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Longevity, fecundity, and fertility of the red palm weevil, *Rynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae) on natural and artificial diets

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Abstract: Life parameters including pre-oviposition period, oviposition period, larval and pupal periods, adult male and female development times, and generation span, were obtained for the red palm weevil, *Rhynchophorus ferrugineus* Olivier, reared on artificial diets of oat, potato, pineapple, and palm fiber sheath, and on natural diets of sugarcane, palm heart, and palm leafbase. Significant differences in the duration of all life parameters were found when fed on various diets. The pre-ovipositional periods ranged from 3.15 to 3.61 d, while the oviposition periods ranged from 3.2 d to 3.8 d. The developmental times of larvae ranged from 70.8 d to 102.2 d, while the development time of pupae ranged from 16.1 d to 22.2 d. The developmental time of adults previously reared on natural diets were longer than those fed on artificial diets. Differences in the development time occurred between males and females reared on different diets, except on sugarcane and palm leafbase. The generation span ranged from 93.2 d to 131.3 d. Significant differences in the average number of eggs deposited per female, previously reared in their larval stages on various diets, ranged from 68.2 eggs to 185.2 eggs, while the average number of eggs deposited per female per day ranged from 1.28 eggs to 3.03 eggs. The percentage of hatchability (viability of eggs) ranged from 74.3% to 93.3%. The mean total number of eggs laid by females, eggs deposited 30 d after one full copulation with males of similar age, and rate of egg hatch decreased significantly with increasing weevil age, and ranged from 65.5 eggs (1-d-old female) to 43.5 eggs (45-d-old female). The rate of egg hatch, also decreased significantly with increasing weevil age, and ranged from 75.8% (1-d-old weevils) to 47.4% (45-d-old weevil). The short copulatory period was adequate for insemination of the female during copulation. Feeding of *R. ferugineus* on different diets resulted in different life parameters.

Key words: *Rhynchophorus ferrugineus*, diet, fecundity, egg production, development time

طول عمر وخصوبة وإخصاب سوسة النخيل الحمراء *Rhychophorus ferrugineus* (Curculionidae: Coleoptera) على الأغذية الطبيعية والاصطناعية

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ملخص: تم الحصول على العديد من معدلات أو مقاييس النمو والحياة (فترة ما قبل الإباضة، فترة الإباضة، فترات نمو الأطوار اليرقية والعذارى، فترات نمو الحشرات البالغة الذكرية والأنثوية، وفترة امتداد الجيل) والخاصة بسوسة النخيل الحمراء والتي تم تربيتها على أغذية اصطناعية (مكونة بشكل أساسي من الشوفان والبطاطس والأناناس وألياف جذع النخيل) وعلى أغذية طبيعية (مكونة بشكل أساسي من قصب السكر وقلب النخيل وقواعد أوراق النخيل). وقد وجدت اختلافات معنوية في فترات جميع معدلات النمو والحياة للحشرات التي تم تغذيتها على مختلف الأغذية. تراوحت فترات ما قبل الإباضة من 3,15 يوم إلى 3, 61 يوم، بينما تراوحت فترات الإباضة من 3,2 يوم إلى 3,8 يوم. وتراوحت فترة نمو

اليرقات على الأغذية المختلفة من 70,8 يوم إلى 102,2 يوم، بينما تراوحت فترات نمو العذارى بين من 16,1 يوم إلى 22,2 يوم. فترة نمو الحشرات البالغة التي تم تربيتها على الأغذية الطبيعية كانت أطول من تلك البالغات التي تم تغذيتها على الأغذية الاصطناعية. وقد ظهرت اختلافات معنوية في فترة النمو بين الذكور والإناث التي تم تربيتها على أغذية مختلفة، باستثناء الأغذية المكونة بشكل أساسي من قصب السكر وقواعد أوراق النخيل. وتراوحت فترة الجيل من 93,2 يوم إلى 131,2 يوم. وهناك اختلافات معنوية في معدل عدد البيض الموضوع من قبل أنثى واحدة تم تربية أطوارها اليرقية على مختاف الأغذية، وتراوح العدد من 68,2 بيضة إلى 185,2 بيضة، بينما تراوح معدل عدد البيض الموضوع من كل أنثى بالغة وفي كل يوم من 1,28 بيضة إلى بيضة. وتراوحت نسبة الفقس (قابلية البيض للحياة) من 74,3% إلى 93,3%. وقد انخفض، بشكل معنوي، متوسط مجموع عدد البيض الذي تم وضعه من قبل الإناث (بيض منتج 30 يوماً بعد جماع كامل للإناث مع ذكور بعمر مماثل) ونسبة فقس البيض مع زيادة عمر السوسة، وتراوح عدد البيض الموضوع من 65,5 بيضة (إناث بعمر 1 يوم) إلى 43,5 بيضة (إناث بعمر 45 يوم). وقد انخفضت نسبة الفقس، بشكل معنوي، بزيادة عمر السوسة، وتراوحت النسبة من 75,8% (سوس بعمر 1 يوم) إلى 47,4% (سوس بعمر 45 يوم). وقد وجد أن فترة الجماع كانت كافية لتخصيب الإناث خلال فترة الجماع. وقد نتج عن تغذية سوسة النخيل الحمراء على أغذية مختلفة اختلافات في معدلات النمو والحياة.

كلمات مفتاحية: غذاء، خصوبة، إنتاج البيض، فترة النمو.

Introduction

The red palm weevil, *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae), is an economically important, tissue-boring pest of date palm in many parts of the world. The insect was first described in India as a serious pest of coconut palm (Lefroy, 1906; Nirula, 1956) and later on date palm (Lal, 1917; Buxton, 1918). This weevil has been advancing westwards very rapidly since the mid 1980's (Gomez and Ferry, 1999). It was reached the Kingdom of Saudi Arabia, the United Arab Emirates, and the Sultanate of Oman in 1985 (Abozuhairah et al. 1996; El-Ezaby, 1997; Kaakeh et al, 2001b), Savaran region of Iran in 1996 (Faghih, 1996), Sharquiya region of Egypt in 1992 (Cox, 1993), southern of Spain in 1994 (Barranco et al. 1996), and Israel, Jordan, Palestine and the occupied territories in 1999 (Kehat, 1999). The agroclimatic conditions prevalent in the date producing countries and the unique morphology of the crop, coupled with intensive modern date palm farming, have offered the pest an ideal ecological habitat (Abraham et al., 1998).

Symptoms of damage caused by *R. ferrugineus* on date palm were summarized by Kaakeh *et al*. (2001b). Damage was categorized by the presence of tunnels on the trunk and base of leaf petiole, oozing of thick yellow brown fluid from the tunnels, appearance of frass in and around openings of tunnels, fermented odor of the fluid inside the infested tunnel, appearance of a dried offshoot, production of a gnawing sound by the grubs, presence of cocoon/adults in the leaf axiles, and breaking of the stem or toppling of the crown when the palm is severely infested. The life cycle of laboratory-reared *R. ferrugineus* was reported on date palm trunks (El-Ezaby, 1997) and sugarcane (Rahalaker et al., 1972, 1985; Weissling and Giblin-Davis, 1994, 1995; Aldhafer et al., 1998).

The main objective of this study was to examine the effect of diets on various life parameters of *R. ferrugineus* collected from the field in the UAE, and reared on sugarcane and several artificial diets. Specific objectives were to (1) determine the effect of selected diets on the longevity or larval and adult development times, (2) estimate the fecundity and egg viability (percentage of egg hatch), and (3) determine the effect of mating frequency and duration on egg deposition.

Materials and Methods

Test insects

The insects used in this study were originally obtained from infested palm trees in Masafi area in the Fujairah Emirate in 1997. The insects were cultured in a rearing room of the Plant Protection Laboratory at 24±2°C, 70±5% RH, and a photoperiod of 12 : 12 (L:D) h. Larvae were provided with sugarcane for feeding, while the adults provided with cotton wicks saturated with a 10% sugar solution for feeding and egg laying. Adults were sexed after emergence from cocoons and kept separately in small jars prior to the beginning of the observations. Sexing of adults was done according to the presence of a series of black hairs on the dorsal, frontal part of snouts of males and their absence in the females.

Diets

Table 1 shows the main ingredients of natural and artificial diets used in this study. The methodology of rearing *R. ferrugineus* in sugarcane and artificial diets were previously reported (Kaakeh at al. 2001a). The main ingredient for each artificial diet (oat, potato, pineapple, palm fiber sheath) was blended with water (1 - 2 liter of water for a diet weighing 500 - 1000 g) for approximately 5 minutes. Each artificial diet also included bacto-agar, multi-vitamins, and chemical preservatives. Bacto-agar was dissolved in water and added to other ingredients (sugar, yeast, molasses, and salt). The mixture for each artificial diet was then autoclaved for 20 min at 120ºC. Each artificial diet was poured in diet stainless-steel round trays or cups while still warm. All trays and cups were stored at room temperature until required. Larvae were placed on artificial diets after total coolness. Three natural diets (sugarcane, palm heart, and palm leafbase) were selected. No other ingredients were added or mixed with these diets.

Longevity (larvae and adult development times)

Newly hatched larvae of *R. ferrugineus* (n = 36), deposited by females on cotton wicks, were transferred with a camel's hair brush to artificial diets or pieces of natural diets. Last larval instars, fed on various artificial diets or palm heart and palm leafbase, were transferred to sugarcane stems to make cocoons. The size of sugarcane stems was based on the size of larvae at different developmental stages. The following developmental parameters were recorded: larval period, pupal period, adult male and female development times, and generation time.

Fecundity and egg viability

Cocoons, harvested from the sugarcane stems previously fed on various diets, were placed in plastic containers until adult emergence. Adults after emergence were sexed and one male and one female were placed in small 1-liter glass jars (n = 36 for each sex and diet combination). Adults were provided with cotton wicks saturated with a 50% honey solution for feeding and egg laying.

Table 1. Percentage of ingredients used in artificial diets used to study the longevity, fecundity, and fertility of *R. ferrugineus*.

Diet based on	% ingredients in each diet										
	Sugarcane	**Oat**	**Potato**	**Pineapple**	**Palm Heart***	**Palm Leafbase***	**Palm fiber sheath**	**Sugar**	**Yeast**	**Molasses**	**Salt**
Sugarcane*	100	-	-	-	-	-	-	-	-	-	-
Palm Heart*	-	-	-	-	100	-	-	-	-	-	-
Palm Leafbase*	-	-	-	-	-	100	-	-	-	-	-
Oat	-	100	-	-	-	-	-	2	9	7	1
Potato	-	-	55	-	-	-	-	25	7	12	1
Pineapple	-	-	-	60	-	-	-	25	7	12	1
Oat-Palm fiber sheath	-	50	-	-	-	-	25	10	10	4	1
Oat-Potato	-	35	25	-	-	-	-	20	9	10	1
Oat-Pineapple	-	35	-	25	-	-	-	20	9	10	1

* indicates natural diet

Jars were staked side by side or on the top of each other on working benches. Few holes were made on all lids of boxes and jars for ventilation. Paired males and females were kept together for 63 days. Deposited eggs were transferred from the cotton wicks, using a camel hair brush, and placed on wet filter papers inside the Petri dishes. The total number of eggs deposited from each female, the number of eggs per female per day, the number of hatched eggs, and the % hatching rate were determined.

Adult age and egg deposition

To determine the effect of age of mated females on the production of eggs 30 d after one full copulation, females of different ages (1, 7, 21, and 45 d; n = 12 per female per age), held without males before copulation, were separated from males after the termination of copulation. Each female was placed in a jar and provided with one cotton wick saturated with 10% sugar solution for feeding and egg laying. The cotton wick was replaced weekly and the number of eggs recorded. The viability of the eggs was determined by counting the number of hatched larvae.

Statistical analysis

MSTAT Program (Michigan State University Statistical Package Program) was used to carry out the statistical analysis. Data for life parameters were analyzed for a randomized complete block design (RCBD) according to procedure outlined by Steel and Torrie (1980). Differences in each parameter were evaluated by Analysis of Variance (ANOVA). When F values were significant ($P < 0.05$), means were compared using the Least Significance Difference test (LSD) for all parameters. Data for life parameters (X) were transformed to square root scale of ($X \pm 0.5$) to stabilize variances before analysis. Means of non-transformed data are presented.

Results and Discussion

Longevity (larvae and adult development times)

Significant differences ($P < 0.05$) in the duration of all life parameters of *R. ferrugineus* on different diets were found (Table 2). These included pre-ovipositional period, oviposition period, larval and pupal periods, adult male and female development times, and generation span. The pre-oviposition period ranged from 3.1 d on potato and pineapple diets to 3.6 d on palm leafbase diet. The oviposition period for females reared on various diets ranged from 3.2 d on potato, pineapple, or oat-potato diets to 3.8 d on palm heart diet. These results agree with the estimates of 3-4 d (Ghosh, 1912; Aldhafer *et al*. 1998), 3-5 d (Frohlich and Rodewald, 1970), 3 d (Lever, 1969; Hartley, 1977), and 4.5 d (El-Ezaby, 1977).

Significant differences in the developmental time of larvae occurred when reared on various diets, and ranged from 70.8 d on potato diet to 102.2 d on oat-pineapple diet (Table 2). Diets containing potato, pineapple, and sugarcane resulted in shorter developmental time periods of larvae, as compared with other diets. These time periods were similar to previous estimates of 60-120 d (Lever, 1969) and 69-85 d (El-Ezaby, 1977). In other cases, our results were not comparable (lower or higher) with the estimates of 30-35 d (Ghosh, 1912), 35-38 d (Viado and Bigornia, 1949), 55 d (Nirula, 1956), 60 d (Hartley, 1977), 105 d (Leefmans, 1920), and 165-182 d (Aldhafer et al., 1998).

Table 2. Longevity or development time (d) of different stages of *R. ferrugineus* reared on different diets.

Diet[a]	Parameter, d						
	Pre-oviposition period	Oviposition period	Larval period	Pupal period*	Adult male development time	Adult female development time	Generation span[b]
Sugarcane	3.5 ab	3.6 ab	82.2 e	19.1 cd	75.2 c *	84.3 a	108.4 e
Palm Heart	3.5 ab	3.8 a	86.1 c	21.0 abc	96.3 a ns	96.0 a	124.4 cd
Palm Leafbase	3.6 a	3.7 ab	84.1 d	17.6 de	84.2 b *	71.2 bc	119.0 d
Oat	3.4 abc	3.7 ab	91.2 d	21.2 abc	49.2 g ns	44.7 e	119.4 d
Potato	3.1 d	3.2 c	70.8 g	16.1 e	51.2 g ns	53.2 d	93.2 g
Pineapple	3.1 d	3.2 c	75.1 f	18.3 de	57.2 f ns	51.1 d	99.7 f
Oat-Palm fiber sheath	3.4 abc	3.6 ab	101.1 a	23.2 a	77.3 c ns	73.3 b	131.3 a
Oat-Potato	3.2 cd	3.2 c	99.2 b	20.0 bcd	65.2 e ns	68.4 c	125.6 bc
Oat-Pineapple	3.3 bcd	3.4 bc	102.2 a	22.2 ab	69.9 d ns	72.2 bc	131.0 ab
P	0.001	0.005	0.001	0.001	0.001	0.001	0.001
LSD value	0.251	0.351	3.294	2.653	3.259	3.923	5.483

Means in the same raw followed by the same letter are not significantly different at the $P = 0.05$ level (LSD test). The asterisk "*" indicates significant differences in the development time between males and females reared on the same diet. The "ns" indicates no significant differences.

[a]Last larval instars, reared on all artificial diets, were transferred to pieces of sugarcane stems for pupation.

[b]Generation span includes a time period from the pre-oviposition period to emergence of adults from cocoons (pupal period).

Differences in the developmental time of pupae occurred when larvae reared on different diets, and ranged from 16.1 d on palm leafbase diet to 23.2 d on oat-palm fiber sheath diet (Table 2). Diets containing potato, palm leafbase, pineapple, and sugarcane resulted in shorter developmental time periods of pupae, as compared with other diets. The results agree with the estimates of Aldhafer et al. (1998) where the pupal period last for 21.1 d (range: 19-25 d) for males and 23.3 d (range: 21-26 d) for females.

The longevity or development times of adults previously fed (i.e., reared during their larval stages) on natural diets were significantly ($P < 0.001$ for the overall treatment comparison) longer than those fed on artificial diets (except for oat-palm fiber sheath diet) (Table 2). Diets containing oat, potato, and pineapple resulted in shorter male or female developmental time periods, as compared with other diets. The apparent differences of development periods of adults on natural diets were not clearly understood, especially that the oviposition, larval and pupal periods were similar for both adults previously reared on different diets. The development times of adults reported here were similar to the previous estimates of 50-90 d (Ghosh, 1912), 83.6 d for males and 60 d for females (Viado and Bigornia, 1949), and 60-90 d (Nirula, 1956). The results were considerably lower than those reported by Aldhafer et al. (1998), where the adult longevity period was 161 d (range: 67-257 d) for males and 113 d (range: 70-150 d) for females, and 90-120 d (Lever, 1969) and 120 d (Hartley, 1977). No significant differences in the development time occurred between males and females reared on different diets, except for those reared on sugarcane and palm leafbase diets (Table 2). The development time of males ranged from 49.2 d on oat diet to 96.3 d on palm heart diet. The development time of females ranged from 44.7 d on oat diet to 96.0 d on palm heart diet.

Significant differences in the generation span (a time period from the pre-oviposition period to emergence of adults from cocoons) of *R. ferrugineus* were found (Table 2). Diets containing potato, pineapple, and sugarcane resulted in shorter generation times, as compared with other diets. The generation span ranged from 93.2 d on potato to 131.3 d on oat-palm fiber sheath diet. These time periods were similar to previous estimates of 96 d (Nirula, 1956), 100.5 d for the first generation (El-Ezaby, 1997). The generation span reported here was considerably shorter than the estimates of 95-210 d (Kalshoven, 1981) and 223 d (Aldhafer et al., 1998).

Fecundity and egg viability

All diets were significantly different from each other for eggs deposited per female (Table 3). The numbers ranged from 77.2 eggs on pineapple diet to 185.2 eggs on sugarcane diet. These numbers are comparable to the previous estimates of 127-276 eggs (Ghosh, 1912), 162-350 eggs (Viado and Bigornia, 1949), 204 eggs (Frohlich and Rodewald, 1970), and 77-283 eggs (El-Ezaby, 1997). The numbers also are lower than the previous estimates of 531 eggs (Leefmans, 1920), 355-760 eggs (Nirula, 1956), 200-500 eggs (Lever, 1969; Hartley, 1977), and 55-412 eggs (Aldhafer et al., 1998).

In this study, differences in the average number of eggs per female per day, for females previously reared on various diets, were significant ($P < 0.001$) (Table 3). The numbers ranged from 1.34 eggs on oat-pineapple diet to 3.03 eggs on oat diet. The percentage of hatchability (viability of eggs) ranged from 74.3% on sugarcane diet to 93.3% on palm heart diet. These results agree with the estimates of 79% and 83% egg viability when females reared on coconut and sugarcane, respectively (Nirula, 1956), 87% (Leefmans, 1920), 86% (Viado and Bigornia, 1949), and 65-95% (Aldhafer et al., 1998). The rate of egg hatching increases as temperatures increases (El-Ezaby, 1977). The comparable and lower estimates of fecundity and egg viability by this study and the previous studies may have been due to suboptimal conditions (food type, temperature, and rearing methodology), decreasing or increasing the number of eggs deposited by the females and the rate of egg hatching. In addition, males in this study were confined with females throughout the course of the study. The presence of males in small jars may have interfered with oviposition or increased damage to larvae and eggs (Giblin-Davies et al., (1989). Rannavare et al. (1975) reported that *R. ferrugineus* females laid less eggs when confined with males than without.

Table 3. Egg deposited by females *R. ferrugineus* reared in their larval stage on different diets, kept with males for 63 days, and exposed to multiple copulations.

Diet	No. eggs Per Female	No. eggs per Female per day	No. Hatched Eggs	% Hatching
Sugarcane	185.2 a	2.10 b	137.6 a	74.3 d
Palm Heart	141.7 b	1.65 d	132.2 b	93.3 a
Palm Leafbase	128.4 d	1.81 c	110.3 c	85.9 b
Oat	135.3 c	3.03 a	105.4 d	77.9 c
Potato	68.2 i	1.28 g	54.3 g	79.6 c
Pineapple	77.2 h	1.51 e	56.3 g	72.9 d
Oat-Palm fiber sheath	102.3 e	1.39 f	76.3 e	74.6 d
Oat-Potato	92.3 g	1.35 fg	72.0 f	78.0 c
Oat-Pineapple	96.5 f	1.34 fg	77.4 e	80.2 c
P	0.003	0.001	0.001	0.001
LSD value	2.928	0.077	3.319	3.319

Means in the same column followed by the same letter are not significantly different at the *P* = 0.05 level (LSD test).

Adult age and egg deposition

The effect of age of mated females on the deposition of eggs 30 d after one full copulation with males of similar age, and the rate of egg hatching is given in Table 4. The mean total number of eggs laid by the females decreased significantly (*P* < 0.001) with increasing weevil age, and ranged from 65.5 eggs (1-d-old female) to 43.0 eggs (45-d-old female). The rate of egg hatching also decreased significantly (*P* < 0.001) with increasing weevil age, and ranged from 75.8% (1-d-old weevils) to 47.4% (45-d-old weevil).

Table 4. Eggs deposited by *R. ferrugineus* females mated with males of similar age 30 days after one full copulation.

	Age of mated female (d)					
	1	7	21	45	*P* value	LSD
No. of Eggs Laid	65.5 a	68.0 a	51. b	43.0 c	4.1	0.001
No. of Eggs Hatched	49.5	41.0	25.3	20.4	-	-
Hatching Rate (%)	75.8 a	60.3 b	49.1 c	47.4 c	3.9	0.001

Means in each raw followed by the same letter are not significantly different at the *P* = 0.05 level (n = 12; LSD test).

Females separated from males for periods as long as 30 d still produced fertile eggs. This may indicate that sperm from one mating can produce fertile eggs for the reproductive life of the female. The high capability of female *R. ferrugineus* for sperm storage would assure the continuation of production of offspring under low densities and where the chances of encountering a mate would be greatly reduced. The short copulatory period (2.9 – 4.8 min) reported previously (Kaakeh, 1998) was adequate for insemination of the female during copulation. Females may not need to frequently mate with other males. Insemination of the female by several males may be necessary in the field for maintaining genetic variability in the population.

Life parameters, reported in this study, were estimated at constant temperatures under laboratory conditions. Therefore, direct comparison to field conditions cannot be made, but similar trends are evident. Under field conditions, many factors such as ambient temperatures, affect developmental and reproductive times, and enhance the fecundity at different times over constant temperatures.

Fecundity of *R. ferrugineus* varies among individuals within the same population fed on different food types (unpublished data). Several diet ingredients were necessary for completion pf the life cycle of *R. ferrugineus*. Feeding on different host species or diets have resulted in different rates of most biological parameters. In this study, differences were detected in weevil life parameters on different food types. Differences in total fecundity appeared more closely related to insect physiology than to any other factors.

Many factors, both density dependent and independent (day length, light intensity, and tree nutrition), affect weevil development time and growth rate in the field; some of which were controlled in this study. Other factors affecting the variability in weevil performance were not controlled and difficult to quantify. Temperature fluctuation may directly affect the weevil itself through its effect on developmental time, total fecundity, fertility rate, and weevil survival. The high temperatures during the summer in the UAE might have reduced the reproductive rates and increased the mortality rates of weevils in the field.

The interrelationship of various factors regulating weevil population in this study, as compared with previous reports, may not necessarily all apply, or have the same importance for every individual weevil, or at different population densities, and locations. However, when normal regulating mechanisms break down as a result of unusual phenomenon, conditions of weevils may change. Variations in the results between food types and experiment locations would be expected when experiments are conducted under different conditions.

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