BIODIVERSITAS
Volume 24, Number 6, June 2023
Pages: 3325-3331

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d240627

Short Communication: Feeding trial, biological, and demographic parameters of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on several Graminae species (laboratory trial scale)

ANAK AGUNG AYU AGUNG SRI SUNARI[1], I WAYAN SUPARTHA[1,♥], I WAYAN SUSILA[1], I WAYAN EKA KARYA UTAMA[2], I WAYAN SANDIKA YASA[3], I KADEK WISMA YUDHA[2]

[1]Laboratory of Integrated Pest Management, Faculty of Agriculture, Universitas Udayana. Jl. PB. Sudirman, West Denpasar, Denpasar 80231, Bali, Indonesia. Tel.: +62-361-222450, ♥email: yansupartha@yahoo.com

[2]Doctoral Program of Agriculture Science, Faculty of Agriculture, Universitas Udayana. Jl. Raya Kampus UNUD, Bukit Jimbaran, Kuta Selatan, Badung 80361, Bali, Indonesia

[3]Magister Program of Biotechnology, Faculty of Agriculture, Universitas Udayana. Jl. Raya Kampus UNUD, Bukit Jimbaran, Kuta Selatan, Badung 80361, Bali, Indonesia

Manuscript received: 11 May 2023. Revision accepted: 19 June 2023.

Abstract. *Sunari AAAAS, Supartha IW, Susila IW, Utama IWEK, Yasa IWS, Yudha IKW. 2023. Short Communication: Feeding trial, biological, and demographic parameters of* Spodoptera frugiperda *(Lepidoptera: Noctuidae) on several Graminae species (laboratory trial scale). Biodiversitas 24: 3325-3331.* The fall armyworm *Spodoptera frugiperda* J.E Smith is a new pest that has entered Indonesia. The ability of the *S. frugiperda* pest adaptation to several types of graminae plants is important to determine the distribution of potential hosts in the field. The adaptability of *S. frugiperda* was observed from two parameters, namely biology, and demography, which were tested on three plant types of the Graminae family consisting of hybrida variety corn, Jatiluwih local rice, and sorghum. This research was conducted from May to November 2022 at the Integrated Pest and Disease Management Laboratory (IPMLab), Faculty of Agriculture, Udayana University. The observation was made on several bionomic and demographic parameters. Demographic parameters were determined by observing the gross reproduction rate (*GRR*), net reproductive rate (R_0), intrinsic rate of increase (*r*), generation time (*T*), doubling time (*DT*), and observing the fecundity rate of *S. frugiperda*. The results showed that *S. frugiperda* biology was best in hybrid corn plants with a short duration of larval life. The survival chances were obtained from daily observations of *S. frugiperda*, which decreased on day 32 on hybrid corn and sorghum plants. On the other hand, on Jatiluwih local rice plants, imago's survival chance started to decrease at 34 days old. In observing demographic parameters, lower R_0 and r values and higher T and DT values indicate that hybrid corn plants are the best for S. frugiperda to grow and develop.

Keywords: Biological parameters, demographic parameters, graminae plant, *Spodoptera frugiperda*

INTRODUCTION

The fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), is a polyphagous pest originating from America. This pest eats around 353 plant species belonging to 76 plant families and prefers to attack crops with economic value, such as corn, sorghum, rice, millet, and sugarcane (Montezano et al. 2018; Chormule et al. 2019). *Spodoptera frugiperda* can damage various plants quickly, thereby reducing the nutritional value of the affected plants (Prasanna et al. 2018). In dealing with this pest, farmers generally use insecticides more. However, Idrees et al. (2022a) reported the second instar *S. frugiperda* larvae were susceptible to the tested by synthetic insecticides; broflanilide and abamectin proved to be the most toxic having the highest toxicity index of 100 and 78.29%, respectively, followed by cypermethrin and bifenthrin were showed toxicity index of 75.47 and 66.89%, respectively. Many pest control measures for *S. frugiperda* have been developed by utilizing biological agents, such as *Metarhizium anisopliae*, *Penicillium citrinum*, *Penicillium* sp., and *Cladosporium* sp. These biological agents can potentially infect the immature stages and feeding performance of *S. frugiperda* (Idrees et al. 2023); furthermore, five fungal isolates, *Aspergillus* sp. BM-3 and SE-2-1, *Cladosporium tenuissimum* SE-10, *Penicillium citrinum* CTD-24, and *Beauveria bassiana* ZK-5 could be suitable candidates for developing biopesticides in an integrated manner to control the Fall Armyworm (FAW) population (Idrees et al. 2021b; Idrees et al. 2022a).

This pest has spread to various parts of the world; from its origins in the western hemisphere, it has spread to eastern regions such as Africa to Asia (Goergen et al. 2016; Sharnabasappa et al. 2018). The first time this pest entered the Asian region was reported in India in 2018 (Ganiger et al. 2018) and damaged maize plants (Sharnabasappa et al. 2018). A year later, *S. frugiperda* was found in Indonesia and West Africa (Ahissou et al. 2022; Lestari et al. 2020). In Pakistan, *S. frugiperda* was initially discovered on maize crops in Pakistan's southern province of Sindh in 2019 and has now spread to various parts of the country and attacks maize, millet, and sorghum (Gilal et al. 2020; Khan et al. 2021; Ramzan et al. 2021). Developing *S. frugiperda* control utilizing plant extracts and synthetic pesticides can synergize the toxicity of *S. frugiperda* larvae in Pakistan (Ahmed et al. 2022). The damage caused by *S. frugiperda* eaters to maize crops was enormous; losses of 73% in Latin America (Hruska and Gould 1997) and 21-53% in Africa (Makgoba et al. 2021) have been reported. *S. frugiperda* is a polyphagous pest of various crops (Montezano et al. 2018); however, it shows a preference for maize and sorghum, which are C4 crops, in contrast to C3 crops such as cotton or soybean (Hadke et al. 2015). Young larvae hide in corn leaf buds during the day and emerge at night to feed on the leaves (Day et al. 2017). In addition, if the larvae damage the young leaf shoots or the plant's growing point, they can kill the plant (Supartha et al. 2022a).

The *S. frugiperda* larvae feed on their host plants' stems, leaves, and reproductive parts (Midega et al. 2018). Two *S. frugiperda* strains have been reported worldwide: the maize strain and the rice strain. The maize strain prefers maize and sorghum, while the rice strain prefers grasslands, including rice (Piggott et al. 2021: Herlinda et al. 2022). Larval diets significantly varied the finite and intrinsic increase rates, reflecting that maize was the most suitable diet (Altaf et al. 2022). Changes in insect pest populations depend on the nutrients and properties of their host plants, which affect their population growth (Supartha et al. 2022b). Traits of the life history of insects, including growth, reproduction, and survival, are affected by the different nutrients of the different host plants that the insects feed on during their larval stage (Keerthi et al. 2021a). Demographic studies are important in population dynamics and pest status (Zhang et al. 2019: Li-mei et al. 2021). However, reports from Akhtar et al. (2022) indicated that several biological and demographic parameters were negatively affected by using chlorantraniliprole. Although *S. frugiperda* prefers maize as its main host, other plants can be suitable hosts even without maize (Idrees et al. 2021). Given the further spread of *S. frugiperda* in Indonesia (Supartha et al. 2022b), there is an urgent need to uncover the biological performance of this pest not affect other economically important crops such as maize, sorghum, local rice, and other types of graminae.

Therefore, information about the developmental biology, biotic potential, and life history parameters of this new pest that feeds on diverse plant graminae species is unavailable in Indonesia. It is necessary to conduct a comprehensive study of the biology and life history of *S. frugiperda* on various graminae host plants. Therefore, to understand and predict population growth, it is important to use the life table theory to analyze the development and fecundity of the next generation. It is very helpful for studying insect population biology and community ecological analysis. This helps distinguish different life stages and comprises both sexes in analyzing, interpreting, and explaining recorded data. We aimed to evaluate the impact of three host plants, namely corn hybrida, Jatiluwih local rice, and sorghum, on the life table parameters of *S. frugiperda*.

MATERIALS AND METHODS

Preparation of test

The test insects were sampled in the corn planting area in Bali and reared for 2 successive generations in the laboratory. The insects were reared in the Integrated Pest Management, Faculty of Agriculture, Universitas Udayana laboratory, at a temperature of 25°C. *Spodoptera frugiperda* larvae were reared individually in plastic cups (4 cm high and 5.6 cm in diameter) and supplemented with fresh corn cob until the reared larvae became adults.

The plants to be tested include Corn Hybrida, Jatiluwih Local Rice, and Sorghum. The three types of plants were planted in polybags, and each polybag consisted of 2 plants, each repeated 15 times. The plants used in this preference test were four weeks old. All plants to be tested were planted in polybags with a size (height 19 cm x 22 cm) filled with soil and manure with a ratio of 3:1.

Research design

The study was conducted using the randomized block design (RBD) method and consisted of three treatments, namely Corn Hybrida, Jatiluwih Local Rice, and Sorghum. Each treatment was repeated 15 (fifteen) times. In each replication, 1 (one) pair of adult imago was planted (1 male and 1 female imago), and aeration and light intensity were attempted to be uniform in the study area.

Biological and demographic parameters of *S. frugiperda*

Observation of *S. frugiperda* eggs began with preparing 100 eggs from five females in plastic jars. The eggs are incubated until they hatch. Observations were made daily by recording the number of 1^{st} instar larvae that emerged from the plastic jar. The first instar larvae that appeared were then removed and maintained for long observation of the larval stage. The simulation of biological and demographic parameters shows in Figure 1.

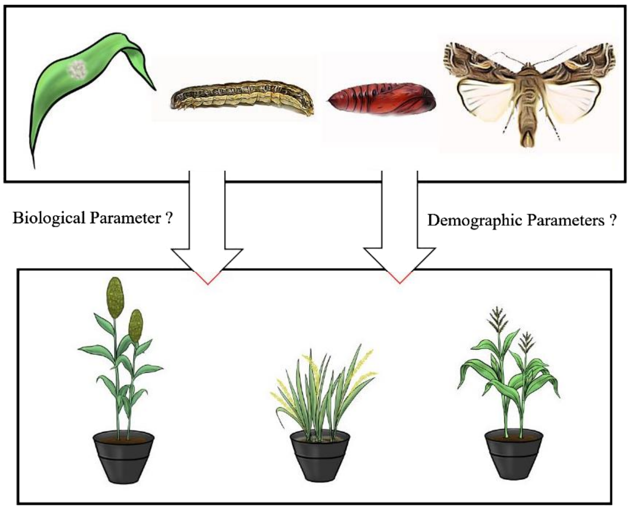

Figure 1. Simulation biological and demographic parameters

Observations of egg stadia included the length of the egg stadia, the number of eggs laid, the number of eggs hatched, and the percentage of hatching. Observation of larval stages using first instar larvae hatched from 100 eggs used at the beginning of the observation. The emerging larvae were placed in plastic containers (length and width = 14 × 9, height = 7 cm) containing their respective feed (Hybrid Corn, Sorghum, Jatiluwih Local Rice). Observation of larval stages was carried out by observing the number of live and dead larvae. Larval development was recorded every day until the larvae became pupae. Observation of this stage provides data on the duration of the larval stage, the distribution of instar ages, and the survival rate of the larvae. The long observation of the pupal stage was carried out from the time the pupa was formed until the pupa became an adult. The pupae formed were placed in a plastic container (diameter = 3 cm, height = 18 cm). This observation produces old data on the pupal stage. The adult that emerged from the pupa in the previous observation was reared in a plastic container containing cotton, which had been moistened with a 10% honey solution as *S. frugiperda* feed and plants (Corn Hybrida, Sorghum, Jatiluwih Local Rice) as a medium for laying egg *S. frugiperda*. Each emerging female adult was exposed to one male adult so that male and female adults could copulate to lay eggs. Exposure was carried out every day and stopped when all adults died. This observation yielded data on male and female adult life cycles and length, preoviposition period, female age when she first laid her eggs, oviposition period, and fecundity. Furthermore, the life expectancy and fecundity data are compiled as a life balance table.

RESULTS AND DISCUSSION

Based on daily observations of *S. frugiperda* on the three types of test plants, the average length of pre-oviposition, oviposition, and post-oviposition successively on corn plants was 2.4, 6.80 and 3.47 days; on sorghum it was 3.2, 6.53 and 3.13 days; and Jatiluwih local rice was 2.73, 7.00 and 3.13 days, respectively. The longest life span of adults was found in corn plants, with an average of 12.60 days, and sorghum and Jatiluwih local rice with an average life span of 11.87 days each. The daily laying rate of the three test plants showed the highest value in corn, with an average of 131.39, followed by sorghum at 129.48 and Jatiluwih local rice at 97.01 eggs/day. The average length of egg hatching in corn plants is 3.37 days, 3.23 for sorghum, and 3.37 for Jatiluwih local rice. The highest laying rate were found in corn plants, with an average laying rate of 131.39 per day, sorghum plants, with an average of 129.48 per day; and Jatiluwih local rice, at 97.01 per day. The average duration of the instars of *S. frugiperda* from instars I to VI on corn plants were 1.27, 1.60, 2.03, 2.60, 2.93, and 3.30, respectively. In sorghum plants, the average duration of instars I to VI was 1.27, 1.87, 2.13, 2.70, 3.03, and 3.33. In Jatiluwih local rice, the average duration of instars I to VI was 1.37, 1.93, 2.37, 2.77, 3.07, and 3.47. The length of the pre-pupa period on corn plants showed an average value of 0.70 days, while the length of the pupal period showed an average value of 9.43 days. While the sorghum plants showed an average value of 0.80 days, the average pupal period was 9.47. Jatiluwih local rice plants show an average value of 0.78 days, and the pupal period shows an average value of 9.20 days (Tables 1 and 2). This aligns with research by Altaf et al. (2022), where *S. frugiperda* prefers corn plants to sorghum, wheat, and rice plants. According to Sharanabasappa et al. (2018) state that the incubation period, larval and pupal periods are 2-3, 14-19, and 9-12 days, respectively by eating sorghum, cabbage, tomatoes, peanuts, and sugarcane.

Studies on the biology of FAW indicated no variation in biological parameters when reared on fodder maize and fodder sorghum; however, they recorded longer larval and pupal duration (16.07 and 10.00 days) when reared on an artificial diet. The adults laid more eggs under crop mosaic conditions with varied phenological crop growth stages, and the fodder maize (782.33 eggs) was most preferred for oviposition (Keerthi et al. 2021b). *Spodoptera frugiperda* female had a strong oviposition preference for maize compared to cabbage and soybean and an aversion to tomato; however, in contrast to oviposition preferences, it was shown that despite low preferences in cabbage, soybean and tomato plants, these crops appeared to provide high benefits for spring performance (Sotelo-Cardona et al. 2021). In selection tests, it was found that moths laid more eggs on highly resistant cultivars and the least on susceptible cultivars; in contrast, larval performance was poor on resistant cultivars but good on susceptible ones. In addition, older FAW larvae showed no discrimination or preference among the tested maize cultivars, indicating that the larvae may have random foraging behavior independent of volatile cues, with low discrimination among hosts and based on visual cues. A previous study also confirmed that plant volatiles does not affect host discovery by FAW, but that tactile cues may be important during oviposition site selection (Guo et al. 2020). The choice of plants is also influenced by the nutritional content in the plants, which has an impact on fecundity and the long duration of adult life (Blair et al. 2019).

The survival rate or chance of survival of *S. frugiperda* was obtained from daily observations made from the egg phase until *S. frugiperda* became an adult. In the three test plants, the lowest survival rate was seen in Hybrid Corn plants, where at 38 days, *S. frugiperda* imago began to show population decline. In sorghum plants, imago age decreased on the 39th day, and in Jatiluwih local rice, it decreased on the 41st day of age. The fecundity of female imago can be determined by counting the number of eggs laid daily. The mx value indicates the number of eggs a female imago aged x days produced. The egg lay in hybrid corn plants after the 27th day, in sorghum plants egg laying after the 28th day, and in Bali rice plants egg laying after the 30th day. The survival and fecundity values for the three types of test plants can be seen in Figures 2, 3, and 4.

Differences in the nutrient content of host plants have a major influence on the life cycle and population change trends of *S. frugiperda* (Wu et al. 2019; Zhao et al. 2020;

Chen et al. 2022). Insect development generally depends on food quality, affecting some *S. frugiperda* instars; the longer larva-to-adult period is thought to reflect a compensatory response in larvae to low-quality feed (Nelly et al. 2023). The nutritional content of maize plants, such as protein and carbohydrates, can affect armyworms' growth and development process. The leaves of maize plants show suitable feed for developing *S. frugiperda*, and good feed quality will affect the duration of larval development. The ability to develop *S. frugiperda* in sweet maize was higher than that of glutinous maize (waxy maize) (Ginting et al. 2020; Dai et al. 2020). Sweet corn leaves contain major nutrients such as starch, protein, vitamin C, fat, amino acids, and higher fiber than glutinous leaves. Insect development generally depends on food quality in the first few instars; a longer larval to adult period reflects a compensatory response in larvae to low-quality feed (Silva et al. 2017; Supartha et al. 2022c).

Table 1. Biological parameters of *Spodoptera frugiperda* on corn, sorghum, and Jatiluwih local rice (N = 30)

Parameters	Corn		Sorghum		Jatiluwih local rice	
	Average ± SE	Range	Average ± SE	Range	Average ± SE	Range
Age of female Imago (days)	10.71 ± 1.05	9-12	10.00 ± 1.22	9-13	11.17 ± 1.47	9-13
Age of male Imago (days)	11.23 ± 1.09	10-13	10.73 ± 1.10	9-12	10.83 ± 1.53	9-14
Length of Eggs to Hatch	3.37 ± 0.49	3-4	3.23 ± 0.63	2-4	3.37 ± 0.49	3-4
Laying Rate (items/day)	131.39 ± 43.34	50-256	129.48 ± 40.65	43-254	97.01 ± 33.31	25-193
Hatching Percentage (%)	97.00 ± 0.015	94-99	95.00 ± 0.023	91-98	94.00 ± 0.018	90-97
Pre-oviposition period (days)	2.40 ± 0.74	2-3	3.20 ± 0.68	2-4	2.73 ± 0.59	2-4
Oviposition period (days)	6.80 ± 2.05	5-10	6.53 ± 2.04	4-7	7.00 ± 2.16	4-9
Time after oviposition (days)	3.47 ± 4.71	3-4	3.13 ± 4.50	3-4	3.13 ± 4.49	3-4
Age of Imago (days)	12.60 ± 0.99	11-14	11.87 ± 0.99	10-13	11.87 ± 0.83	11-12
Prepupa time (days)	0.70 ± 0.18	0.5-1	0.80 ± 0.18	0.5-1	0.78 ± 0.20	0.5-1
Pupa period (days)	9.43 ± 1.04	8-12	9.47 ± 1.04	9-11	9.20 ± 1.19	7-11
1st to 6th instar period (days)						
Female	13.54 ± 1.39	12-16	14.29 ± 1.21	12-17	15.27 ± 1.03	14-17
Male	13.58 ± 1.44	12-16	14.14 ± 1.21	12-16	15.00 ± 1.53	13-17

Table 2. Development time (days) of *Spodoptera frugiperda* on Corn, Sorghum, and Jatiluwih local rice

Life Stage	*n*	Corn	*n*	Sorghum	*n*	Jatiluwih local rice
Egg	30	3.37 ± 0.49	30	3.23 ± 0.63	30	3.33 ± 0.48
1st Instar	30	1.27 ± 0.45	29	1.28 ± 0.45	28	1.36 ± 0.49
2nd Instar	30	1.60 ± 0.50	29	1.86 ± 0.35	26	1.89 ± 0.32
3rd Instar	30	2.00 ± 0.26	28	2.10 ± 0.41	24	2.35 ± 0.63
4th Instar	29	2.59 ± 0.50	28	2.71 ± 0.46	24	2.76 ± 0.44
5th Instar	28	2.93 ± 0.26	27	3.00 ± 0.27	24	3.04 ± 0.20
6th Instar	28	3.29 ± 0.46	27	3.30 ± 0.47	24	3.44 ± 0.51
Pupa	27	9.41 ± 1.08	25	9.40 ± 1.04	23	9.39 ± 1.23
Adults	25	10.32 ± 1.14	24	10.42 ± 1.14	22	11.41 ± 1.44
Female	13	36.69 ± 1.38	17	37.35 ± 2.15	15	39.60 ± 1.96
Male	12	36.58 ± 2.15	7	37.00 ± 1.73	7	39.00 ± 1.29

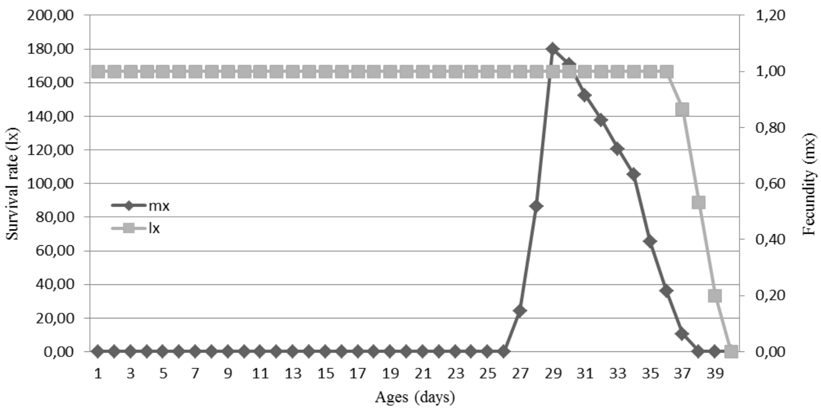

Figure 2. Survival rate (lx) and fecundity (mx) *Spodoptera frugiperda* on corn

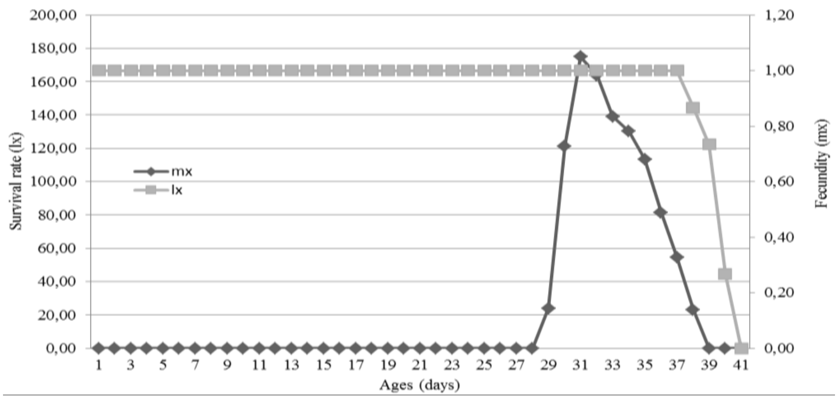

Figure 3. Survival rate (lx) and fecundity (mx) *Spodoptera frugiperda* on sorghum

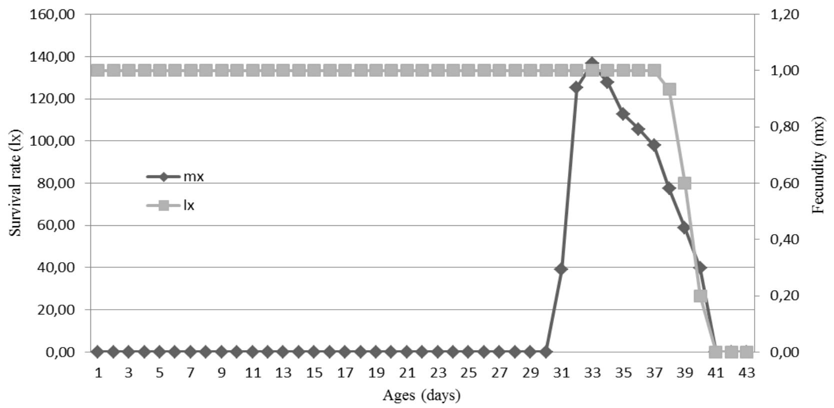

Figure 4. Survival rate (lx) and fecundity (mx) *Spodoptera frugiperda* on Jatiluwih local rice

In observing the three types of test plants, the highest GRR values were shown in hybrid corn plants with a value of 1,090.01, sorghum with 1,025.33, and Jatiluwih local rice with 920.56. The net reproduction rate (Ro) for hybrid corn was 25.62; for sorghum, 23.71; for Jatiluwih local rice, 19.28. The intrinsic rate of increase in corn plants was 0.086, 0.081 for sorghum plants, and 0.073 for Jatiluwih local rice. Generation time (T) for corn plants has an average duration of 37.60; for sorghum plants, it is 38.87; for Jatiluwih local rice, it is 40.60. Doubling time (DT) on hybrid corn plants showed a value of 8.04, 8.51 on sorghum plants, and 9.51 on Jatiluwih local rice (Tables 3-5). The development of *S. frugiperda* was better, given corn and sorghum, compared to Jatiluwih local rice, as seen from the GRR value. This result is the same as the Xie et al. (2021) study, where *S. frugiperda* was more suited to being fed corn than kidney beans.

The nutrient content contained in plants greatly influences the development of *S. frugiperda* pests, especially in terms of their reproductive abilities, as well as the survival and performance of their offspring (Sotelo-Cardona et al. 2021; Supartha et al. 2021). The fertility life table constructed in the present study is significantly important in predicting population dynamics, which will further help in developing effective integrated pest management, and the developed meridic diet with rearing procedure will be helpful in insecticide resistance monitoring programs for *S. frugiperda* folivorous (Sagar et al. 2022).

Table 3. Demographic parameters of *Spodoptera frugiperda* on corn

Parameter	Average/SD
Gross Reproduction Rate (GRR)	1090.01 ± 52.46
Net Reproduction Rate (Ro)	25.62 ± 0.21
Intrinsic Rate of Increase (R)	0.09 ± 0.00
Generation Time (T)	37.60 ± 0.00
Doubling Time (DT)	8.04 ± 0.00

Table 4. Demographic parameters of *Spodoptera frugiperda* on sorghum

Parameter	Average/SD
Gross Reproduction Rate (GRR)	1025.33 ± 51.54
Net Reproduction Rate (Ro)	23.71 ± 0.19
Intrinsic Rate of Increase (R)	0.08 ± 0.00
Generation Time (T)	38.87 ± 0.00
Doubling Time (DT)	8.51 ± 0.00

Table 5. Demographic parameters of *Spodoptera frugiperda* on Jatiluwih local rice

Parameter	Average/SD
Gross Reproduction Rate (GRR)	920.56 ± 43.58
Net Reproduction Rate (Ro)	19.28 ± 0.28
Intrinsic Rate of Increase (R)	0.07 ± 0.00
Generation Time (T)	40.60 ± 0.00
Doubling Time (DT)	9.51 ± 0.00

This study shows that Jatiluwih local rice is a less suitable host plant than corn and sorghum. However, this Jatiluwih local rice plant still supports the full life cycle of *S. frugiperda*, even though the population of *S. frugiperda* optimizes the utilization of Jatiluwih local rice as a host plant, food source in conditions of high population density and food scarcity. Therefore, the presence of *S. frugiperda* in plants should be closely monitored in the future. In addition, clarifying the mechanisms and factors associated with adaptation to several other graminae species, such as those from the rice group, can provide a basis for predicting and controlling *S. frugiperda* population growth.

ACKNOWLEDGEMENTS

We thank the Chancellor of Universitas Udayana (UNUD), Head of the Research and Community Service Institute (LPPM) of Universitas Udayana, and Dean of the Faculty of Agriculture, Udayana University, Bali, Indonesia who has supported the sustainability of this research through Udayana's flagship research collaboration PNBP Fund Number: B/78.1018/UN14.4. A/PT.01.03/2022.

REFERENCES

Ahissou BR, Sawadogo WM, Sankara F, Brostaux Y, Bokonon-Ganta AH, Somda I, Verheggen FJ. 2022. Annual dynamics of fall armyworm populations in West Africa and biology in different host plants. Sci Afr 16: e01227. DOI: 10.1016/j.sciaf.2022e01227.

Ahmed KS, Idrees A, Majeed MZ, Majeed MI, Shehzad MZ, Ullah MI, Afzal A, Li J. 2022. Synergized toxicity of promising plant extracts and synthetic chemicals against fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) in Pakistan. Agronomy 12: 1289. DOI: 10.3390/agronomy12061289.

Akhtar ZR, Afzal A, Idrees A, Zia K, Qadir ZA, Ali S, Haq IU, Ghramh HA, Niaz Y, Tahir MB, Arshad M, Li J. 2022. Lethal, sub-lethal and trans-generational effects of chlorantraniliprole on biological parameters, demographic traits, and fitness costs of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Insects 13: 881. DOI: 10.3390/insects13100881.

Altaf N, Idrees A, Ullah MI, Arshad M, Afzal A, Afzal M, Rizwan M, Li J. 2022. Biotic potential induced by different host plants in the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Insects 13: 921. DOI: 10.3390/insects13100921.

Blair WC, Lorraine WS, Jeremy MG, Nic V, Ed TFW, Marcus JB. 2019. Does host plant quality constrain the performance of the Parthenium beetle *Zygogramma bicolorata*? Biol Control 139: 104078. DOI: 10.1016/j.biocontrol.2019.104078.

Chen YC, Chen DF, Yang MF, Liu JF. 2022. The Effect of temperatures and hosts on the life cycle of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Insects 13: 211. DOI: 10.3390/insects13020211.

Chormule A, Deshmukh S, Shejawal N, Kalleshwaraswamy C, Asokan R, Mahadeva Swamy H. 2019. First report of the fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera, Noctuidae) on sugarcane and other crops from Maharashtra, India. J Entomol Zool Stud 7 (1): 114-117.

Dai QX, Li ZY, Tian YJ, Zhang ZF, Wang L, Lu YY, Li Y, Chen Z. 2020. Effects of different corn varieties on development and reproduction of *Spodoptera frugiperda*. Ying Yong Sheng Tai Xue Bao 31 (10): 3273-3281.

Day R, Abrahams P, Bateman M, Beale T, Clottey V, Cock M, Godwin J. 2017. Fall armyworm: Impacts and implications for Africa. Outlooks Pest Manag 28 (5): 196-201. DOI: 10.1564/v28_oct_02.

Ganiger PC, Yeshwanth HM, Muralimohan K, Vinay N, Kumar ARV, Chandrashekara K. 2018. Occurrence of the new invasive pest, fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), in the maize fields of Karnataka, India. Curr Sci 115 (4): 621-623. DOI: 10.18520/cs/v115/i4/621-623.

Gilal AA, Bashir L, Faheem M, Rajput A, Soomro JA, Kunbhar S, Sahito JGM. 2020. First record of invasive fall armyworm (*Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae)) in corn fields of Sindh, Pakistan. Pak J Agric Res 33 (2): 247-252. DOI: 10.17582/journal.pjar/2020/33.2.247.252.

Ginting S, Nadrawati N, Zarkani A, Sumarni T. 2020. Natural incidence of entomophatogenic fungus *Nomuraea rileyi* on *Spodoptera frugiperda* infesting corn in Bengkulu. Jurnal Hama Penyakit Tumbuhan Tropika 20 (2): 85-91. DOI: 10.23960/j.hptt.22085-91. [Indonesian]

Goergen G, Kumar PL, Sankung SB, Togola A, Tamò M. 2016. First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. PloS One 11 (10): 1-9.DOI: 10.1371/journal.pone.0165632.

Guo J-F, Zhang M-D, Gao Z-P, Wang D-J, He K-L, Wang Z-Y. 2020. Comparison of larval performance and oviposition preference of *Spodoptera frugiperda* among three host plants: potential risks to potato and tobacco crops. Insect Sci 28 (3): 602-610. DOI: 10.1111/1744-7917.12830.

Hadke JT, Lorenz III GM, Leonard BR. 2015. Fall Armyworm (Lepidoptera: Noctuidae) Ecology in Southeastern Cotton. J Integ Pest Manag 6 (1): 1-8. DOI: 10.1093/jipm/pmv009.

Herlinda S, Suharjo R, Sinaga ME, Fawwazi F, Suwandi S. 2022. First report of occurrence of corn and rice strains of fall armyworm, *Spodoptera frugiperda* in South Sumatra, Indonesia and its damage in maize. J Saudi Socf Agric Sci 21 (6): 412-419. DOI: 10.1016/j.jssas.2021.11.003.

Hruska AJ, Gould F. 1997. Fall armyworm (Lepidoptera: Noctuidae) and *Diatraea lineolata* (Lepidoptera: Pyralidae): impact of larval population level and temporal occurrence on maize yield in Nicaragua. J Econ Entomol 90: 611-622. DOI: 10.1093/jee/90.2.611.

Idrees A, Qadir ZA, Akutse KS, Afzal A, Hussain M, Islam W, Waqas MS, Bamisile BS, Li J. 2021. Effectiveness of entomopathogenic fungi on immature stages and feeding performance of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) larvae. Insects 12: 1044. DOI: 10.3390/insects12111044.

Idrees A, Qadir ZA, Afzal A, Ranran Q, Li J. 2022a. Laboratory efficacy of selected synthetic insecticides against second instar invasive fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) larvae. PLoS ONE 17 (5): e0265265. DOI: 10.1371/journal.pone.0265265.

Idrees A, Afzal A, Qadir ZA, Li J. 2022b. Bioassays of *Beauveria bassiana* isolates against the fall armyworm, *Spodoptera frugiperda*. J Fungi 8: 717. DOI: 10.3390/jof8070717.

Idrees A, Afzal A, Qadir ZA, Li J. 2023. Virulence of entomopathogenic fungi against fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) under laboratory conditions. Front Physiol 14: 1107434. DOI: 10.3389/fphys.2023.1107434.

Keerthi MC, Padmaja PG, Bhargavi HA, Manjunatha N, Deb D. 2021a. Nutritional indices of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on selected sorghum genotypes. Range Manag Agrofor 42 (1): 71-77.

Keerthi MC, Mahesha HS, Manjunatha N, Gupta A, Saini RP, Shivakumara KT, Bhargavi HA, Gupta G, Kulkarni NS. 2021b. Biology and oviposition preference of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) on fodder crops and its natural enemies from Central India. Intl J Pest Manag 1-10. DOI: 10.1080/09670874.2020.1871530.

Khan RU, Kauser SAF, Anwar MU, Arshad MA, Hussain H, Zardari WB, Ramzan M. 2021. Occurrence, damage pattern and developmental

parameters of *Spodoptera frugiperda* on corn in Pakistan. Glob Acad J Agric Biosci 3 (5): 75-78. DOI: 10.36348/gajab.2021.v03i05.002.
Lestari P, Budiarti A, Fitriana Y, Susilo Fx, Swibawa IG, Sudarsono H, Suharjo R, Hariri AM, Purnomo, Nuryasin, Solikhin, Wibowo L, Jumari, Hartaman M. 2020. Identification and genetic diversity of *Spodoptera frugiperda* in Lampung Province, Indonesia. Biodiversitas 21 (4): 1670-1677. DOI: 10.13057/biodiv/d210448.
Li-mei H, Teng-li W, Yu-chao C, Shi-shuai G, Wyckhuys KAG, Kong-ming W. 2021. Larval diet affects development and reproduction of East Asian strain of the fall armyworm, *Spodoptera frugiperda*. J Integr Agric 20 (3): 736-744. DOI: 10.1016/S2095-3119(19)62879-0.
Makgoba MC, Tshikhudo PP, Nnzeru LR, Makhado RA. 2021. Impact of fall armyworm (*Spodoptera frugiperda*) (J.E. Smith) on small-scale maize farmers and its control strategies in the Limpopo province, South Africa. Jamba 13 (1): 1016. DOI: 10.4102/jambav13i1.1016.
Midega CA, Pittchar JO, Pickett JA, Hailu GW, Khan ZR. 2018. A climate-adapted push-pull system effectively controls fall armyworm, Spodoptera frugiperda (JE Smith), in maize in East Africa. Crop Prot 105: 10-15. DOI: 10.1016/j.cropro.2017.11.003.
Montezano DG, Specht A, Sosa-Gómez DR, Roque-Specht VF, Sousa-Silva JC, Paula-Moraes SV, Peterson JA, Hunt TE. 2018. Host plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas. Afr Entomol 26 (2): 286-300. DOI: 10.4001/003.026.0286.
Nelly N, Hamid H, Chandralina E, Yunisman, Yaherwandi, Putri YD. 2023. The development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on several varieties of maize. Biodiversitas 24 (1): 523-530. DOI: 10.13057/biodiv/d240161.
Piggott MP, Tadle FPJ, Patel S, Gomez KC, Thistleton B. 2021. Corn-strain or rice-strain? Detection of fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), in northern Australia. Intl J Trop Insect Sci 41: 2607-2615. DOI: 10.1007/s42690-021-00441-7.
Prasanna BM, Huesing JE, Regina ER, Peschke VM.2018. Fall Armyworm in Africa: A Guide for Integrated Pest Management. Penny Hill Press, Maryland.
Ramzan M, Ilahi H, Adnan M, Ullah A, Ullah A. 2021. Observation on fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on maize under laboratory conditions. Egypt Acad J Biol Sci 14 (1): 99-104. DOI: 10.21608/EAJBSA.2021.152337.
Sagar D, Thillainayagam I, Keerthi MC, Sujatha GS, Chander S. 2022. Influence of larval nutrition on biological attributes and reproductive performance in *Spodoptera frugiperda* (Lepidoptera: Noctuidae) under laboratory condition. Anim Biol 72 (3): 203-216. DOI: 10.1163/15707563-bja10077.
Sharanabasappa, Kalleshwaraswamy CM, Maruthi MS, Pavithra HB. 2018. Biology of invasive fall army worm *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) on Maize. Indian J Entomol 80 (3): 540-543. DOI: 10.5958/0974-8172.2018.00238.9.
Silva DMD, Bueno ADF, Andrade K, Stecca CDS, Neves PMOJ, Oliveira MCND. 2017. Biology and nutrition of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) fed on diferent food sources. Sci Agric 74 (1): 18-31. DOI: 10.1590/1678-992X-2015-0160.
Sotelo-Cardona P, Chuang WP, Lin MY, Chiang MY, Ramasamy S. 2021. Oviposition preference not necessarily predicts ofspring performance in the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on vegetable crops. Sci Rep 11: 15885. DOI: 10.1038/s41598-021-95399-4.
Supartha IW, Susila IW, Sunari AAAAS, Mahaputra IGF, Yudha IKW, Wiradana PA. 2021. Damage characteristics and distribution patterns of invasive pest, *Spodoptera frugiperda* (J.E Smith) (Lepidoptera: Noctuidae) on maize crop in Bali, Indonesia. Biodiversitas 22 (6): 3378-3389. DOI: 10.13057/biodiv/d220645.
Supartha, IW, Susila IW, Yuliadhi KA, Haloho ESM, Yudha IKW, Utama IWEK, Wiradana PA. 2022a. Monitoring of damage and distribution of invasive fallarmyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) on maize crop in Karo, North Sumatera, Indonesia. IOP Conf Ser: Earth Environ Sci 951: 012010. DOI: 10.1088/1755-1315/951/1/012010.
Supartha IW, Susila IW, Sumiartha IK, Rauf A, Cruz LBDC, Yudha IKW, Utama IWEK, Wiradana PA. 2022b. Preference, population development, and molecular characteristics of *Spodoptera exigua* (Lepidoptera: Noctuidae) on shallot cultivars: A field trial scale. Biodiversitas 23 (2): 783-792. DOI: 10.13057/biodiv/d230224.
Supartha IW, Susila IW, Yohanes, Yudha IKW, Wiradana PA. 2022c. Potential of parasitoid *Gronotoma micromorpha* Perkin (Hymenoptera: Eucoilidae) as a biocontrol agent for pea leafminer fly, *Liriomyza huidobrensis* Blanchard (Diptera: Agromyzidae). Acta Ecol Sin 42 (2): 90-94. DOI: 10.1016/j.chnaes.2021.06.008.
Wu QL, He LM, Shen XJ, Jiang YY, Liu J, Hu G, Wu KM. 2019. Estimation of the potential infestation area of newly-invaded fall armyworm *Spodoptera frugiperda* in the Yangtze River Valley of China. Insects 11 (8): 521. DOI: 10.3390/insects11080521.
Xie W, Zhi J, Ye J, Zhou Y, Li C, Liang Y, Yue W, Li D, Zeng G, Hu C. 2021. Age-stage, two-sex life table analysis of *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) reared on maize and kidney bean. Chem Biol Technol Agric 8: 44. DOI: 10.1186/s40538-021-00241-8.
Zhang D-W, Xiao Z-J, Zeng B-P, Li K, Tang Y-L. 2019. Insect behavior and physiological adaptation mechanisms under starvation stress. Front Physiol 10: 163. DOI: 10.3389/fphys.2019.00163.
Zhao YX, Huang JM, Ni H, Guo D, Yang FX, Wang X, Wu SF, Gao CF. 2020. Susceptibility of fall armyworm, *Spodoptera frugiperda* (J.E. Smmith), to eight insecticides in China, with special reference to lambda-cyhalothrin. Pestic Biochem Physiol 168: 104623. DOI: 10.1016/j.pestbp.2020.104623.