JOURNAL OF ENTOMOLOGICAL SOCIETY OF IRAN
2018, 38(2), 137–148
نامه انجمن حشره‌شناسی ایران ۱۴۸– ۱۳۷ ,(۲)۳۸ ,۱۳۹۷

DOI: 10.22117/JESI.2018.121942.1226

Double cropping rice systems affect biological parameters of *Chilo suppressalis* (Lepidoptera: Crambidae)

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Abstract
The inclination of rice growers towards double cropping system has raised new concerns about changes in pest biological parameters and the excessive release of pesticides in the environment. In this study, some biological traits of the overwintering larvae of *Chilo suppressalis* (Walker) was compared between single and double cropping rice fields in the northern Iran during 2016 and 2017. Under the same geographical locality, a significantly higher density of the overwintering larvae was observed in double cropping fields during November-March of both years, while larval mortality was lower in double cropping fields. The larvae collected from double cropping fields had significantly wider head capsules and tended to be heavier than those from single cropping ones. Additionally, both male and female pupae collected from double cropping fields had significantly higher body mass than those from single cropping fields. A significant increase in the number of days required for pupation of the overwintering larvae was observed under double cropping system. However, the adult moths emerged from these pupae were significantly higher fecund than those reared from single cropping fields. Results of this study highlight significant changes in some biological traits of *C. suppressalis* under double cropping system. At least, some of these changes are expected to affect the level of crop damage in the next growing season and thereby, demand higher rates of pesticides for satisfactory management of the pest. Therefore, further studies are needed to explore the pest status and management of *C. suppressalis* under double cropping system.
Key words: rice stem borer, double rice cropping, overwintering larvae, mortality, fecundity

اثر سیستم دوکشتی برنج بر برخی خصوصیات زیستی کرم ساقه خوار برنج
Chilo suppressalis (Lepidoptera: Crambidae)

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چکیده
در سال‌های اخیر، تمایل کشاورزان به سیستم دوکشتی برنج نگرانی‌هایی در زمینه تغییر در خصوصیات زیستی آفات و کاربرد بی‌رویه حشره‌کش‌های شیمیایی ایجاد کرده است. در مطالعه حاضر، برخی ویژگی‌های زیستی لاروهای زمستانگذران کرم ساقه‌خوار برنج، *Chilo suppressalis* (Walker) در مزارع یک بار کشت و دو بار کشت برنج در شمال کشور مورد مقایسه قرار گرفت. نمونه‌برداری از مزارعی که در مناطق جغرافیایی یکسان قرار داشتند نشان داد که فراوانی لاروهای زمستانگذران در طول ماه‌های آبان تا اسفند دو سال زراعی ۱۳۹۵ و ۱۳۹۶ در مزارع دوکشتی به میزان معنی‌داری بیشتر از مزارع تک‌کشتی است، در حالی که درصد مرگ و میر لاروها در مزارع دوکشتی کمتر از مزارع تک‌کشتی است. عرض کپسول سر در لاروهای زمستانگذران جمع‌آوری شده از مزارع دوکشتی به میزان معنی‌داری بیشتر از مزارع تک‌کشتی بوده و وزن آنها کم و بیش بیشتر از لاروهای جمع‌آوری‌شده از مزارع تک‌کشتی بود. به علاوه، شفیره‌های حاصل از لاروهای زمستانگذران، در مزارع دوکشتی به میزان معنی‌داری سنگین‌تر از مزارع تک‌کشتی بودند. لاروهای جمع‌آوری شده از مزارع دوکشتی به تعداد روزهای بیشتری برای شفیره‌شدن نیاز داشتند، با این حال، شب پره‌های حاصل از این شفیره‌ها، زادآوری

Received: 21 May 2018, *Accepted:* 4 September 2018
Subject Editor: Ahad Sahragard

بیشتری در مقایسه با حشرات مزارع تک‌کشتی داشتند. نتایج این مطالعه نشان می‌دهد که برخی از ویژگی‌های زیستی کرم ساقه‌خوار برنج در سیستم دوکشتی برنج تحت تاثیر قرار می‌گیرند. حداقل برخی از این تغییرات ممکن است روی فراوانی و شدت خسارت آفت در فصل زراعی بعدی تأثیر گذاشته و در نتیجه، تقاضا برای کاربرد حشره‌کش‌های شیمیایی به منظور کنترل آفت را افزایش دهند. بنابراین، پیشنهاد می‌شود در برنامه‌های مدیریتی، از مجموعه‌ای از روش‌ها به صورت تلفیقی استفاده شود تا در کنار مدیریت کارآمد آفت، از ورود بی‌رویه آفتکش‌ها به محیط زیست جلوگیری شود.

واژه‌های کلیدی: کرم ساقه‌خوار برنج، سیستم دوکشتی برنج، لارو زمستانگذران، مرگ و میر، زادآوری

دریافت: ۱۳۹۷/۰۲/۳۱، پذیرش: ۱۳۹۷/۰۶/۱۳.

Introduction

Asia, particularly southeastern Asia and the Middle East, account for about 90% of the global rice production and consumption (Hossain & Narciso, 2004). Despite being cultivated on small and fragmented farmlands with population pressure and the risk of land use change, the global rice production has experienced significant increase over the last half century. This increase is largely related to the technological advances in irrigation and crop management as well as development of double cropping systems in many growing areas (Hossain & Narciso, 2004; Fan *et al*., 2012). Mazandaran and Guilan Provinces are the major centers for rice cultivation in Iran, accounting for about 78% of the cultivation area and rice production of the country (Daliri *et al*., 2009). Within four decades (1980-2010), Iran has changed from the leading rice importing country (Calpe, 2006) to the eleventh rice producer of the world (Feizabadi, 2011).

During the last decades, multiple cropping, *i.e*. production of two or more crops per year on the same land, has received growing attention as a mean for increasing crop production without increases in cultivated areas. Multiple cropping systems are designed for optimum use of natural resources in regions in which factors such as sunshine, temperature, water and soils are not limiting. However, the potential impacts of double cropping systems on pests biology and performance have been very poorly studied (Kega *et al*., 2015). Although, crop rotation and intercropping with nectar bearing plants, such as sesame, soybean, and clover, has proved as an efficient mean of reducing pest and weed damage (Gliessman, 1985; Filizadeh *et al*., 2007; Xu *et al*., 2017), double cultivation of the same plant may result in a converse impact on pest populations through providing longer and continuous food resources for the pests. For example, the African white rice stem borer, *Maliarpha separatella* Rag. (Lepidoptera: Pyralidae) has been shown to establish higher number of larvae and cause higher frequency of white head symptoms in rice double cropping systems when compared to single rice cropping (Kega *et al*., 2015).

During the last decade, double cultivation of rice has become very popular in paddy fields of the northern Iran as a mean for raising farmer's income and increasing rice production. Although, the regular growing period for single cropping system is late March to early August, the second cropping can prolong food availability for the pests by early November. Besides economical advantages, double rice cropping may cause a variety of concerns such as increase in pest populations and changes in life cycle parameters of pests through prolonging the availability of food resources during the overwintering period. In particular, abundance and survival of the overwintering larvae, as well as the fecundity of adult moths in the next generation are expected to increase because they have had higher access to fresh food resources before being prepared for the overwintering period. Pesticides such as diazinon and fipronil are extensively used for management of *C. suppressalis* in Asia (Zibaee *et al*., 2009; Yao *et al*., 2017). Under double cropping systems, higher frequency of pesticides applications would be required for efficient control of the pests. Besides the harmful effects of these pesticides on human health, the environment, and non-target organisms (Elzen *et al*., 2000; Brunner et al., 2001; Sun *et al*., 2008; Cheng *et al*., 2010; Rogers *et al*., 2011), higher pesticides pressure can accelerate the development of pesticide resistance by the pests.

In this study, some biological parameters of the stripped rice stem borer, *Chilo suppressalis* (Walker) (Lepidoptera: Crambidae), were compared between single and double cropping systems of northern Iran during two growing seasons of 2015 and 2016. *C. suppressalis* is one of the most important pests of rice in Europe, Southeastern Asia and the Middle East, including Iran (Zibaee *et al*., 2009). A variety of broad spectrum pesticides are extensively used for management of this pest in Iran. Irrespective of the reduced efficiency of these compounds due to cryptic activity of the larvae as well as resistance development of the pest, they can negatively affect human health, non-target organisms, and the environment (Li *et al*., 2007, Yao *et al*., 2017). Therefore, it is of great importance to study the effect of double cropping system on different life parameters of the pest.

Materials and methods

Population density and mortality rates of overwintering larvae

According to the previous studies, the mature larvae of *C. suppressalis* enter facultative diapause in response to short-day conditions of autumn (August–September) and overwinter in rice stems near the soil surface (Chen *et al*., 2011). In this study, the population density and mortality rate of *C. suppressalis* overwintering larvae was evaluated in both single and double cropping system in four geographically isolated regions of Mazandaran Province (North of Iran) with different climatic conditions during growing seasons of 2015 and 2016. The regions were located at Rice Research Institute of Iran (Amol County, 36˚29'23'' N, 52˚29'40" E), Zargar Mahalleh plain (Babol County, 36˚31'17" N, 52˚34'32" E), Armak semi-plain (Babol County, 36˚29'04" N, 52˚40'36" E), and Eastern Band-e-Pey mountains (Babol

County, 36˚18'38" N, 52˚37'34" E). The experimental units in each region included a single and a double cropping field (~ 3000 m^2). In each field, a first point of sampling was selected randomly and a total of 40 quadratic frames (50 × 50 cm) were placed at 15-m intervals by walking in a zigzag pattern along the field. Within each plot, all rice stalks were finely monitored to record the number of overwintering larvae, as well as the number of dead larvae. In each year, a total of five samplings were done on monthly basis during November to March.

Biological characters of overwintering larvae and pupae

The physical characters of the overwintering larvae and pupae were determined in both single- and double cropped rice fields (~ 4000 m^2), both located at Rice Research Institute of Iran (Amol County, 36˚29' N, 52˚29 E) in two consecutive years. For each cropping system, an approximate of 50 fifth instar larvae were collected in 4 January, 4 February, and 4 March. The larvae were immediately weighed using a digital scale with an accuracy of 0.001 g. The head capsule width of the last instar larvae was measured under a stereo-microscope (Olympus SZ40, Japan) equipped with an ocular micrometer. The larvae were individually transferred into glass tubes (2 cm in diameter, 12 cm in height) and maintained in a growth chamber (25 ± 1 °C, 65 ± 5% RH, 16:8 h = L:D photoperiod) to stimulate pupation and adult emergence. A fresh rice stem (10 cm in length) was placed in each tube to preserve moisture. After pupation, the 3-day old pupae were sexed and weighed using the above-mentioned scale. The pupae were individually maintained in the growth chamber to study the reproductive potential of emerged adults (Ding *et al*., 2013). After adult emergence, one pair of adult moths were released in an Erlenmeyer flask (10 cm in bottom diameter, 20 cm in height) and allowed to mate for 24 hours. Several rice stalks were provided in the Erlenmeyer flask with their cutoff edges being placed on a wet cotton layer to preserve freshness. After 24 hours, the adult males were removed and the females were maintained for further 24 hours. The mated females were then anesthetized on ice and dissected under a stereo-microscope to count the number of eggs carried inside their abdomen (Ding *et al*., 2013).

The diapause intensity is a physiological trait that can be defined as the duration of diapause under given environmental conditions (Xiao *et al*., 2010). The intensity of the larval diapause was evaluated in last instar larvae of *C. suppressalis*, collected from both single- and double cropped rice fields. For this, the last instar diapausing larvae, collected from single - and double cropped fields at 4 January, 4 February, and 4 March of each year, were individually placed inside a glass tube (2 cm in diameter, 12 cm in height), with a fresh piece of rice stem, and maintained in a growth chamber (25 ± 1 °C, 65 ± 5% RH, 16:8 h L:D photoperiod). The larvae were monitored every two days and the date of pupation was recorded (Xiao *et al*., 2010).

Data Analysis

Data were analyzed using SPSS software ver. 17.1 (SPSS, 2015). All data including the number of overwintering larvae, the percentage of dead larvae as well as larval and pupal physical characters, diapause intensity and female fecundity, were compared between single- and double-cropping systems of each year using *t*-student tests. Percentage and numerical data were respectively arcsine- and square-root transformed before being used in analysis. Non-transformed means are presented in tables.

Results and Discussion

Generally, stem borers are polyvoltine, meaning that the number of generations within a year may vary depending on the environmental factors, such as temperature, rainfall, and crop availability (Pathak & Khan, 1994). We hypothesized that double cropping rice system can negatively affect biological traits of the striped rice stem borer from pest management point of view. To test this hypothesis, we compared some biological parameters of the overwintering larvae of *C. suppressalis* between populations collected from single and double cropping rice fields in the north of Iran. To exclude the effect of locality and seasonal factors, the population density and survival of the overwintering larvae was analyzed in four localities, during two consecutive years. As expected, in both years in almost all overwintering months (November-March), significantly higher frequency of the overwintering larvae was observed in double cropped fields regardless of the locality (Table 1). In agreement with these results, Kega *et al*., (2015) reported higher frequency of larvae and white head damages by the African white rice stem borer, *M. separatella*, in double cropping rice systems than single cropping or ratoon crop. Accordingly, our samplings in both years revealed significantly lower percentages of the dead larvae in double cropping fields in almost all studied time points (Table 2). These results may imply that *C. suppressalis* can establish larger population size and suffer lower mortality rate during winter in double cropped fields. This higher overwintering survival may be explained by the higher access of larvae to food resources during late season, which is expected to be reflected in higher storage of energy and larger body size. To test this claim, some physical parameters of the overwintering larvae and resultant pupae were compared between populations from single and double cropped fields. In both years, the larvae collected from double cropped fields, had significantly wider head capsules than those from single cropped ones, at all three sampling time points (Tables 3). Although, the larvae collected from double cropped fields were nearly heavier than those from single cropped ones, the difference between these two cropping systems was not statistically significant (Table 4). However, both male and female pupae emerged from the overwintering larvae of double cropped fields were significantly heavier than those from single cropped fields at all sampling time points in both years (Tables 5 & 6). According to the previous studies, food consumption and energy storage play important roles in overwintering survival of insects (Hokkanen, 1993; Liu *et al*., 2010; Metspalu *et al*., 2013; Knapp & Uhnava, 2014). For example, positive relationships between body weight and overwintering survival have been already reported in the beetle *Meligethes aeneus* Fabricius (Col.: Nitidulidae) (Hokkanen, 1993), and the moths, *Mamestra brassicae* L. (Metspalu *et al*., 2013) and *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae) (Liu *et al*., 2010). Therefore, higher access to fresh food resources at late season of double cropping systems may play a role in more energy accumulation, larger body size, and higher survival of the larvae during overwintering period.

Table 1. The average frequency (±SE) of the overwintering larvae of *Chilo suppressalis* sampled from both single and double cropping rice fields of four geographic locations during overwintering months of two growing seasons (2015 and 2016)

Month	Location 1		Location 2		Location 3		Location 4	
	Single	Double	Single	Double	Single	Double	Single	Double
November 2015	1.44 ± 0.08	1.99 ± 0.09**	0.76 ± 0.05	1.70 ± 0.08**	0.71 ± 0.05	0.82 ± 0.05*	0.78 ± 0.04	0.86 ± 0.08ns
December 2015	1.13 ± 0.07	2.40 ± 0.08**	0.65 ± 0.05	1.36 ± 0.07**	0.60 ± 0.04	0.79 ± 0.07**	0.63 ± 0.03	0.74 ± 0.09ns
January 2016	0.86 ± 0.06	1.11 ± 0.10**	0.54 ± 0.05	1.00 ± 0.07**	0.49 ± 0.04	0.66 ± 0.10*	0.56 ± 0.03	0.71 ± 0.04**
February 2016	0.75 ± 0.05	0.88 ± 0.06*	0.53 ± 0.05	0.82 ± 0.06**	0.50 ± 0.04	0.66 ± 0.05*	0.63 ± 0.04	0.69 ± 0.05ns
March 2016	0.61 ± 0.05	0.75 ± 0.07*	0.52 ± 0.05	0.67 ± 0.06*	0.53 ± 0.04	0.63 ± 0.03*	0.55 ± 0.04	0.66 ±0.03*
Total 2015-2016	0.97 ± 0.03	1.42 ± 0.06**	0.60 ± 0.02	1.10 ± 0.04**	0.60 ± 0.03	0.69 ± 0.03*	0.63 ± 0.02	0.72 ± 0.03**
November 2016	1.49 ± 0.09	1.77 ± 0.10*	0.81 ± 0.08	1.42 ± 0.11**	0.83 ± 0.09	1.11 ± 0.11**	0.89 ± 0.10	1.15 ± 0.10*
December 2016	1.21 ± 0.08	1.94 ± 0.10**	0.72 ± 0.08	1.12 ± 0.09**	0.74 ± 0.06	0.90 ± 0.08*	0.76 ± 0.05	0.95 ± 0.09*
January 2017	0.93 ± 0.07	1.40 ± 0.14**	0.60 ± 0.07	0.96 ± 0.08**	0.54 ± 0.06	0.73 ± 0.11**	0.66 ± 0.07	0.81 ± 0.05*
February 2017	0.83 ± 0.09	1.07 ± 0.09**	0.52 ± 0.07	0.76 ± 0.05ns	0.51 ± 0.03	0.69 ± 0.06**	0.63 ± 0.06	0.73 ± 0.06ns
March 2017	0.74 ± 0.04	0.95 ± 0.08**	0.43 ± 0.04	0.64 ± 0.05**	0.45 ± 0.06	0.66 ± 0.05**	0.49 ± 0.08	0.70 ± 0.06**
Total 2016-2017	1.03 ± 0.04	1.44 ± 0.06**	0.57 ± 0.03	0.90 ± 0.04**	0.58 ± 0.02	0.71 ± 0.04**	0.66 ± 0.03	0.78 ± 0.05*

pairwise comparisons (*t*-tests) were performed between single and double cropped fields of the same locations in each month, ns, non-significant, * and **, significant at $P<0.05$ and $P<0.01$, respectively

Table 2. The average percentage (±SE) of dead larvae of *Chilo suppressalis* sampled from either single or double cropped rice fields of four geographic locations during overwintering months of two growing seasons (2015 and 2016)

Month	Location 1		Location 2		Location 3		Location 4	
	Single	Double	Single	Double	Single	Double	Single	Double
November 2015	0.11 ± 0.02	0.05 ± 0.01**	0.27 ± 0.03	0.10 ± 0.02**	0.30 ± 0.04	0.22 ± 0.03*	0.37 ± 0.03	0.25 ± 0.05**
December 2015	0.20 ± 0.02	0.05 ± 0.01**	0.46 ± 0.04	0.19 ± 0.03**	0.47 ± 0.04	0.30 ± 0.05**	0.48 ± 0.04	0.36 ± 0.05*
January 2016	0.41 ± 0.04	0.22 ± 0.04**	0.54 ± 0.06	0.33 ± 0.05**	0.62 ± 0.04	0.50 ± 0.06ns	0.68 ± 0.04	0.58 ± 0.04ns
February 2016	0.54 ± 0.04	0.26 ± 0.03**	0.61 ± 0.05	0.31 ± 0.04**	0.64 ± 0.03	0.53 ± 0.06ns	0.77 ± 0.04	0.61 ± 0.05**
March 2016	0.62 ± 0.06	0.49 ± 0.06ns	0.80 ± 0.04	0.62 ± 0.05**	0.75 ± 0.05	0.62 ± 0.04*	0.87 ± 0.03	0.71 ± 0.04**
Total 2015-2016	0.37 ± 0.03	0.21 ± 0.05**	0.53 ± 0.03	0.31 ± 0.04**	0.55 ± 0.02	0.50 ± 0.02ns	0.64 ± 0.03	0.54 ± 0.05*
November 2016	0.14 ± 0.03	0.07 ± 0.02**	0.19 ± 0.02	0.08 ± 0.03**	0.24 ± 0.03	0.22 ± 0.04ns	0.26 ± 0.02	0.18 ± 0.03*
December 2016	0.17 ± 0.03	0.09 ± 0.02**	0.32 ± 0.05	0.16 ± 0.04**	0.33 ± 0.02	0.26 ± 0.02*	0.33 ± 0.04	0.24 ± 0.04ns
January 2017	0.29 ± 0.03	0.19 ± 0.04*	0.50 ± 0.06	0.29 ± 0.06**	0.42 ± 0.05	0.30 ± 0.05*	0.38 ± 0.07	0.30 ± 0.04ns
February 2017	0.47 ± 0.05	0.28 ± 0.05**	0.57 ± 0.06	0.38 ± 0.05**	0.51 ± 0.05	0.40 ± 0.04*	0.37 ± 0.03	0.36 ± 0.04ns
March 2017	0.59 ± 0.05	0.33 ± 0.07**	0.65 ± 0.06	0.47 ± 0.07**	0.57 ± 0.04	0.53 ± 0.04ns	0.48 ± 0.05	0.37 ± 0.03**
Total 2016-2017	0.34 ± 0.04	0.19 ± 0.05**	0.47 ± 0.05	0.28 ± 0.04**	0.43 ± 0.04	0.32 ± 0.05*	0.35 ± 0.03	0.30 ± 0.03*

pairwise comparisons (*t*-tests) were performed between single and double cropped fields of the same locations in each month, ns, non-significant, * and **, significant at *P*<0.05 and *P*<0.01, respectively

Table 3. The average head capsule width (±SE) of *Chilo suppressalis* last instar larvae collected from either single or double cropped rice fields during January-March 2016 and 2017

Crop system	2016			2017		
	January	February	March	January	February	March
Single 2016	1.24 ± 0.05	1.33 ± 0.03	1.37 ± 0.03	1.28 ± 0.04	1.31 ± 0.05	1.33 ± 0.05
Double 2016	1.44 ± 0.06**	1.42 ± 0.04**	1.48 ± 0.06**	1.41 ± 0.05**	1.44 ± 0.04**	1.41 ± 0.04**
t value (df)	18.54 (98)	17.19 (98)	22.11 (98)	14.80 (98)	16.11 (98)	8.44 (98)

** in each column shows significant difference at *P*<0.05 and *P*<0.01 level, respectively (*t*-test)

Table 4. The average wet body weight (±SE) of *Chilo suppressalis* last instar larvae collected from either single or double cropped rice fields during January-March 2016 and 2017

Crop system	Head capsule width (mm)			Larval weight (μg)		
	January	February	March	January	February	March
Single 2016	73.25 ± 5.10	79.00 ± 8.77	68.43 ± 6.06	74.07 ± 4.71	72.20 ± 8.31	77.73 ± 8.14
Double 2016	80.14 ± 4.10ns	84.50 ± 4.63ns	81.7 ± 5.3*	83.28 ± 7.52ns	80.48 ± 4.19ns	81.44 ± 6.17ns
t value (df)	2.80 (98)	1.25 (98)	15.07 (98)	1.85 (98)	1.05 (98)	0.94 (98)

* and ** in each column show significant difference at *P*<0.05 and *P*<0.01 level, respectively (*t*-test)

The intensity of larval diapause was evaluated by recording the days required for pupation of the larvae under controlled conditions, according to the method proposed by Xiao *et al*. (2010). The number of days required for pupation of the larvae in double cropped fields was significantly more than those collected from single cropped fields in all three time points (Table 7). This difference may be directly related to prolonged activity of larvae towards late season, as they have enough access to food resources, while the climatic conditions of the studied area are not a limiting factor. In agreement with previous studies (Xiao *et al*., 2010; Ding *et al*., 2013), the diapause intensity weakened as overwintering progressed irrespective of the cropping system (Table 7).

Table 5. The average body weight of male *Chilo suppressalis* pupae collected as overwintering larvae from either single or double cropped rice fields during January-March 2016 and 2017

Crop system	2016			2017		
	January	February	March	January	February	March
Single	43.65 ± 2.6	41.56 ± 2.52	41.40 ± 2.94	42.14 ± 3.58	40.38 ± 2.46[b]	43.40 ± 2.76[b]
Double	50.75 ± 3.41**	47.16 ± 1.71**	50.06 ± 2.01*	48.75 ± 2.35**	49.25 ± 1.66[a]	49.65 ± 3.80[ab]
t value (df)	9.40 (40)	6.16 (33)	3.19 (34)	11.29 (30)	9.82 (34)	8.17 (29)

* and ** in each column show significant difference at P<0.05 and P<0.01 level, respectively (*t*-test)

Table 6. The average body weight of female *Chilo suppressalis* pupae collected as overwintering larvae from either single or double cropped rice fields during January-March 2016 and 2017

Crop system	2016			2017		
	January	February	March	January	February	March
Single 2016	52.20 ± 2.4	52.75 ± 2.39	52.06 ± 1.38	50.11 ± 1.51	51.40 ± 2.59	50.42 ± 2.41
Double 2016	61.60 ± 1.03**	58.53 ± 3.62**	57.31 ± 2.11*	58.18 ± 1.83**	58.64 ± 3.02**	58.01 ± 1.84**
t value (df)	8.48 (38)	8.80 (33)	4.46 (30)	9.11 (28)	12.50 (36)	11.69 (32)

* and ** in each column show significant difference at P<0.05 and P<0.01 level, respectively (*t*-test)

Table 7. The average (±SE) number of days required for pupation of *Chilo suppressalis* overwintering larvae in either double or single cropping rice fields in growing seasons of 2016 and 2017

Crop system	2016			2017		
	January	February	March	January	February	March
Single	36.40 ± 4.84	33.40 ± 2.88	23.50 ± 2.78	40.05 ± 2.60	37.44 ± 3.51	30.37 ± 2.55
Double	45.60 ± 3.97**	42.70 ± 4.89**	34.58 ± 3.92**	45.16 ± 4.39**	43.14 ± 4.32*	38.62 ± 3.29**
t value (df)	19.13 (18)	17.82 (18)	13.15 (20)	12.22 (20)	4.61 (18)	16.55 (22)

* and ** in each column show significant difference at P<0.05 and P<0.01 level, respectively (*t*-test)

The adult moths emerged from the overwintering larvae were allowed to mate and the number of eggs was counted and compared between single and double cropping systems

(Ding *et al*., 2013). According to our results, in both years, female moths collected from the double cropping fields produced significantly higher number of eggs than those reared from single cropping fields in all three time points (Table 8). Again, this difference may be related to the differential energy storage of the moths during the larval stages. Support for this claim comes from many previous studies which show a positive relationship between food consumption, body size, and fecundity in herbivorous insects (Büns & Ratte, 1991; Armbruster & Hutchinson, 2002; Awmack & Leather, 2002; Calvo & Molina, 2005; Knapp & Uhnava, 2014). As a relevant example, a positive correlation between pupal mass and female fecundity has been already reported in the leaf miner moth, *Cameraria ohridella* Deschka & Dimić (Lep.: Gracillariidae) (Walczak *et al*., 2017) and the mosquito, *Aedes albopictus* Skuse (Dip.: Culicidae) (Armbruster and Hutchinson, 2002).

Table 8. The average number (±SE) of eggs carried by adult females of *Chilo suppressalis*, the overwintering larvae were collected from either double or single cropping rice fields at three consecutive months (January-March 2016) and reared in the laboratory until adult emergence,

Crop system	2016			2017		
	January	February	March	January	February	March
Single	193.53 ± 8.40	199.07 ± 6.38	178.43 ± 15.49	207.25 ± 11.61	211.83 ± 9.77	199.84 ± 11.60
Double	270.47 ± 16.77**	273.53 ± 11.41**	284.71 ± 20.59**	265.15 ± 17.73**	259.48 ± 13.02**	240.52 ± 14.84**
t value (df)	11.13 (28)	17.13 (30)	32.68 (26)	22.19 (26)	18.24 (32)	14.84 (30)

** in each column shows significant difference at *P*<0.01 level (*t*-test)

Conclusion

The number of generations in different species of rice stem borers has been argued to be a function of temperature, daylight, and availability of food resources. Indeed, whenever only one single rice crop is grown within a year, the borers aestivate or hibernate for a relatively long period. However, in area where two or more rice crops are grown within a year, the borers can remain active throughout the year or undergo only a temporary quiescent stage or weak diapause for short periods when the host plants are absent in the field (Pathak & Khan, 1994). As a consequence, the increased number of pest generations is inevitable under multiple cropping systems, a condition that may affect the annual life cycle, seasonal occurrence, and population dynamics of the pest. Results of the current study showed that some biological parameters of the overwintering larvae of *C. suppressalis* are different between populations grown in single or double cropping systems. The overwintering larvae in double cropping fields had wider head capsules and produced heavier pupae than those grown in single cropping fields. Additionally, a significantly higher frequency of the overwintering larvae with lower percentage of mortality was observed in populations sampled from double cropping fields. The larvae in double cropping systems required longer time for pupation. However, the adult moths, emerged from these pupae laid a significantly higher number of eggs, in next generation. The differences in biological traits of this economically important pest, especially those associated with fecundity and larval frequency and mortality during winter months, are expected to elevate the level of crop damage at the next growing season and thereby, demand higher rates of pesticides for satisfactory management of the pest under double cropping systems. Therefore, further studies are required to accurately evaluate the level of damage caused by the pest under either double or single cropping rice systems. If this claim is true, some changes in pest control strategies are required to occur in order to avoid the excessive release of broad-spectrum pesticides in the environment. In this context, a variety of biological control agents, resistant rice cultivars and more selective pesticides with lower toxicity to non-target organisms can be integrated for efficient management of the pest.

Acknowledgements

The authors would like to appreciate the Rice Research Institute of Iran-Deputy of Mazandaran for assigning the rice field and the laboratory equipment required for this study. We are also grateful to Maesoumeh Ghalandari, Taraneh Oskoo, Mohsen Omrani, Ne'mat Darvishzadeh, and Hosein Daryabari for their generous helps with this study.

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