* (L.) P. Beauv. (Cyperales Poaceae); rice cutgrass, *Leersia oryzoides* L. (Cyperales Poaceae); bog bulrush, *Schoenoplectus mucronatus* L. (Cyperales Cyperaceae), sea club rush, *Bolboschoenus maritimus* L. (Cyperales Cyperaceae); mud plantain, *Heteranthera reniformis*

Table 1. List of host plants on which RWW was detected in different countries. D = dicotyledons, M = monocotyledons.

Family		China (Chen *et al*., 2004)	Taiwan (Shih and Cheng, 1992)	USA (Tindall and Stout, 2003)	Italy (Lupi *et al*., 2007b; 2008; new record**)
Amarantaceae	D			*Alternathera philoxeroides* (Mart.) Griseb., *Amaranthus* spp.	
Asteraceae	D			*Eclipta alba* (L.) Haask.	*Artemisia vulgaris* L.
Convolvulaceae	D			*Ipomoea* spp.	
Euphorbiaceae	D			*Caperonia palustris* (L.) St. Hil	
Fabaceae	D			*Aeschynomene indica* L., *Sesbania exaltata* (Raf.) A.W. Hill.	
Poligonaceae	D				*Rumex acetosa* L.
Rubiaceae	D				*Galium aparine* L., *G. tricornutum* Dandy.
Valerianaceae	D				*Valerianella* spp.
Araceae	M	*Acorus calamus* L.			
Juncaceae	M	*Juncus bufonius* L., *J. effusus* L., *J. gracillimus* (Buch.) V. Krecz. et Gontsh.			
Alismataceae	M	*Alisma orientale* (Sam.) Juzepcz., *Sagittaria sagittifolia* L.			
Butomaceae	M	*Butomus umbellatus* L.			
Commelinaceae	M	*Commelina communis* L.	*Commelina communis* L.		
Cyperaceae	M	*Carex onoei* Franch. et Sav., *C. tangiana* Ohwi, *Cyperus difformis* L., *C. glometuratus* L., *Eleocharis valleculosa* Ohwi, *Juncellu serotinus* (Rottb.) C. B. Clarke, *Pycreus sanguinolentus* (Vahl) Ness, *Scirpus planiculmis* Fr. Schmidt, *S. tabernaemontani* Gmel, *S. triqueter* L.	*Cyperus difformis* L., *C. inia* L., *C. rotundus* L., *C. serotinus* Rottb., *C. juncoides* Roxb.	*Cyperus* spp.	*Carex hirta* L., *Cyperus difformis* L., *C. esculentus* L., *C. glomeratus* L., *C. strigosus* L., *Bolboschoenus maritimus* (L.) Palla, *Eleocharis* spp.
Iridaceae	M	*Iris ensata* Thunb.			*Iris pseudacorus* L.**
Poaceae	M	*Agropyron cristatum* (L:) Gaertn., *Agrostis stolonifera* L., *Alopecurus aequalis* Sobol., *A.littoralis* var. *sinensis* Debeaux, *Aneurolepidium chinense* (Trin.) Kitag., *Arthraxon hispidus* (Thund.) Makino, *Beckmannia syzigachne* (Steud.) Fernald, *Calamagrostis pseudophragmites* (Hall. f.) Koel, *Chloris virgata* Swartz, *Coix lacrymajobi* L., *Digitaria adscendens* (H. B. K.) Henr., *D. sanguinalis* (L.) Scop., *Diplachne fusca* (L.) Beauv., *Echinochloa crus-galli* (L.) Beauv., *E. crus-galli* var. *cruspavonis* (H. B. K.) Hitch., *Eleusine indica* (L.) Gaertner, *Eragrostis autumnalis* Keng, *E. cilianensis* (All.) Link, *Eriochloa villosa* (Thunb.) Kunth, *Hierochloe odorata* (L.) Beauv., *Imperata cylindrica* (L.) Beauv. var *major* Hubb., *Leersia japonica* (Makino) Keng f., *Miscanthus sacchariflorus* (Maxim.) Benth. et Hook. F., *Oryza sativa* L., *Panicum miliaceum* L., *Parapholis incurva* (L.) C. E. Hubb., *Pennisetum alopecuroides* (L.) Spreng., *Phragmites communis* Trinius, *Phyllostachys bambusoides* Sieb. et Zucc., *Poa annua* L., *Puccinellia chinampoensis* Ohwi, *Roegneria kamoji* Ohwi, *Saccharum sinensis* Roxb., *Setaria italica* (L.) Beauv., *S. lutescens* (Weigel) Hubb., *S. viridis* (L.) Beauv., *Shorgum vulgare* Pers., *Spartina angelica* C. E. Hubb., *Themeda triandra* Forsk. var. *japonica* (Willd.) Makino, *Zea mays* L., *Zizania aquatica* L.	*Alopecurus aegualis* Sobal. var *amurensis* (Komar.) Ohwi, *Bambusa multiplex* (Lour.) Raeuschel, *Cynodon dactylon* Pers., *Digitaria decumbens* Stent., *Echinochloa crus-galli* Beauv. var. *formosensis* Ohwi, *E. crus-galli* Beauv. var. *oryzicola* Ohwi, *Eleusine indica* (L.) Gaertn., *Eragrotis japonica* (Thunb.) Trin, *Imperata cylindrica* (L.) Beaur., *Kyllinga brevifolia* Rottb., *Leersia hexandra* Sw., *Miscanthus floridulus* (Labill.) Warb., *M. sinensis* Anderss, *Oryza sativa* L., *Panicum repens* L., *Paspalum distichum* L., *P. thunbergii* Kunth, *Poa anua* L., *Rhynchelytrum repens* (Willd.) C. E. Hubbard, *Saccharum officinarum* L., *Setaria viridis* (L.) Beauv. Hubbard, *Zea mays* L., *Zizania latifolia* Turcz.	*Brachiaria platyphylla* (Griseb.) Nash., *Cynodon dactilon* (L.) Pers., *Echinochloa crus-galli* (L.) Beauv., *Leptochloa* spp., *Oryza sativa* L., *Panicum dichotomiflorum* Michx., *Paspalum dilatatum* Pour.	*Agrostis stolonifera* L., *Agropyron repens* (L.) Beauv., *Alopecurus* sp., *Arrhenatherum elatius* L., *Bromus sterilis* L., *Cynodon dactylon* (L.) Pers., *Dactylis glomerata* L., *Digitaria sanguinalis* (L.) Scop., *Echinochloa crus-galli* (L.) Beauv., *Glyceria maxima* (Hartman) Holmb., *Holcus* spp., *Leersia oryzoides* (L.) Swartz, *Leptochloa* spp., *Oryza sativa* L., *Panicum dichotomiflorum* Michx, *Phragmites australis* (Cav.) Trinius, *Poa trivialis* L., *Setaria italica* (L.) Beauv., *S. viridis* (L.) Beauv., *Sorghum halepense* (L.) Pers., *Zea mays* L.
Pontaederiaceae	M			*Heteranthera limosa* (Sw.) Willd.	
Potamogetonaceae	M	*Potamogeton distinctus* A. Bennet			
Typhaceae	M	*Typha angustifolia* Bory et Chaub, *T. minima* Funk, *T. orientalis* Presl.			

Ruiz et Pavon (Liliales Pontederiaceae) and common waterplantain, *Alisma* spp. (Alismatales Alismataceae) were tested.

Rice water weevil collection

RWW adults were randomly collected from rice plants in Bereguardo, Pavia province, (45°15,264N 9°01,271E - GPS coordinates, map datum WGS84) at the beginning of June 2006. After collection, the samples were brought to the laboratory of DiPSA (Faculty of Agriculture, of Milan) and preconditioned on rice leaves in a climatic chamber with a 14:10 (L:D) photoperiod at 28 °C for three days. As the insect population in Italy is composed only by parthenogenetic individuals, trials were executed on females.

Host plants cultivation

To supply fresh leaves to RWW, weeds were planted separately into tanks (100×45×49 cm) and positioned open air inside the Faculty of Agriculture of Milan. Each tank was covered with a structure of plastic and net to preclude insects infestations. Water management was conducted as in commercial rice fields.

Bioassay procedures

No choice tests were conducted in climatic chambers with 14:10 (L:D) photoperiod.

To evaluate the plants on which the insect was able to feed, trials were initially performed at 28 °C on *E. crus-galli*, *L. oryzoides*, *S. mucronatus*, *B. maritimus*, *H. reniformis*, and *Alisma* spp. If the insect was able to feed on a weed, temperatures from 10 to 50 °C were tested to determine the entire range of temperatures at which the insect was able to feed.

Petri dishes were prepared with a sheet of paper towel on the bottom. Adults were individually inserted in each Petri. Only the youngest leaves at the apex of the weeds cultivated in the Faculty of Agriculture were used. A piece of leaf of about 5 cm in length was added to each Petri at the beginning of the trial. Water was added to create a film, necessary both for insect survival and leaf preservation. Ten Petri dishes were prepared for each weed at each temperature. Every 24 hours, over a period of 4 days, each leaf was removed and a fresh one provided. A total of forty observations were obtained for each weed at each temperature. Water was added when necessary. Leaf pieces removed from the Petri dishes were fixed to a white paper using a transparent adhesive tape. A ruler was positioned on the same paper to calibrate the pixel conversion. Each leaf was scanned with an EPSON 2450 Photo® scanner at 300dpi and saved as a jpg file. Leaf area consumption was calculated with the image processing program SigmaScan Pro® used for studies on leaf damage (Kerguelen and Hoddle, 1999; Lupi and Jucker, 2004).

The following parameters were estimated for each weed at each temperature: number of scars per day, daily food consumption, scars mean area, dimension of the largest scar, numbers of days of feeding activity over a period of four days. Daily food consumption was calculated as total area per day as the leaf thickness is assumed to be the same in the different plants considered.

Data were analyzed with SPSS 17® by one way ANOVA with replications and means separated by Duncan's Multiple Range Test DMRT ($P < 0,05$).

To examine the relationships between the days of feeding, temperature, and weed species, regression analyses were performed.

Results

Trials at 28 °C showed that *H. reniformis*, *E. crus-galli*, *L. oryzoides*, and *B. maritimus* are preferred as food by adult *L. oryzophilus*. Scars were not detected on *S. mucronatus* and *Alisma* spp. (table 2). Results showed significant differences among weeds for daily food consumption ($F = 78.171$; df =3; $P < 0.0001$), mean scar area ($F = 104.769$; df = 3; $P < 0.0001$), largest scar dimensions ($F = 108.508$; df = 3; $P < 0.0001$), and number of scars ($F = 62.491$; df = 3; $P < 0.0001$). Least consumption was observed on *H. reniformis*, and the highest on *E. crus-galli.*

Trials were continued on *Echinochloa* spp., *L. oryzoides* and *B. maritimus*. *S. mucronatus* and *Alisma* spp. were discarded as no feeding was detected on them at 28 °C. *H. reniformis* also was discarded because the small area of the scars was influenced by human error during the process of area computation, making it difficult to find differences among temperatures.

The temperature spectrum of activity of RWW on *E. crus-galli*, *L. oryzoides*, and *B. maritimus* was broad. Feeding activity was detected from 14 °C to 48 °C (tables 3-6). Scars were not detected at 10 °C, 12 °C and 50 °C for all the weeds. All parameters considered were

Table 2. Evaluation of the feeding activity and the influence of the host on 4 different parameters at 28 °C.

	Daily food consumption *	Scars mean dimension *	Largest scar dimension *	Daily number of scars
E. crus-galli	29.147 ± 2.103 (c)	4.818 ± 0,278 (c)	8.346 ± 0.439 (c)	6.875 ± 0.588 (c)
L. oryzoides	22.598 ± 2.654 (b)	3.790 ± 0,381 (b)	6.724 ± 0.685 (h)	5.000 ± 0.574 (c)
S. mucronatus	0	0	0	0
B. maritimus	0.437 ± 0.245 (a)	0.160 ± 0,067 (a)	0.244 ± 0.130 (ab)	0.375 ± 0.174 (a)
H. reniformis	0.14 ± 0.045 (a)	0.092 ± 0.045 (a)	0.122 ± 0.049 (a)	0.225 ± 0.098 (b)
Alisma spp.	0	0	0	0

Values are shown as Mean ± SE; Means followed by different letters in the same column are significantly different at $p < 0.05$ by one-way ANOVA with replications and DMRT; * Values are shown in mm^2.

Table 3. Trend of daily food consumption on *E. crus-galli*, *L. oryzoides* and *B. maritimus*.

Temperature	*E. crus-galli*	*L. oryzoides*	*B. maritimus*
14 °C	2.221 ± 0.504 (ab)	2.156 ± 0.490 (ab)	2.049 ± 0.465 (a)
16 °C	6.746 ± 0.928 (bc)	6.550 ± 0.901 (b)	6.222 ± 0.856 (b)
18 °C	9.491 ± 1.387 (cd)	2.657 ± 0.791 (ab)	0.079 ± 0.063 (a)
22 °C	15.804 ± 1.404 (e)	13.690 ± 1.731 (d)	0.461 ± 0.166 (a)
26 °C	23.065 ± 1.917 (f)	14.519 ± 1.831 (de)	0.983 ± 0.306 (a)
28 °C	29.147 ± 2.103 (g)	22.598 ± 2.654 (f)	0.437 ± 0.245 (a)
30 °C	25.619± 2.051 (fg)	10.710 ± 1.418 (d)	1.237 ± 0.364 (a)
32 °C	20.886± 2.983 (f)	5.757 ± 1.491 (b)	6.790 ± 1.318 (b)
34 °C	37.949 ± 3.077 (h)	18.189 ± 2.465 (e)	9.993 ± 1.764 (c)
36 °C	29.416 ± 2.055 (g)	10.288 ± 2.285 (cd)	18.151 ± 2.460 (d)
38 °C	15.958 ± 1.552 (e)	5.218 ± 1.181 (b)	5.448 ± 1.459 (b)
40 °C	12.124 ± 1.563 (de)	2.254 ± 0.609 (ab)	0.953 ± 0.393 (a)
44 °C	1.225 ± 0.406 (a)	0.140 ± 0.081 (a)	0.040 ± 0.040 (a)
48 °C	0.116 ± 0.087 (a)	0 (a)	0.088 ± 0.088 (a)

Values are shown in mm^2 as Mean ± SE; Means followed by different letters in the same column are significantly different at $p < 0.05$ by one-way ANOVA and DMRT.

Table 4. Trend of scars mean dimension on *E. crus-galli*, *L. oryzoides* and *B. maritimus*.

Temperature	*E. crus-galli*	*L. oryzoides*	*B. maritimus*
14 °C	1 077 ± 0.251 (bc)	1.045 ± 0.244 (bc)	0.993 ± 0.232 (bc)
16 °C	2.613 ± 0.324 (ef)	2.537 ± 0.315 (de)	2.410 ± 0.299 (d)
18 °C	2.827 ± 0.305 (efg)	1.508 ± 0.442 (bc)	0.038 ± 0.026 (a)
22 °C	3.737 ± 0.305 (hi)	3.344 ± 0.373 (fg)	0.259 ± 0.082 (ab)
26 °C	4.209 ± 0.221 (il)	3.482 ± 0.383 (fg)	0.589 ± 0.253 (ab)
28 °C	4.818 ± 0.278 (l)	3.790 ± 0.381 (g)	0.160 ± 0.067 (ab)
30 °C	3.070 ± 0.236 (fgh)	1.831 ± 0.250 (cd)	0.548 ± 0.161 (ab)
32 °C	1.802 ± 0.229 (cd)	0.895 ± 0.217 (b)	2.948 ± 0.499 (de)
34 °C	4.520 ± 0.633 (l)	2.943 ± 0.288 (ef)	1.612 ± 0.291 (c)
36 °C	3.512 ± 0.145 (ghi)	1.666 ± 0.266 (bc)	3.265 ± 0.766 (e)
38 °C	2.830 ± 0.194 (efg)	1.183 ± 0.208 (bc)	0.839 ± 0.175 (abc)
40 °C	2.250 ± 0.181 (de)	0.868 ± 0.210 (b)	0.268 ± 0.078 (ab)
44 °C	0.526 ± 0.156 (ab)	0.070 ± 0.041 (a)	0.040 ± 0.040 (a)
48 °C	0.116± 0.087 (a)	0 (a)	0.088 ± 0.088 (a)

Values are shown in mm^2 as Mean ± SE, Means followed by different letters in the same column are significantly different at $p < 0.05$ by one-way ANOVA and DMRT.

Table 5. Trend of dimension of the largest scar on *E. crus-galli*, *L. oryzoides* and *B. maritimus*.

Temperature	*E. crus-galli*	*L. oryzoides*	*B. maritimus*
14 °C	1.441 ± 0.325 (b)	1.399 ± 0.316 (ab)	1.323 ± 0.300 (bc)
16 °C	3.661 ± 0.472 (c)	3.554 ± 0.458 (de)	3.377 ± 0.435 (d)
18 °C	4.043 ± 0.520 (c)	1.843 ± 0.520 (bc)	0.044 ± 0.031 (ab)
22 °C	5.940 ± 0.476 (d)	5.112 ± 0.577 (fg)	0.284 ± 0.090 (ab)
26 °C	7.338 ± 0.495 (ef)	5.557 ± 0.620 (fgh)	0.711 ± 0.263 (abc)
28 °C	8.346 ± 0.439 (f)	6.724 ± 0.685 (h)	0.244 ± 0.130 (ab)
30 °C	6.520 ± 0.595 (de)	4.553 ± 0.543 (ef)	0.708 ± 0.204 (abc)
32 °C	4.000 ± 0.589 (c)	2.315 ± 0.570 (bcd)	4.086 ± 0.645 (d)
34 °C	6.851 ± 0.505 (de)	6.398 ± 0.746 (gh)	3.284 ± 0.616 (d)
36 °C	6.091 ± 0.323 (d)	3.244 ± 0.563 (cde)	6.410 ± 1.044 (e)
38 °C	4.584 ± 0.346 (c)	2.134 ± 0.409 (bc)	1.844 ± 0.458 (c)
40 °C	3.494 ± 0.299 (c)	1.192 ± 0.287 (ab)	0.359 ± 0.160 (ab)
44 °C	0.626 ± 0.299 (ab)	0.092 ± 0.054 (a)	0.040 ± 0.040 (ab)
48 °C	0.116 ± 0.087 (a)	0 (a)	0.088 ± 0.088 (ab)

Values are shown in mm^2 as Mean ± SE; Means followed by different letters in the same column are significantly different at $p < 0.05$ by one-way ANOVA and DMRT.

Table 6. Trend of daily number of scars on *E. crus-galli*, *L. oryzoides* and *B. maritimus*.

Temperature	*E. crus-galli*	*L. oryzoides*	*B. maritimus*
14 °C	1.275 ± 0.261 (ab)	0.875 ± 0.187 (ab)	0.525 ± 0.119 (ab)
16 °C	2.650 ± 0.281 (bc)	1.900 ± 0.223 (bc)	1.250 ± 0.163 (bc)
18 °C	2.525 ± 0.338 (b)	0.675 ± 0.187 (a)	0.100 ± 0.078 (a)
22 °C	4.000 ± 0.332 (cd)	3.350 ± 0.361 (de)	0.400 ± 0.138 (ab)
26 °C	5.700 ± 0.442 (ef)	3.575 ± 0.420 (e)	0.825 ± 0.214 (ab)
28 °C	6.875 ± 0.588 (f)	5.000 ± 0.574(fg)	0.375 ± 0.174 (ab)
30 °C	9.100 ± 0.678 (g)	5.625 ± 0.619 (g)	0.700 ± 0.187 (ab)
32 °C	8.275 ± 1.007 (g)	2.850 ± 0.583 (cde)	1.875 ± 0.310 (cd)
34 °C	11.175 ± 0.805 (h)	5.500 ± 0.573 (g)	5.275 ± 0.748 (e)
36 °C	8.400 ± 0.503 (g)	4.000 ± 0.576 (ef)	5.743 ± 0.773 (e)
38 °C	5.500 ± 0.450 (ef)	2.341 ± 0.397 (cd)	2.829 ± 0.591 (d)
40 °C	4.900 ± 0.567 (de)	1.175 ± 0.282 (ab)	1.050 ± 0.397 (abc)
44 °C	0.06 ± 0.195 (a)	0.150 ± 0.084 (a)	0.025 ± 0.025 (a)
48 °C	0.05 ± 0.035 (a)	0 (a)	0.025 ± 0.025 (a)

Values are shown Mean ± SE; Means followed by different letters in the same column are significantly different at $p < 0.05$ by one-way ANOVA and DMRT.

influenced by temperature. Results showed that *E. crus-galli* was the most preferred plant at all temperatures tested while *B. maritimus* was the least favoured at all temperatures with the only exception at 36 °C at which the consumption was higher on *B. maritimus* than on *L. oryzoides* (figure 1).

Daily consumption of *E. crus-galli* ($F = 53{,}239$; $df = 15$; $P < 0.0001$) was very low at 14 °C and above 44 °C. Values peaked at 34 °C for total daily consumption (table 3) and daily number of scars (table 6), at 28 °C for the largest scar (table 5), and at 28 °C and 34 °C for scar mean dimension (table 4).

Daily consumption of *L. oryzoides* ($F = 24.094$; $df = 15$; $P < 0.0001$) was very low at 14 and above 40 °C. Values peaked at 28 °C for total daily consumption (table 3), scar mean dimension (table 4), and the largest scar (table 5), and at 28, 30, and 32 °C for daily number of scars (table 6).

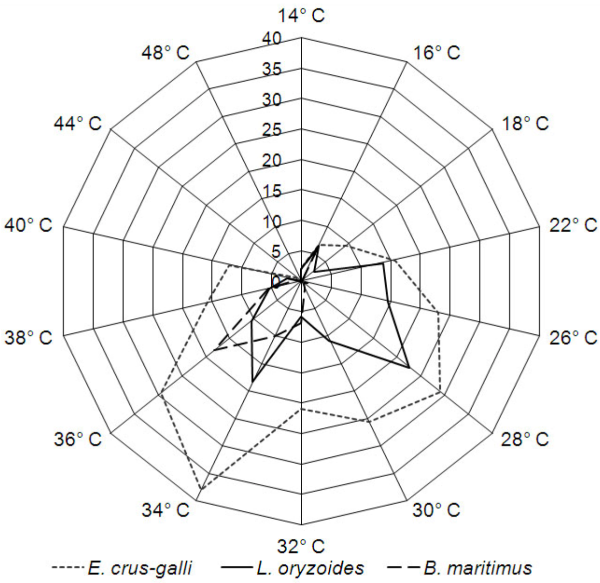

Figure 1. Trend of daily food consumption on *E. crus-galli*, *L. oryzoides* and *B. maritimus* at different temperatures.

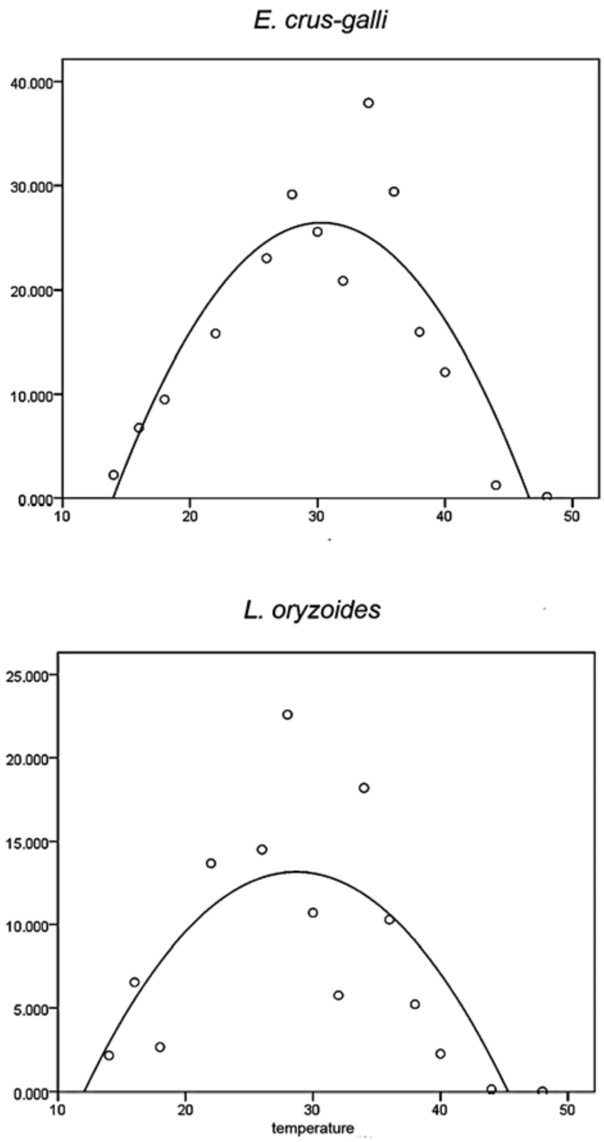

Figure 2. Relationship between temperature and daily food consumption in *E. crus-galli* and *L. oryzoides*.

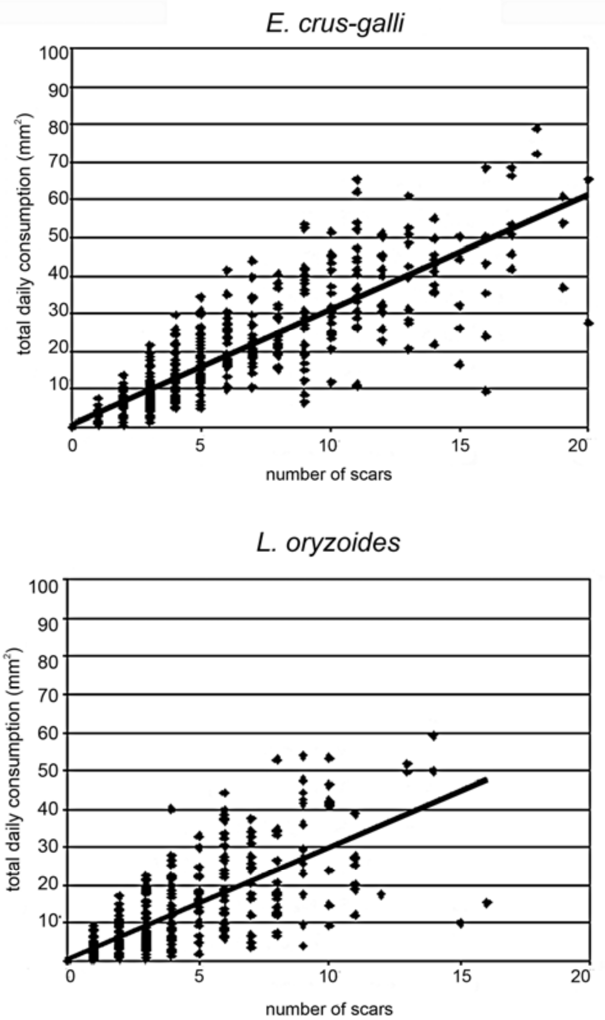

Figure 3. Relationship between number of scars and total daily consumption.

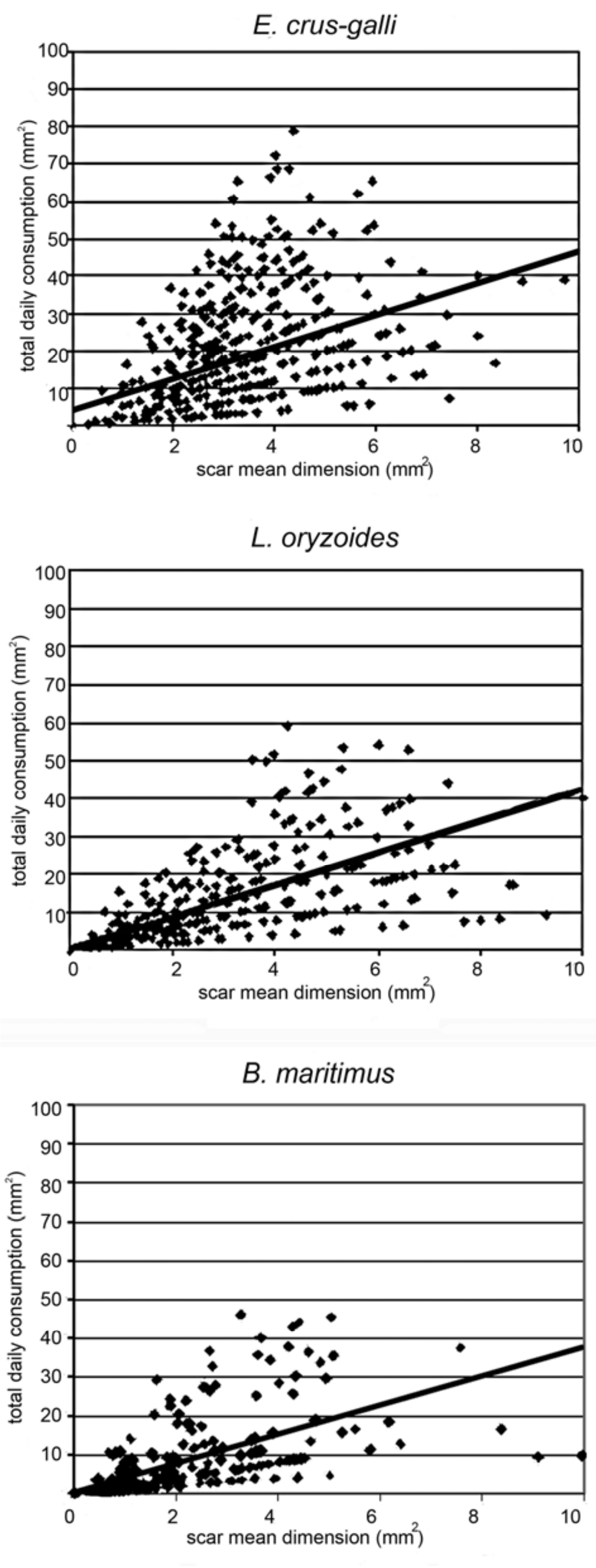

Figure 4. Relationship between scar mean dimension and total daily consumption.

Daily consumption of *B. maritimus* (F = 27.771; df = 15; P < 0.0001) was very low at nearly all the temperatures tested. Values peaked from 32 to 36 °C (table 3-6).

The relationship between daily consumption and temperature can be represented with a quadratic equation for both *E. crus-galli* and *L. oryzoides* (significance at P < 0.001, regression equations: $y = -0.0825\,x^2 + 5.0408\,x - 51.648$ for *E. crus-galli* and $y = -0.0397\,x^2 + 2.3217\,x - 21.443$ for *L. oryzoides*) (figure 2). No regression line fits this relationship for *B. maritimus*.

The relationships among daily consumption and number of scars and scar dimensions were analysed. Daily consumption was directly proportional to scar mean dimensions for *B. maritimus* and to both number of scars and scar mean dimension for *E. crus-galli* and *L. oryzoides.* Linear regression between number of scars and total daily consumption was significant at P < 0.001 for *E. crus-galli* (R^2 = 0.7935; regression equation $y = 3.0319\,x + 0.8033$) and *L. oryzoides* (R^2 = 0.6777; regression equation $y = 2.9793\,x + 0.2776$) (figure 3).

Linear regression between scars mean dimension and total daily consumption was significant at P < 0.001 for *L. oryzoydes* (R^2 = 0.6027; regression equation $y = 4.1643\,x + 0.6163$) *B. maritimus* (R^2 = 0.532; regression equation $y = 3.748\,x + 0.2819$) and *E. crus-galli* (R^2 = 0.460; regression equation $y = 5.4756\,x + 0.0189$) (figure 4).

Table 7. Days of feeding on *E. crus-galli*, *L. oryzoides* and *B. maritimus*.

Temperature	*E. crus-galli*	*L. oryzoides*	*B. maritimus*
14 °C	1.6 ± 0.52 (a)	1.60 ± 0.52 (a)	1.60 ± 0.52 (a)
16 °C	3.00 ± 0.67 (c)	3.00 ± 0.67 (b)	3.00 ± 0.67 (a)
18 °C	3.10 ± 0.99 (b)	1.30 ± 1.42 (b)	0.20 ± 0.42 (a)
22 °C	3.50 ± 0.71 (b)	3.30 ± 0.48 (b)	0.90 ± 0.99 (a)
26 °C	4.00 ± 0.00 (b)	3.50 ± 0.53 (b)	1.60 ± 1.58 (a)
28 °C	4.00 ± 0.00 (b)	3.40 ± 0.70 (b)	0.60 ± 1.26 (a)
30 °C	4.00 ± 0.00 (b)	3.40 ± 0.97 (ab)	1.20 ± 1.14 (a)
32 °C	3.00 ± 1.63 (a)	1.80 ± 1.75 (a)	2.90 ± 1.60 (a)
34 °C	3.90 ± 0.32 (b)	3.60 ± 0.52 (ab)	3.00 ± 1.05 (a)
36 °C	4.00 ± 0.00 (b)	2.80 ± 0.92 (a)	3.40 ± 0.70 (ab)
38 °C	3.80 ± 0.63 (b)	2.40 ± 1.07 (a)	2.00 ± 1.05 (a)
40 °C	3.60 ± 0.52 (c)	1.80 ± 0.92 (b)	1.10 ± 0.74 (a)
44 °C	1.00 ± 1.05 (b)	0.30 ± 0.48 (a)	0.10 ± 0.32 (a)
48 °C	0.10 ± 0.32 (a)	0 (a)	0.10 ± 0.32 (a)

Values are shown Mean ± SE; Means followed by different letters in the same line are significantly different at $p < 0.05$ by one-way ANOVA and DMRT.

The activity of the insect assessed as days of feeding over the trial period was related to the host. Major activity was observed on *E. crus-galli*, less on *B. maritimus* (table 7). On *B. maritimus*, the number of days of feeding was significantly lower than on *E. crus-galli* and *L. oryzoides* at nearly all the temperatures tested.

Discussion

The present study identified some of the hosts preferred by *L. oryzophilus*. The trials confirmed that the insect is able to feed only on some specific plants. Among the plants tested, weeds in the family Poaceae were preferred. It was demonstrated that only some cyperaceous plants are accepted as food by RWW since no scar was detected on *S. mucronatus*.

E. crus-galli was the most preferred of all the weeds tested. This supports the report by Tindall *et al.* (2004), where Barnyardgrass was more preferred than rice for feeding and oviposition.

The relation among plants preferred as food by adults and plants on which the development (from eggs to adults) can be completed seems strict. In Lupi *et al.* (2007b), RWW completed development only on *L. oryzoides*, *E. crus-galli*, and *B. maritimus*, whereas neither larvae nor pupae were detected on *A. geniculatus*, *H. reniformis*, and *S. mucronatus.*

Trials from 10 to 50 °C allowed to acquire information about the insects behaviour in function of the temperature and host. The wide range of feeding activity (14-48 °C; preferred range: 26-34 °C), demonstrated the adaptability of this species to various conditions and helps explain the wide geographic occurrence of this species (e.g., in the United States, China, Korea and Italy).

Studies on feeding behaviour of *L. oryzophilus* on different weeds might help understand the factors that influence the population dynamics of the pest in fields. According to Norris and Koogan (2005), the complexity of the interaction between arthropods and weeds increases when assessed at ascending ecological scales from individual to population level to ecosystem or ecoregion. For RWW it may be important to control certain weeds since they provide food and shelter where and when rice is not cultivated, especially in spring before rice emergence or when rice is unsuitable for insect feeding, owing to its physiological maturity. Furthermore the presence of certain weeds in the spring contributes to the development of flight muscles and oogenesis. For proper management of RWW via an integrated pest management (IPM) program, at a farm-level, the growers can manipulate weed presence/absence in fields and in non-cropped areas, such as field margins or adjacent fields in hope of decreasing RWW population and, consequently, rice attack. Anyway, this approach could be unsuccessful as host weeds are very widespread and the RWW can fly long distances. Trying to manage RWW through regional vegetation, management would require an immense amount of efforts and cooperation by farmers over a large area. Besides attention needs to be paid to weed management as RWW, colonizing the weeds, may be driven onto the crop when the weeds are removed, with intense crop losses.

At a landscape or ecoregion level the presence of weeds that support RWW could represent, in a fragmented landscape, a pathway for insect spread. This approach is really important when a newly introduced species (e.g. RWW) is involved. Management at this level is immensely difficult because of the requirement of cooperation among farmers, private and public agencies.

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