LIFE TABLE OF THE MIGRATORY LOCUST (Locusta migratoria L.) ON DIFFERENT HOST PLANTS

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Abstract. *The migratory locust (Locusta migratoria L.) is an important agricultural pest and has a broad host range, including various Gramineae plants, such as maize, rice, sorghum, barley, grasses, bamboo leaves, and several other types of plants. Due to the variety of existing plants in an area, understanding how different host plants affect migratory locust may provide insight into the population dynamic of this insects. This information may reveal susceptible phases for pest management. This study was designed to compile and to measure demographic parameters of the migratory locust on different types of host plants. The results showed that, locust migratory developed the fastest when fed with maize and the longest life span of imago was 131.00 days (males) and 122.33 days (females).Demographic parameters of migratory locust showed the highest number (G = 17.67 and R0 = 13.57 female individuals). At all stage of life and demographic parameters, locust fed with corn leaf showed that it was a suitable host plant for the development of locusts.This information may imply that continuous planting of maize may possess the risk of the migratory locust to develop rapidly. Therefore, diversification might be needed to suppress locust growth..*

Keywords: *biodemography, host plant, life table, life transition curve, locust*

1. INTRODUCTION

The migratory locust (Locusta migratoria L.) is an established global agricultural pest which have been reported to cause severe damage on cultivated and wild plants. Migratory locusts are widely distributed due to their ability to live in hot and cold-tempered areas (Tokuda et al., 2010; Jing and Kang 2003). In addition, respective to this latitude differences, locust in tropical areas are multivoltine while only univoltine in northern areas as has been recorded in southern and northern areas of Europe, China, and Japan. Since the 1980's, locust outbreaks have been recorded to occur in China, Australia, and Japan, possibly due to changes in climate and land-use (Scanlan et al. 2001; Tokuda et al., 2010; Wang and Kang 2005). Locust exhibits polyphenism between a solitary stage and a gregarious phase which is triggered by epigenetic cues, such as population density and accumulation levels of volatiles from locust fecal (Robinson et al. 2011; Shi et al. 2011). Notable changes may occur in morphology and behavioral traits due to their change from solitary to gregarious phase (Tokuda et al., 2010). In the gregarious phase, locust will be able to travel long-distances in swarms causing severe damage to plants along their path and becoming an important insect pest for humans.

To this date, migratory locust control has relied on chemical insecticides and biocontrol agents, such as parasitoids and entomopathogenic organisms (Bitsadze et al. 2013).In Indonesia, active ingredients, such as fenobucarb, beta-cyfluthrin, and fipronil, are registered for this pest by the Ministry of Agriculture (Republic Indonesia Ministry of Agriculture). Insect growth regulators (IGR), which are considered "softer" insecticides, have been tested on the migratory locust and resulted in promising results (Bitsadze et al. 2013); however, other research have also showed that control from insecticides to be life-stage specific, causing insecticide applications to be less effective on specific insect phases (Onyeocha and Fuzeau-Braesch 1991). Although there has not yet been reports of existing resistances within Indonesian locust populations, resistances of organophosphates have been reported elsewhere (Yang et al. 2009). It is noteworthy that developing novel insecticides is time costly and laborious; thus, it essential to conserve the effectiveness of existing active ingredients by developing other control measures or spraying strategies. In addition, the use of chemical insecticides is complicated by the raised concerns from scientist on their impact to the environment if continuously used. Therefore, more information regarding the biology of the migratory locust is required to target susceptible and even may help refine management strategies.

2. LITERATURE REVIEW

Sustainable pest management strategies should be based a range of information regarding the biology of our focal pest and crop (Bostanian et al., 2012).Life tables provide essential demographic parameters of pests regarding to their population dynamics, such as their survival, development, and survival possibility under different growing situations (Ali & Rizvi, 2010). This information provides insights into species population dynamics which is useful to identify susceptible life stages, monitor, forecast, and regulate populations before ascending to devastating populations (Wiman et al., 2014, Mangan et al., 2013; Permana, 1997). Life tables are can be categorized into two types, which are horizontal life tables which covers organism with short lifespans, such as insects, and vertical life tables which cover organism with longer lifespans (Southwood, 1971; Bellow et al., 1992; Tarumingkeng, 1994; Untung, 2006).Research have shown that demographic parameters regarding to life tables are affected by external factors, such as temperature and humidity (Chen et al. 2017) and the plants the feed on (Golizadeh et al. 2009).Insect diet affect certain demographic parameters within life table due to plant's great differences in nutritional value and secondary metabolites (Soroushmehr et al., 2008; Segoli and Rosenheim 2013; Tanga et al., 2013). In nature, various species of plants are available within landscapes causing population dynamics of herbivores and their interactions with other organisms. Therefore, identifying the effects of different host plant available in a focal landscape on demographic parameters, may provide insight on understand population dynamic and serve as additional information for management.

Several research efforts have covered the effects of temperature to body weight, oviposition rate, and developmental rate of the migratory locust (Tu et al. 2012, 2014); however, to our knowledge none have examined the effects of different host plants towards this insect's demographic parameters, especially host plants found in tropical areas, such as Nusa Tenggara Timur. Thus, to elucidate potential demographic changes of this insects in tropical ecosystem, we observed migratory locust survivorship, and developmental time on several wild and cultivated plants found in Indonesia. The information from this research will help cover potential population growth of the migratory locust in Indonesia.

3. RESEARCH METHODS/METHODOLOGY

Research was conducted between June and October 2018 at the Lapang Kefamenanu semi-field laboratory, Central North Timor Regency, Nusa Tenggara Timur. Average air temperature and humidity were 28°C and ± 60%, respectively, with L:D period of 12:12.Locust population used in this study were obtained from a maize filed and surrounding prairie at Bibin Village (S 09º20'01,7", E124º50'46,0"). Locust were collected during the night by attracting locust to a light source. Locust were then collected by hand. Both female and male insects were infested into an insect cage for mass rearing (Jones, 1961). This mass rearing cage was 2 m x 3 m x 2 m andmade from wood, bamboo, and transparent plastic roofing a fine mesh was used as walls ensure air ventilation. Sandy loam soil was placed on the bottom of rearing cages and was maintained to field capacity to maintain humidity within the cage.

3.1 Life table experiment

This experiment tested life parameters of migratory locust on 9 different diet treatment, including (1) maize (*Zea mays*); (2) rice (*Oryza sativa*); (3) sorghum (*Sorghum bicolor*); (4) foxtail millet (*Setaria italica*); (5) cogon grass (*Imperata cylindrica*); (6) king grass (*Pennisetum purpuphoides*); (7) wild sugarcane (*Saccharum spontaneum*); (8) bamboo leaves (subfamily Bambusoideae); (9) mixture of the previous plants.

Fifty migratory locust eggs were placed in a glass jar diameter 5 cm and height of 7.5 cm filled with sandy loam soil held at soil's water capacity. Jars were then placed inside 30 cm x 30 cm x 40 cm experimental cages. Cages were made out of wood, plywood, transparent plastic, and white mesh to ensure sufficient air circulation. Observation started 1 day after eggs hatched and continued until imagoes died. Food was given according to the corresponding treatments and were changed every 2 days to ensure healthy food for migratory locust. Each treatment was replicated three times. This experiment was set as a complete randomized block design.

We recorded time required for eggs to hatch into nymphs, time required to develop through each nymph instars until imagoes, and imagoes mortality. Mortality numbers at each life stages were recorded as well. Survival data were made into a life table and survival curve. Life table was constructed based on number of live individuals at x days (n_x), number of dead individuals at x days (d_x), proportion of life individuals at x days (l_x), death rate (q_x), and living probability (e_x). Survival curve was based on l_x at each x days from each life stages. Crude reproduction (G), net reproduction rates (R_0), generation time(T), and intrinsic growth (rm) were calculated as demographic parameters of migratory locust. Formula used were based on Price (1997):

$$\boldsymbol{G} = \sum m_x \qquad (1)$$
$$\boldsymbol{R_0} = \sum l_x m_x \qquad (2)$$
$$\boldsymbol{T} = \sum \frac{x l_x m_x}{l_x m_x} \qquad (3)$$
$$\boldsymbol{R_m} = \frac{(ln R_0)}{T} \qquad (4)$$

Remarks:

m_x : fecundity of female individuals at day x

l_x : proportion of living individuals at day x

The value of r_m was obtained by correction using Euler equation (Gotelli, 1995): $\sum e^{-rmx} l_x m_x = 1$

Value of each demographic parameter from each replication were average.

3.2 Data analysis

Developmental time at each life stage were compared between diet treatments using a one-way ANOVA. Subsequent Tukey-Kramer test was done on results that indicated significant effects from diet treatment. All tests were done at $\alpha = 0.05$.

4. RESULTS AND DISCUSSION

The results from this experiment demonstrates the various effects of plant diet on migratory locust. Plant diet significantly affected development time of all locust's life stages and total lifespans of imagoes (Table 1). Developmental time of locust at pre-adult stages were not significantly different between each other when feed with Gramineae plants. Developmental time of locust feeding on bamboo leaves were significantly longer than maize at all developmental stages. This implies that bamboo may not be as suitable as maize for locust development. Faster development time and higher fecundity have showed to correlate with better suitable host (Slansky and Rodriquest in Wibowo et al., 1995; Savopoulou, 1994). Similar results were also demonstrated on cabbage worm (Plutella xylostella) on different brassicaceous hosts and Aphis spiraecolae (Golizadeh et al. 2009; Tsai and Wang 2001). Our observations in the field indicates that locust in Nusa Tenggara Timur primarily feed on maize, rice, sorghum, and foxtail millet. Only when population increases, locust will feed on secondary crops, such as bamboo, coconut, and ground nut leaves in order to survive. Our observations in the field were similar to the findings of Murray (2016), which stated that locust damage in the United States on maize, wheat, soybean, cultivated vegetable, and some weed species.

Table 1. Mean developmental times (mean ± SE; days) of various *Locusta migratoria* life stages on various host plants.

Life stage	Maize	Rice	Sorghum	Foxtail millet	Cogon grass	King grass	Wild sugarcane	Bamboo	Mixed
	Pre-adult								
Egg	22.33 ± 1.53 a	21.67 ± 1.15 a	22.67 ± 1.15 a	22.33 ± 1.53 a	22.33 ± 1.53 a	22.67 ± 2.52 a	22.67 ± 1.15 a	23.33 ± 0.58 a	23.33 ± 1.53 a
1^{st} Instar	6.67 ± 0.58 a	7.00 ± 1.00 a	7.33 ± 0.58 a	7.67 ± 0.58 a	8.33 ± 0.58 ab	8.00 ± 1.00 ab	8.33 ± 0.58 ab	9.67 ± 0.58 b	7.33 ± 0.58 a
2^{nd} Instar	6.33 ± 0.58 a	6.67 ± 0.58 ab	7.00 ± 0.00 ab	7.33 ± 0.58 abc	8.00 ± 0.00b c	7.67 ± 0.58 abc	8.00 ± 0.00 bc	8.67 ± 0.58 c	7.00 ± 1.00 ab
3^{rd} Instar	7.00 ± 0.00 a	7.33 ± 0.58 ab	7.67 ± 0.58 abc	7.33 ± 0.58 ab	8.33 ± 0.58 bc	7.67 ± 0.58 abc	8.33 ± 0.58 bc	8.67 ± 0.58 c	7.00 ± 0.00 a
4^{th} Instar	10.33 ± 1.53 a	10.67 ± 0.58 ab	11.00 ± 0.00 ab	11.33 ± 0.58 ab	11.67 ± 1.53 ab	11.33 ± 1.53 ab	12.00 ± 1.00 ab	13.33 ± 0.58 b	10.67 ± 0.58 ab
5^{th} Instar	8.67 ± 0.58 abc	9.33 ± 0.58 bcd	10.67 ± 0.58 d	7.67 ± 0.58 ab	8.33 ± 0.58 abc	8.00 ± 1.00 abc	8.33 ± 0.58 abc	9.67 ± 0.58 cd	7.33 ± 0.58 a
	Imagoes life spans								
Male	112.33 ± 0.58 a	104.33 ± 0.58 a	111.66 ± 0.58 a	112.33 ± 1.15 a	112.33 ± 1.53 a	113.00 ± 1.00 a	108.00 ± 7.00 a	106.00 ± 5.29 a	131.00 ± 1.00 b
Female	100.00 ± 1.00 ab	101.00 ± 0.00 b	99.67 ± 0.58 ab	99.00 ± 1.00 ab	98.67 ± 2.31 ab	99.33 ± 1.15 ab	98.00 ± 1.00 ab	96.67 ± 1.53 a	122.33 ± 0.58 b
	Length from egg-adult mortality								
Male	173.56 ± 1.58 b	167 ± 1.58 a	178 ± 1.58 d	175.99 ± 0.58 c	179.32 ± 1.58 e	178.67 ± 0.58 d	175.66 ± 0.58 c	179.34 ± 0.58 e	193.66 ± 0.58 f
Female	163.33 b	163.67 ± 1.15 b	166.01 ± 1.15 e	162.66 ± 1.53 a	165.66 ± 1.33 d	164.67 ± 1.67 c	165.88 ± 2.33 de	170.01 ± 1.15 f	184.66 ± 1.53 g

Nutrients play an important role in determining the success rate of insect development due protein, sugar, fat, vitamin, and minerals effects towards insect physiology (Wigglesworth, 1953; Hause, 1961). Protein are used to form cell tissues and other compounds that can be converted into carbohydrates which serves as an energy source, regulates blood pressure within insects (Chapman, 1975), and essential ingredient in egg development. Fat in insects are also used as energy sources by converting sterol form cholesterol (Dadd 1960). Vitamin acts as catalyst of several metabolism process within insects. Previous research show that plant differ in host suitability to certain insects by affecting developmental time, survivorship, fecundity, and other life parameters (Tsai and Wang 2001; Lorena et al. 2012; Nikooei et al. 2015). Morrison (1961) stated that maize possessed superior nutrition compared to rice, sorghum, and other Gramineae species. Developmental time of locust fed with a mixed diet also showed non-significant differences compared to maize which may imply that although mixed with other host plants, maize was still able to provide substantial nutrition for insect developments. This Shorter developmental time is an indicator of host suitability for insects. However, before drawing conclusion on population dynamics of an insect, other information, such as their mortality and reproduction ability should be taken into consideration. Besides that, at a landscape level, land-use for certain cultivated or wild plants may substantially effect insect dynamics depending on its location (Karp et al. 2018). Our research covers an aspect to understand migratory locust at landscape scale by providing life parameter information regarding to different host plants.

Survival rates of locust fed with maize was consistently the highest amongst all plant hosts at all life stages followed by rice (Table 2). The lowest survivorship was shown by locust fed with bamboo leaves. At the beginning of this experiment, drastic decreases of age-specific survival rates were observed from locust fed with bamboo leaves (Figure 1). Higher survival on maize may be due to the source of locust population used in this experiment. Locust population was collected from maize fields and maize is common crop found in Nusa Tenggara Timur. In addition, maize and rice are cultivated crops that regularly receive fertilizing treatments. Research on brown plant hopper (*Nilaparvata lugens*) on rice showed that body weight and fecundity, which are also indicators of host suitability, increase respectively to nitrogen rates (Horgan et al. 2016). This same phenomenon may occur for locust in this experiment.

Table 2. Survival proportion and life expectancy of *Locusta migratoria* on various host plants

Plant host	Eggs	1st instar	2nd instar	3rdinstar	4thinstar	5thinstar	Imago
Survival proportion							
Maize	1.00	0.96	0.95	0.93	0.91	0.83	0.77
Rice	1.00	0.87	0.82	0.79	0.77	0.71	0.67
Sorghum	1.00	0.84	0.83	0.73	0.69	0.64	0.49
Foxtail millet	1.00	0.84	0.75	0.73	0.69	0.61	0.52
Cogon grass	1.00	0.77	0.68	0.64	0.57	0.47	0.39
King grass	1.00	0.87	0.77	0.64	0.61	0.49	0.51
Wild sugarcane	1.00	0.79	0.62	0.58	0.53	0.46	0.37
Bamboo	1.00	0.72	0.61	0.49	0.42	0.29	0.18
Mixed	1.00	0.89	0.84	0.79	0.76	0.71	0.65
Life expectancy (e_x)							
Maize	5.83	5.06	4.12	3.20	2.26	1.43	0.50
Rice	5.13	4.80	4.08	3.23	2.30	1.43	0.50
Sorghum	4.71	4.52	3.58	3.00	2.13	1.26	0.50

Foxtail millet	4.65	4.44	3.93	2.99	2.13	1.35	0.50
Cogon grass	4.01	4.04	3.53	2.72	2.01	1.33	0.50
King grass	4.47	4.05	3.54	3.15	2.26	1.38	0.50
Wild sugarcane	3.85	3.73	3.63	2.84	2.08	1.31	0.50
Bamboo	3.21	3.27	2.75	2.30	1.61	1.13	0.50
Mixed	5.15	4.71	3.98	3.18	2.30	1.42	0.50

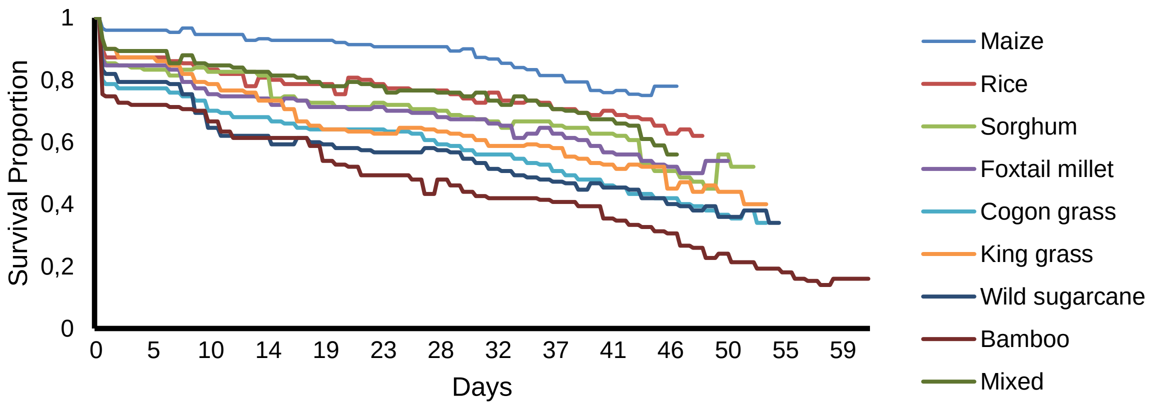

Figure 1. Age-specific survival rates (l_x) for pre-adult stages of *Locusta migratoria* on various host plants.

Brute reproduction rate was significantly affected by plant host where the highest reproduction rate was shown from maize while the lowest was observed on locust fed with bamboo leaves (Table 4). In addition, generation length of locust fed with maize and mixed diets were the lowest compared to other diets. Locust fed with bamboo leaves showed the longest generation length.

Net reproduction rate (R_0) demonstrates the average female individuals produced by a female in one generation was 13.57 individuals/female/generation on maize. If $R_0 > 1$, population will grow and if $R_0 = 1$ then a stable population will be achieved (Price, 1997). Higher G and R_0 values indicated host suitability for locust. The lowest intrinsic rate of increase found on locust fed with bamboo leaves while the highest were found on locust fed with maize. Intrinsic rate of increases is determined by the number off offspring during growth, survival rates during reproductive stages, and the length of the reproductive stage (Brewer, 1979). Average generation length of locust fed with maize and mixed host were the shortest (5.33 days) indicating the quickest development through instar stages.

Table 3. Demographic parameters of *Locusta migratoria* on several hosts

Plant Host	Demographic parameters			
	G	Ro	T	r
Maize	17.67 ± 2.08 d	13.57 ± 2.10 d	100.00 ± 0.10 ab	0.0261 ± 0.0013 e
Rice	14.67 ± 1.15 cd	9.80 ± 1.22 cd	101.00 ± 0.00 ab	0.0225 ± 0.0012 de
Sorghum	10.33 ± 2.08 bc	5.14 ± 1.79 ab	99.67 ± 0.58 ab	0.0160 ± 0.0039 c
Foxtail millet	11.00 ± 1.00 bc	5.73 ± 0.86 bc	99.00 ± 0.10 ab	0.0176 ± 0.0013 cd
Cogon grass	7.33 ± 1.15 ab	2.85 ± 0.60 ab	98.67 ± 2.31 ab	0.0105 ± 0.0024 b
King grass	10.33 ± 3.21 bc	5.40 ± 2.60 bc	99.33 ± 1.15 ab	0.0163 ± 0.0043 c
Wild sugarcane	7.33 ± 1.15 ab	2.73 ± 0.40 ab	98.00 ± 1.00 ab	0.0102 ± 0.0015 b
Bamboo	3.67 ± 1.15 a	0.67 ± 0.28 a	96.67 ± 1.53 a	0.0047 ± 0.0041 a
Mixed	14.00 ± 2.00 cd	9.20 ± 2.04 cd	122.33 ± 0.58 c	0.0180 ± 0.0017 cd

CONCLUSION

This research shows that different host plant species had significant effects to development time and survivorship of migratory locust at different life stages. Results also showed that cultivated crops, such as maize and rice had positive results towards the two previous parameters.

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REFERENCES

Ali A, Rizvi P Q. (2010). Age and stage specific life table of *Coccinella septemounctata* (Coleoptera: Coccinellidae) at varying temperature. *World Journal of Agriculture Science* 6:268-273.

Behmer S T. (2009). Insect herbivore nutrient regulation. Annual Review of Entomology 54: 165-187. https://doi.org/10.1146/annurev.ento.54.110807.090537

Bellows Jr T S, Van Driesche R G, Elkinton J S. (1992). Life Table construction in the evalution of natural enemies. *Annual Review of Entomolgy* 37: 587-612.

Bitsadze, N., Jaronski, S., Khasdan, V., Abashidze, E., Abashidze, M., Latchininsky, A., Samandashvili, D., Sokhadze, I., Rippa, M., Ishaaya, I., Horowitz, A. R. (2013). Joint action of *Beauveria bassiana* and the insect growth regulators diflubenzuron and novaluron, on the migratory locust, *Locusta migratoria*. *Journal of Pest Science* 86(2): 293–300. https://doi.org/10.1007/s10340-012-0476-4

Bostanian, N. J., Wise, J. C., & Isaacs, R. (2012). Pesticides for Arthropod Control in Vineyards. In Arthropod Management in Vineyards: Pests, Approaches, and Future Directions (pp. 139–157). https://doi.org/10.1007/978-94-007-4032-7

Chen, Q., N. Li, X. Wang, L. Ma, J. Huang, and G. Huang. (2017). Age-stage, two-sex life table of *Parapoynxcrisonalis* (Lepidoptera: Pyralidae) at different temperatures. *PLos One*: 1–12.

Dadd, R. H. (1960). The nutritional requirements of locusts-I Development of synthetic diets and lipid requirements. *Journal of Insect Physiology* 4(4): 319–347. https://doi.org/10.1016/0022-1910(60)90057-3

Brewer R. (1979). *Principles of Ecology.* W.B Sounders Co, Philadelphia.

Carey J R. (1982). Practical application of the stable age distribution: Analysis of a Tetranychid mite (Acari: Tetranychidae) population outbreak. *Environmental Entomology* 12:10-18 doi: http://doi.org/10.1093/ee/12.1.10.

Chapman, R. F. (1975). *The Insect. Structure and Function*. The English Universities Press, Ltd. London.

Gomez, K A. and Gomez, A A. (1983). Prosedur Statistik Untuk Penelitian Pertanian. Ed. II. Translated by Sjamsudin E, dan Baharsjah J.S*, 1995.* Universitas Indonesia Press. Jakarta.

Gotelli, N J. (1995). A Primer of Ecology*.* Cambrige: Sinauer Associates

Hause, H L. (1961). Insect nutrition. *Annual Review Entomology* 6: 13-26.

Horgan, F. G., Suja, T., Naik, B. S., Fame, A., Bernal, C. C., Liberty, M., & Almazan, P. (2016). Effects of nitrogen on egg-laying inhibition and ovicidal response in planthopper-resistant rice varieties. *Crop Protection* 89: 223–230. https://doi.org/10.1016/j.cropro.2016.07.033.

Hunter, M D, Price P W. (1992). Playing chutes and ladders: Heterogeneity and the relative roles of bottom-up and top-down forces in natural communities. *Ecology* 73(3): 724– 732.

Jing, X. H., & Kang, L. (2003). Geographical variation in egg cold hardiness: A study on the adaptation strategies of the migratory locust Locusta migratoria L. *Ecological Entomoogy* 28(2): 151–158. https://doi.org/10.1046/j.1365-2311.2003.00497.x.

Jones, H P. (1966). Rearing and Breeding in the Laboratory. Anti Locust Res. Centre. London. 12 p.

Karp, D. S., R. Chaplin-Kramer, T. D. Meehan, E. A. Martin, F. DeClerck, H. Grab, C. Gratton, L. Hunt, A. E. Larsen, A. Martínez-Salinas, M. E. O'Rourke, A. Rusch, K. Poveda, M. Jonsson, J. A. Rosenheim, N. A. Schellhorn, T. Tscharntke, S. D. Wratten, W. Zhang, A. L. Iverson, L. S. Adler, M. Albrecht, A. Alignier, G. M. Angelella, M. Zubair Anjum, J. Avelino, P. Batáry, J. M. Baveco, F. J. J. A. Bianchi, K. Birkhofer, E. W. Bohnenblust, R. Bommarco, M. J. Brewer, B. Caballero-López, Y. Carrière, L. G. Carvalheiro, L. Cayuela, M. Centrella, A. Ćetković, D. C. Henri, A. Chabert, A. C. Costamagna, A. De la Mora, J. de Kraker, N. Desneux, E. Diehl, T. Diekötter, C. F. Dormann, J. O. Eckberg, M. H. Entling, D. Fiedler, P. Franck, F. J. Frank van Veen, T. Frank, V. Gagic, M. P. D. Garratt, A. Getachew, D. J. Gonthier, P. B. Goodell, I. Graziosi, R. L. Groves, G. M. Gurr, Z. Hajian-Forooshani, G. E. Heimpel, J. D. Herrmann, A. S. Huseth, D. J. Inclán, A. J. Ingrao, P. Iv, K. Jacot, G. A. Johnson, L. Jones, M. Kaiser, J. M. Kaser, T. Keasar, T. N. Kim, M. Kishinevsky, D. A. Landis, B. Lavandero, C. Lavigne, A. Le Ralec, D. Lemessa, D. K. Letourneau, H. Liere, Y. Lu, Y. Lubin, T. Luttermoser, B. Maas, K. Mace, F. Madeira, V. Mader, A. M. Cortesero, L. Marini, E. Martinez, H. M. Martinson, P. Menozzi, M. G. E. Mitchell, T. Miyashita, G. A. R. Molina, M. A. Molina-Montenegro, M. E. O'Neal, I. Opatovsky, S. Ortiz-Martinez, M. Nash, Ö. Östman, A. Ouin, D. Pak, D. Paredes, S. Parsa, H. Parry, R. Perez-Alvarez, D. J. Perović, J. A. Peterson, S. Petit, S. M. Philpott, M. Plantegenest, M. Plećaš, T. Pluess, X. Pons, S. G. Potts, R. F. Pywell, D. W. Ragsdale, T. A. Rand, L. Raymond, B. Ricci, C. Sargent, J.-P. Sarthou, J. Saulais, J. Schäckermann, N. P. Schmidt, G. Schneider, C. Schüepp, F. S. Sivakoff, H. G. Smith, K. Stack Whitney, S. Stutz, Z. Szendrei, M. B. Takada, H. Taki, G. Tamburini, L. J. Thomson, Y. Tricault, N. Tsafack, M. Tschumi, M. Valantin-Morison, M. Van Trinh, W. van der Werf, K. T. Vierling, B. P. Werling, J. B. Wickens, V. J. Wickens, B. A. Woodcock, K. Wyckhuys, H. Xiao, M. Yasuda, A. Yoshioka, and Y. Zou. 2018. Crop pests and predators exhibit inconsistent responses to surrounding landscape composition. *Proceeding National Academy of Science* 115: E7863–E7870.

Lorena, M., Nava, D. E., Roberto, J., & Nava, D. E. (2012). Life table of *Tamarixia radiata* (Hymenoptera : Eulophidae) on *Diaphorina citri* (Hemiptera : Psyllidae) at different temperature. *Journal of Economic Entomology* 105(2): 338–343.

Murray, Dewey W. (2016). The Biology, Ecology, and Management of the Migratory Grasshopper, Melanoplus sanguinipes (Fab.). University of Nebraska.

Mangan, R., Baars, J. R. (2013). Use of life table statistics and degree day values to predict the colonisations success of *Hydrellia lagarosiphon* Deeming (Diptera: Ephydridae), a leafmining fly of *Lagarosiphon major* (Ridley) Moss (Hydrocharitaceae), in Ireland and therest of Europe. Bio. Con. 64: 142-151.

Nikooei, M., Fathipour, Y., Javaran, M. J., & Soufbaf, M. (2015). How different genetically manipulated brassica genotypes affect life table parameters of *Plutella xylostella* (Lepidoptera: Plutellidae). *Journal of Economic Entomology* 108(2): 515-524.https://doi.org/10.1093/jee/tov018.

Onyeocha, F. A., & Fuzeau-Braesch, S. (1991). Comparative toxicity of some synthetic insecticides, and a growth inhibitor, in the migratory locust, *Locusta migratoria*. *Comparative Biochemistry and Physiology* 100(3): 361–363. https://doi.org/10.1016/0742-8413(91)90009-I.

Pener, M. P., & Simpson, S. J. (2009). Locust phase polyphenism: an update. Adv. in Ins. Phy. 36: 1-272.

Permana, A.D. (1997). Analisis tabel hidup dalam populasi serangga. Seminar/Workshop: Matematika Terapan, Wawasan Matematika Diskrit dan Aplikasi. ITB-IAEUP, Bandung (ID) : ITB Bandung.

Pedigo L P, Rice M E. (2006). Entomology and Pest Management. New Jersey: Prentice Hall.

Price, P W.(1997). Insect Ecology. Third ed. John Wiley and Sons' Inc. New York. 607 p.

Robinson, K. L., Tohidi-Esfahani, D., Lo, N., Simpson, S. J., & Sword, G. A. (2011). Evidence for widespread genomic methylation in the migratory locust, *Locusta migratoria* (Orthoptera: Acrididae). *PLoS ONE* 6(12): e28167. https://doi.org/10.1371/journal.pone.0028167.

Savopoulou-soultoni M, Stavridis D G, Vassillou A, Stafilidis J E, Irakiidis J. 1994. Response of *Lobesia botrana* (Lepidoptera: Tortricidae) to levels of sugar and protein in artificial Diets. Laboratory of Applied Zoology and Parasitology Faculty of Geotechnical Science. Aristotelian University of Thessalonik Greece. P. 85-89.

Scanlan, J. C., Grant, W. E., Hunter, D. M., & Milner, R. J. (2001). Habitat and environmental factors influencing the control of migratory locusts (*Locusta migratoria*) with an entomopathogenic fungus (*Metarhizium anisopliae*). *Ecological Modelling* 136(2–3): 223–236. https://doi.org/10.1016/S0304-3800(00)00424-5.

Segoli, M., & Rosenheim, J. A. (2013). The link between host density and egg production in a parasitoid insect : comparison between agricultural and natural habitats. *Functional Ecology* 27(5): 1224–1232. https://doi.org/10.1111/1365-2435.12109.

Simpson S, Clissold F, Lihoreau M, Ponton F, Wilder S, Raubenheimer D. (2015). Recent advances in the integrative nutrition of arthropods. *Annual Review of Entomology* 60: 293– 311. https://doi.org/10.1146/annurev-ento-010814-020917

Slansky, F. (1993). Nutritionl Ecology: The Fundamental Quest For Nutrient. Champman and Hall, New York.

Slansky, F Jr, Scriber J M. (1985). Food Consumption and Utilization. In: G.A. Kerkut and L.I. Gilbert (Eds) Comprehensive Insect Physiology Biochemistry and Pharmacology. Vol 4.

Soroushmehr, Z., Sahragard, A., & Salehi, L. (2008). Comparative life table statistics for the ladybeetle *Scymnus syriacus* reared on the green citrus aphid, *Aphis spiraecola*, fed on two host plants. *Entomological Science* 11: 281–288. https://doi.org/10.1111/j.1479-8298.2008.00275.x

Southwood. 1971. Ecologycal Methods with Particular reference to Study of Insect Population. Chapman and Hall.

Tanga, A., Chrysantus, M., & Samira, A. (2013). Effect of Six Host Plant Species on the Life History and Population Growth Parameters of *Rastrococcus iceryoides* (Hemiptera : Pseudococcidae). *Florida Entomology* 96(3): 1030–1041.

Tarumingkeng, R.C. (1994). Dinamika populasi: kajian ekologi kuantitatif. Pustaka Sinar Harapan dan Universitas Kristen Krida Wacana, Jakarta.

Tokuda, M., Tanaka, S., & Zhu, D. H. (2010). Multiple origins of *Locusta migratoria* (Orthoptera: Acrididae) in the Japanese Archipelago and the presence of two major clades in the world: Evidence from a molecular approach. *Biological Journal of the Linnean Society* 99(3): 570–581. https://doi.org/10.1111/j.1095-8312.2010.01386.x

Tsai, J. H., & Wang, J. (2001). Effects of host plants on biology and life table parameters of *Aphis spiraecola* (Homoptera: Aphididae). *Environmental Entomology* 30(1): 44–50.

Tu, X., Z. Zhang, D. L. Johnson, G. Cao, Z. Li, S. Gao, X. Nong, and G. Wang. 2012. Growth, development and daily change in body weight of locusta migratoria manilensis (Orthoptera: Acrididae) nymphs at different temperatures. *Journal of Orthoptera Research*. 21: 133–140.

Untung, K. (1996). Penghantar Pengelolahan Hama Terpadu. Gajah Mada University Press. Yogyakarta.

Waldbauer, G P., Cohen R W, Friedman S. (1984). An Improved Procedure for Laboratory Rearing of The Corn Earworm *Heliothis zea* (Lepidoptera: Noctuidae). *The Great Lakes Entomology* 17:113-118.

Wang, X. H., & Kang, L. (2005). Differences in egg thermotolerance between tropical and temperate populations of the migratory locust *Locusta migratoria* (Orthoptera: Acridiidae). *Journal of Insect Physioology* 51(11): 1277–1285. https://doi.org/10.1016/j.jinsphys.2005.07.010

Wibowo, L., Martono E, Yusuf E. (1995). *Laju Pertumbuhan Intrinsik Nezara viridula pada Kedelai, Kacang panjang, dan Buncis*. M.Sc. thesis. Program Studi Ilmu Hama Tumbuhan. UGM. Yogyakarta.

Wigglesworth V B. (1953). *The Principles of Insect Physiology*. Muthuer and Co. Ltd. London. 546 p

White T. (1984). The abundance of invertebrate herbivores in relation to the availability of nitrogen in stressed food plants. Oecology 63(1): 90– 105. https://doi.org/10.1007/BF00379790

Wiman, N. G., V. M. Walton, D. T. Dalton, G. Anfora, H. J. Burrack, J. C. Chiu, K. M. Daane, A. Grassi, B. Miller, S. Tochen, X. Wang, and C. Ioriatti. 2014. Integrating temperature-dependent life table data into a matrix projection model for *Drosophila suzukii* population estimation. *PLoS One* 9.

Yang, M. L., Zhang, J. Z., Zhu, K. Y., Xuan, T., Liu, X. J., Guo, Y. P., & Ma, E. B. (2009). Mechanisms of organophosphate resistance in a field population of oriental migratory locust, *Locusta migrotoria* Manilensis (meyen). *Archives of Insect Biochemistry and Physiology* 71(1): 3–15. https://doi.org/10.1002/arch.2025

Young A M. (1978). *Population Biology of Tropical Insect.* New York: Plenum Pr.