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水稻二化螟的交配行为

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摘要:在室内条件下,对水稻二化螟 *Chilo suppressalis* 的交配行为及能力进行了研究。结果表明:大多数二化螟雌蛾一生只交配一次,平均0.92次;而雄蛾具有多次交配能力,最多达4次,平均2.72次。二化螟雌蛾的日龄影响其交配率、交配起始时间和持续时间,随二化螟雌蛾日龄的增加,其交配率逐渐下降,交配起始时间逐渐提前,而交配持续时间逐渐上升。相反,二化螟雄蛾日龄对其交配率、交配起始时间和持续时间没有明显影响。交配日龄对二化螟雌蛾的生殖力也存在显著影响,随着二化螟雌蛾交配日龄的增加,雌蛾产卵量下降,卵孵化率降低,产卵期缩短,它们都与雌蛾交配日龄存在显著的负相关;而雌蛾产卵前期和雌蛾寿命随雌蛾交配日龄的增加而延长,与雌蛾交配日龄存在显著的正相关。但二化螟雄蛾交配日龄对雌蛾的生殖力没有明显影响,二化螟雄蛾一生都具有较强的交配繁殖能力。同时,不同交配史的雄蛾与雌蛾交配,对雌蛾的生殖力也没有显著影响。表明二化螟的交配活动是由雌蛾主导控制的。最后,对这些结果在二化螟性信息素防治中应用的可行性进行了探讨。在应用性信息素控制二化螟的实践中,可以在两方面取得实效,一是性信息素可以阻碍雌雄之间正常交配,降低交配率;二是可以推迟二化螟雌虫的交配,使其产卵量和卵孵化率降低。

关键词:二化螟;交配行为;延迟交配;雄虫交配史

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Mating behaviour of the rice stem borer, *Chilo suppressalis* (Walker)

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Abstract: In China, the rice stem borer (RSB), *Chilo suppressalis* (Walker) causes (extensive rice damage and yields loss. One of compatible management strategies and methods for an integrated approach to the RSB control is to manipulate RSB's reproductive behavior, which suppression of pheromonal communication via trapping and interfering mating is a particularly common method. Therefore, it's very important to understand the mating process, the factors affecting it as well as its role in reproduction. In this study, we focused on RSB mating ability, the effects of delayed mating and male mating history on the longevity and reproductive performance of female RSB under laboratory condition.

When daily paired with 2-day-old virgin males, females normally copulated only once in their whole life span. However, the mating frequency of males was much higher, 2.7 times per life span when they daily paired with 2-d-old virgin females, few males could even mate 4 times during their life span. Female age influenced mating behavior as well: the ratio of mating increased with the age and reached the maximum when females were 2 or 3 days old, then, decreased rapidly with age. The onset time of mating (time after light switched off) would start earlier with the increase of the female age, which ranged from 225.5 min to 120.0 min. However, the duration of mating prolonged as the female mating age increased. On the contrary, both the starting time and duration of mating were not significantly affected by mating age of males.

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In another experiment, the mating of virgin male and female RSB moths of different age groups (female 1, 2, 3, 5 and 7 d, and male 1, 2, 3, 4 and 6 d, respectively) were delayed to determine the effects of delayed mating on female longevity, preoviposition period, oviposition periods, fecundity, and egg fertility. The results indicated that female delayed mating significantly influenced the reproductive output and longevity of female RSB. Both female longevity and the preoviposition period increased as female mating age increased, showing positive correlation. When female mated on following night of eclosion, they survived for 6.3 days in average. Longevity increased as mating delayed, which females could survive for 10.2 days when their mating was prolonged for 7 days. And virgin females survived even longer, 10.6 days. However, female delayed mating had negative impact on the oviposition period, fecundity and egg fertility. The oviposition period decreased with the mating delay, depending on the mating age. Oviposition was delayed or disappeared in the absence of mating, and virgin females laid an average of 18 eggs, which indicated that mating could result in the maturation and deposition of eggs. Mean fecundity and egg fertility were 241.3 and 98.3% for the female mating in the day after emergence, and 96.2 and 75.5% for the mating at 7 day after emergence. Both were reduced significantly when mating was delayed over 5 days after emergence. The reduced fecundity and fertility with female mating delay resulted in a 69.4% decrease in the number of viable eggs laid. On the contrary, delayed mating of male had less impact on reproductive output and longevity of female RSB than that of female, no matter how long the male mating had delayed. In addition, we also studied the effect of male mating history on female reproductive output. The results showed that males with different mating history did not result in a significant difference in the quality of their contributions to females.

In conclusion, the female mating delay caused more negative impact on female reproductive potential than that of male. Therefore, reducing the mating rate as well as delaying mating can help us to successfully control RSB in the field using the sex pheromone.

Key words: *Chilo suppressalis*; mating behavior; delayed mating; mating history

二化螟 *Chilo suppressalis* (Walker) 是水稻的重要害虫。随着我国耕作制度和水稻品种的改变,全球气候变暖,二化螟的生存环境极大改善,种群数量显著上升。以二化螟为主的水稻螟虫成为继20世纪80年代稻飞虱、90年代棉铃虫之后又一严重威胁国计民生的重大害虫[1]。目前,我国水稻二化螟防治主要依靠化学农药,导致二化螟的抗药性明显上升,如江苏高淳和徐州等地的二化螟抗性已达高水平[2]。为了克服施用化学农药给农业生态系统所带来的一系列不良影响,实现农业的可持续发展,开展二化螟的无公害防治迫在眉睫。当前,在诸多无公害防治措施中,应用性信息素防治二化螟已取得很大进展[3]。在害虫防治过程中,了解害虫的交配过程、掌握影响交配过程的因子及交配过程对害虫生殖力的影响是采用性信息素控制害虫的基础[4]。许多研究结果表明,在采用性信息素防治害虫时,害虫不同交配史和延迟交配能显著降低害虫的产卵量和卵孵化率[5~8]。在室内对二化螟的交配行为进行较为系统的研究,可为水稻二化螟性信息素防治提供进一步的理论依据。

1 材料与方法

1.1 供试虫源

供试水稻二化螟主要来自田间越冬代老熟幼虫,带回室内在培养箱中培养。用玻璃小试管(直径1.2 × 高8.0 cm)分装,每管2头幼虫,管口用棉球塞住。待幼虫钻入棉球后(在棉球内化蛹),瓶底用注射器注入2 ml灭菌水保湿。保持培养箱内温度25℃,光照16:8 h (L:D) (每晚20:00熄灯),供老熟幼虫正常化蛹。每天按时收集雌、雄蛹,蛹采用单头、单管饲养(避免蛹羽化后雌、雄蛾的交配),管底用棉球保湿,管口用棉球塞住。每天定时观察二化螟蛹的羽化情况,收集成虫备用。

1.2 实验设计

1.2.1 二化螟交配次数的测定 从二化螟雌蛾羽化之日起,单头引入200 ml的透明塑料杯中,杯底放有一吸水的棉球,暗期前1 h每杯中引入1头2日龄的处女雄蛾。每天早上用另1头2日龄的处女雄蛾替换前晚杯

中的雄蛾,直到雌蛾死亡。待雌蛾死亡后在显微镜下解剖其交配囊,检查精包有无及数量,精包的个数代表雌蛾的交配次数。本实验设25次重复;二化螟雄蛾交配次数的测定方法同前。

1.2.2 日龄对二化螟交配的影响 设羽化当晚的二化螟成虫日龄为0,第二天羽化的成虫日龄为1,依次类推。处女雌蛾根据推迟交配时间分为5组,即1日龄、2日龄、3日龄、5日龄和7日龄(预备实验结果表明,雌蛾一生平均寿命为10.2 d;雄蛾平均为7.1 d)。每年龄组25头,把单头雌蛾引入200 ml的透明塑料杯中,杯底放一吸水棉球。在进入暗期前1 h每雌蛾引入1头2日龄的处女雄蛾。在雌、雄配对当晚,每隔30 min红灯观察其交配行为。如正常交配,则记载其交配的起始时间及持续时间。处女雄蛾根据推迟交配时间分为5组,即1日龄、2日龄、3日龄、4日龄和6日龄,每年龄组25头。其他操作同前。

1.2.3 二化螟雌蛾推迟交配对其生殖生物学特性的影响 成虫日龄的设定同前。处女雌蛾根据推迟交配时间分为5组,即1日龄、2日龄、3日龄、5日龄和7日龄,每年龄组50~60头。把单头雌蛾引入200 ml的透明塑料杯中,杯底放有一吸水的棉球,同时放入长5 cm、宽2 cm的1条蜡纸,以便于雌蛾在上面产卵。暗期前1 h每雌蛾引入1头2日龄的处女雄蛾。在雌雄配对的当晚,每隔30 min红灯观察其交配行为。杯中的雌雄蛾如果没有成功交配,就把它们去除,不再继续观察。如果能成功交配,第二天早上把雄蛾去除,每天定期查看蜡纸条上是否有二化螟卵。一旦发现蜡纸条上出现卵块,每天用新的蜡纸条替换含卵蜡纸条,把含卵蜡纸条放入培养皿中保湿培养,直到幼虫进入黑头期。同时记载雌蛾寿命、产卵前期、产卵期、产卵量和卵孵化率,直至雌蛾死亡。

1.2.4 二化螟雄蛾推迟交配对雌蛾生殖生物学特性的影响 用于交配的处女雄蛾根据推迟交配时间分为5组,即1日龄、2日龄、3日龄、4日龄和6日龄,每年龄组50~60头。其他操作见前"二化螟雌蛾推迟交配对其生殖生物学特性的影响"部分。

1.2.5 二化螟雄蛾多次交配对雌蛾生殖力及寿命的影响 把单头处女雄蛾与多头处女雌蛾配对,保持1~3d,根据雌蛾体内所含的精包数来确定雄蛾交配史(已交配次数)。2日龄处女雌蛾与具有不同交配史的雄蛾(处女雄蛾、交配1次、2次、3次和4次)配对。交配行为具体操作步骤同前。

1.3 数据分析

不同处理间的数据采用单因素方差分析(One-Way ANOVA, SPSS 10.0)进行比较。百分率数据在比较前先进行反正弦变换。

2 结果与分析

2.1 二化螟雌蛾和雄蛾交配次数的测定

在25头雌蛾中,有23头能正常交配,雌蛾交配率较高。但雌蛾一生交配次数有限,在交配雌蛾中,没有发现多次交配现象,每只雌蛾平均交配0.92次。而在25头雄蛾中,有22头能正常交配,其余3头在2d内死亡。可见,雄蛾的交配率和雌蛾相当。但雄蛾一生交配次数远高于雌蛾,每只雄蛾平均交配2.72次,其中有5头雄蛾交配可达4次。

2.2 二化螟日龄对其交配的影响

由表1可见,二化螟雌蛾的日龄显著影响其交配行为。1日龄雌蛾交配率为44%;2~3日龄雌蛾达到高峰,约70%。然后急剧下降,7日龄雌蛾的交配率仅有4%。相反,交配日龄对二化螟雄蛾交配能力的影响较小,6日龄雄蛾的交配率仍高达48%。二化螟雄蛾的寿命在室内同条件下大约为7.1 d,可见雄蛾在死前一直保持较高的交配能力。1日龄处女雌蛾平均在熄灯225 min后开始交配,随着雌蛾交配日龄的增加,交配起始时间逐渐提前,7日龄雌蛾的交配起始时间平均为熄灯后135 min,较1日龄处女雌蛾的交配起始时间提前90 min。而雄蛾日龄对交配起始时间基本没有影响,在熄灯后210 min左右开始交配。交配日龄对成虫交配持续时间也有显著影响。低日龄交配持续时间短,随着日龄的增加,成虫交配持续时间逐渐延长。1日龄雌、雄蛾平均交配持续时间分别为86 min和97 min,而7日龄雌蛾和6日龄雄蛾平均持续时间为167 min和163 min,相应接近1日龄的2倍。

表1　二化螟日龄对其交配活动的影响

Table 1　Effect of RSB age on mating activity

日龄 Age indays		观察对数 No. of pairs observed	交配对数 No. of pairs mated	交配率 Ratio of mating (%)	交配起始时间* Onset time of mating (min)	交配持续时间 Duration of mating (min)
♀	1	25	11	44.0	225.5±7.2a	86.3±4.9b
	2	25	18	72.0	200.6±8.9a	113.9±4.6ab
	3	25	17	68.0	163.9±6.2b	134.2±6.9a
	5	25	7	28.0	150.1±7.1b	146.6±8.5a
	7**	25	1	4.0	120.0	150.0
♂	1	25	12	48.0	208.8±8.5a	97.5±6.3b
	2	25	20	80.0	218.4±12.9a	122.3±4.1b
	3	25	18	72.0	225.4±10.6a	136.0±5.2ab
	4	25	16	64.0	207.3±9.4a	106.1±7.3b
	6	25	12	48.0	215.7±15.7a	163.5±6.5a

* 为熄灯后时间 Time after light switched off; * * 数据不参与统计 Data not used to be compared;同一列数据(平均值±标准误)标有不同小写字母表示处理间差异显著($p<0.05$) Values (Mean (SE) with different letters in the same row are of significant difference ($p<0.05$)

2.3　二化螟交配日龄对雌蛾生殖力及寿命的影响

雌蛾交配日龄对其生殖力和寿命的影响见表2。随着雌蛾交配日龄的增加,雌蛾产卵量(y_1)、卵孵化率(y_2)依次下降,5日龄后达显著水平。同时,雌蛾产卵期(y_3)也相应显著缩短。它们都与雌蛾交配日龄(x)存在显著的负相关($y_1=-25.866x+285.176$, $n=5$, $R^2=0.943$; $y_2=-4.166x+105.476$, $n=5$, $R^2=0.921$; $y_3=-0.273x+3.364$, $n=5$, $R^2=0.863$)。但随着雌蛾交配日龄的增加,雌蛾的产卵前期(y_4)和寿命(y_5)显著延长,与雌蛾交配日龄存在显著的正相关($y_4=1.034x+0.376$, $n=5$, $R^2=0.991$; $y_5=0.711x+6.172$; $n=5$; $R^2=0.920$)。处女雌蛾的产卵量和卵孵化率显著低于已交配雌蛾,但产卵期和产卵前期及寿命长于已交配雌蛾。此外,还发现处女雌蛾产卵一般散产,而交配雌蛾产卵一般聚集成块。

表2　二化螟雌蛾交配日龄对其生殖力及寿命的影响

Table 2　Effect of female mating age on reproductive output and longevity of RSB

交配日龄 Mating age	雌蛾数 No. females	产卵前期 Preoviposition period	产卵期 Oviposition period	产卵量 Fecundity	卵孵化率 Egg fertility	寿命 Longevity
1	30	1.3±0.1a	3.0±0.2a	241.3±15.2a	98.3±0.2a	6.3±0.1a
2	30	2.7±0.1b	2.6±0.1b	236.7±10.3a	97.4±0.4a	8.0±0.2b
3	30	3.5±0.1c	2.8±0.1ab	230.8±12.7a	97.8±0.5a	8.2±0.1b
5	25	5.2±0.1d	2.3±0.1c	155.3±19.3b	83.4±7.8b	9.4±0.1c
7	25	7.8±0.1e	1.2±0.1d	96.2±14.8c	75.5±6.4c	10.2±0.2c
处女* ♀	24	8.3±0.1	4.1±0.1	18.0±3.1	0±0	10.6±0.2

* 数据不参与统计 Data not used to be compared;同一列数据(平均值(标准误)标有不同小写字母表示处理间差异显著($p<0.05$) Values (Mean±SE) with different letters in the same row are of significant difference ($p<0.05$)

与雌蛾相比,雄蛾交配日龄对雌蛾生殖力和寿命的影响较小,见表3。不同日龄雄蛾与2日龄雌蛾交配对卵孵化率的影响,只有6日龄与1~3日龄雄蛾存在显著差异。不同交配日龄雄蛾对雌蛾的产卵量、产卵期和寿命都没有显著影响。

表3　二化螟雄蛾交配日龄对雌蛾生殖力及寿命的影响

Table 3　Effect of male mating age on female reproductive output and longevity of RSB

交配日龄 Mating age	雌蛾 No. females	产卵期 Oviposition period	产卵量 Fecundity	卵孵化率(%) Egg fertility	寿命 Longevity
1	30	2.5±0.1a	241.7±12.1a	96.1±3.1a	8.3±0.2a
2	30	2.4±0.1a	243.3±16.3a	97.3±2.6a	8.4±0.1a
3	30	2.5±0.1a	230.8±18.6a	98.8±1.3a	8.5±0.1a
4	25	2.3±0.1a	235.3±17.9a	93.4±4.7ab	8.2±0.2a
6	20	2.6±0.2a	236.9±11.5a	89.5±7.4b	8.4±0.2a

同一列数据(平均值±标准误)标有不同小写字母表示处理间差异显著($p<0.05$) Values (Mean±SE) with different letters in the same row are of significant difference ($p<0.05$)

2.4 二化螟雄蛾多次交配对雌蛾生殖力及寿命的影响

由前面结果可知二化螟雄蛾具有多次交配能力,雄蛾最高交配次数可达4次。具不同交配史的雄蛾与雌蛾交配,对二化螟雌蛾生殖力及寿命的影响见表4,雄蛾不同交配史对雌蛾产卵期、卵量、卵孵化率和寿命等生物学指标没有显著不良影响。交配4次的雄蛾与2日龄处女雌蛾交配,雌蛾产卵量及其卵孵化率仍高达251.3个和94.2%,与处女雄蛾交配的结果没有显著差异。

表4 二化螟雄蛾多次交配对雌蛾生殖力及寿命的影响

Table 4 Effect of male multiple mating on female reproductive output and longevity of RSB

交配次数 Mating times	雌蛾数 No. females	产卵期 Oviposition period	产卵量 Fecundity	卵孵化率(%) Egg fertility	寿命 Longevity
0	30	2.5±0.1a	257.1±17.9a	95.9±2.6a	8.3±0.2a
1	30	2.3±0.1a	256.3±14.6a	93.7±1.3a	8.4±0.1a
2	30	2.6±0.1a	238.8±15.2a	96.8±3.2a	8.0±0.2a
3	24	2.4±0.1a	245.3±12.5a	96.4±1.0a	8.2±0.1a
4	18	2.6±0.2a	251.3±19.6a	94.2±5.6a	8.3±0.2a

同一列数据(平均值±标准误)标有不同小写字母表示处理间差异显著($p<0.05$) Values (Mean±SE) with different letters in the same row are of significant difference ($p<0.05$)

3 讨论

本研究表明,二化螟雌蛾没有多次交配现象,这与孙丽娟等[9]的试验结果基本一致。雄蛾具多个夜晚连续交配的能力[10],在本试验中得到进一步的证实,并且发现,其最高交配次数可达4次,平均交配次数为2.72次。这样,在田间应用性信息素防治二化螟时,只有将雌、雄性比增加到3:1或更大时,才能获得较为理想的防治效果。

雌蛾交配日龄对交配率和交配时间的影响显著大于雄蛾。二化螟雌蛾日龄显著影响其交配行为,3日龄前的雌蛾,其交配率保持在较高水平,5日龄后急剧下降,7日龄雌蛾的交配率仅有4%。棉红铃虫 *Pectinophora gossypiella* 当雌、雄配对推迟后,雌蛾很少能交配[11]。此外,在其它蛾类中,随雌蛾日龄的增加,其交配率下降的现象也很常见[6~8]。相反,日龄对二化螟雄蛾交配能力的影响较小,6日龄雄蛾的交配率仍高达48%。随着雌蛾交配日龄的增加,交配起始时间逐渐提前;而雄蛾日龄对交配起始时间基本没有影响,可见二化螟成虫的交配行为由雌蛾主导。雌蛾交配日龄对成虫交配持续时间也有明显影响。低日龄成虫的交配持续时间较短,但随着成虫日龄的增加,平均交配时间逐渐延长。这可能是对推迟交配给雌蛾生殖带来不利影响的一种补偿机制。随交配时间逐渐延长,害虫被捕食性天敌捕食的风险增加,有利于害虫控制。

成虫日龄不仅影响成虫的交配率和交配持续时间,而且也影响成虫的一系列繁殖生物学特性,最为显著的影响是雌蛾产卵量和卵孵化率。随着雌蛾交配日龄的增加,其产卵量、卵孵化率依次下降,这一现象在昆虫中普遍存在[6~8]。该现象在用性信息素防治害虫的实践中无疑具有特别重要的意义。同时,雌蛾产卵期也相应缩短,但雌蛾产卵前期和寿命相应延长,可见交配能促进雌蛾提前产卵,增加产卵量,同时,雌蛾寿命缩短。与雌蛾相比,雄蛾交配日龄对雌蛾生殖力和寿命的影响较小。1~6日龄雄蛾与2日龄雌蛾交配,交配日龄对雌蛾的产卵量、卵孵化率、产卵前期、产卵期和寿命都没有显著影响。相似结果在粉纹夜蛾 *Trichoplusia ni* 中也可见到[12]。相反,也有许多文献报道雄蛾交配日龄对雌蛾生殖力和寿命影响显著,雌、雄蛾交配日龄都显著降低雌蛾生殖力[6,7],可见,雄蛾交配日龄对雌蛾生殖力和寿命的影响依不同害虫种类而异。对水稻二化螟,雌蛾交配日龄对其繁衍后代的影响显著大于雄蛾。这样,在应用性信息素诱捕法防治二化螟时,即使不能完全阻断雌、雄蛾间的交配,但随着绝大部分雄蛾被诱杀,大部分雌蛾不能及时交配,即使有些能获得交配机会,其交配日龄已经大为推迟,这样就可降低雌蛾的产卵量和卵孵化率,部分实现降低田间种群的目标。葛绍奎等[13]在用性信息素诱捕法防治棉铃虫 *Helicoverpa armigera* 时,发现诱杀区棉铃虫卵田间孵化率较对照区下降13.5%;Keiji 在用诱捕法防治甘薯小象甲 *Cylas formicarius* 时,发现诱杀区已交配雌虫体内精子数显著低于对照区[14];师光禄等开展大面积诱杀法防治枣林枣镰翅小卷蛾 *Ancylis sativa* 的试验,结果表明诱杀区和对照

区相比较,有效卵的减退率为68.5%~85.2%[15];盛承发等在沿江稻区用性诱剂诱捕法防治水稻二化螟时,发现与对照区相比,诱杀区每块卵平均卵量显著下降[16]。焦晓国等田间大面积诱杀实验发现诱杀区每块卵平均卵粒数和卵块孵化率均显著低于对照区[17]。

根据二化螟交配行为及交配能力的研究结果,应用性信息素诱捕法或是迷向法防治水稻二化螟时可以在两方面取得防治效果:减少雌蛾的交配率;推迟雌蛾交配,使其错过最适交配时间,从而导致其产卵量及卵孵化率下降。后者是应用性信息素技术控制害虫的间接机制。

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