Journal of

Entomology

ISSN 1812-5670

Academic
Journals Inc.

www.academicjournals.com

Journal of Entomology 10 (2): 86-94, 2013
ISSN 1812-5670 / DOI: 10.3923/je.2013.86.94

Influence of Temperature and Humidity on the Population Growth of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) on Milled Rice

L.P. Astuti, G. Mudjiono, S. Rasminah and B.T. Rahardjo
Department of Plant Protection, Agriculture Faculty, University of Brawijaya Malang, Indonesia

Corresponding author: L.P. Astuti, Department of Plant Protection, Agriculture Faculty, University of Brawijaya Malang, Indonesia

ABSTRACT

One of the most important pest storage on milled rice is *Rhyzopertha dominica* (Coleoptera: Bostrichidae). Despite of both quantity and quality of food, temperature and relative humidity in the warehouse are important factors that affect the development and growth population of *R. dominica*. The effect of temperature and humidity on the population growth of *R. dominica* (F.) on milled rice was studied in a laboratory experiment. The treatment consisted of eight temperature levels (20, 25, 30, 32, 34, 36, 38 and 40°C) and three levels of relative humidities (60, 70 and 80%). The result showed that at all levels of relative humidity tested, *R. dominica* did not survive at 40°C, whereas at 38°C some *R. dominica* produced eggs but none of them hatched. With the temperature-dependent equation it was found that the optimum temperature to produce egg number, larvae number and adult number were 35.05, 33.59 and 33.27°C, respectively. At those optimum temperature, the maximum predicted of egg number, larvae number and adult number occurred at 80% relative humidity, i.e., 209.33 eggs, 128.64 larvae and 38.75 adult insect. The study also showed that *R. dominica* had the shortest (25.00 days) developmental time at 36°C with 80% relative humidity. The longest developmental time (106.33 days) was observed at 20°C with 60% relative humidity. At all relative humidity levels tested, the growth index of *R. dominica* increased with increasing the temperature up to 34°C and then it decreased with further temperature increase.

Key words: Warehouse insect, abiotic factor, lesser grain borer, developmental time

INTRODUCTION

The damage of rice stored in the warehouses is the end result of the operation of several factors which include the biotic and abiotic factors. One of the most important biotic factor is the insect pest of stored products (Prakash and Rao, 1995), while temperature, relative humidity, light and aeration have been identified as the abiotic factors that influence the quality of stored product (Kumawat, 2011; Munroo, 1966; Rees, 2004). These abiotic factors influence both the physical and chemically damages of rice itself and the growth and development of the insect pests.

Prakash and Rao, 1995 identified a number of insects which damage the rice during stored, among of them are: The lesser grain borer (*Rhyzopertha dominica*, F.), the angoumois grain moth (*Sitotroga cerealella*, Olivier), the rice weevil (*Sitophilus oryzae*, L.), the rice moth (*Corcyra cephalonica*, Stainton) and the saw-toothed grain beetle (*Oryzaephilus surinamensis*, L.).

Bashir (2002), Hill (2002) and Edde (2012) observed that *R. dominica* (Coleoptera: Bostrichidae) is the most important pest for stored grain in many regions of the world. By using of their strong mandible both the larvae and adult insects, attacks the whole grain and caused serious damage. *R. dominica* is cosmopolitan and can be a serious pest in hot climates, dry conditions throughout the tropics and subtropics and sheltered conditions in temperate regions (Hill, 2002; Munroo, 1966; Navarro *et al*., 2002; Rees, 2004).

Speight *et al*. (1999) said that the insect's body temperature is affected by the surrounding condition. This phenomenon is known as poikilotherms. The increase of temperature in the warehouse to the near of the optimum temperature would affect the rise of the *R. dominica* development and population growth. Hill (2002) and Rees (2004) noted that at 34°C the *R. dominica* reaches its optimum development, while Navarro *et al*. (2002) noted that the optimum development of *R. dominica* occurred between 32-35°C. Furthermore, Navarro *et al*. (2002) found that the relative humidity was another important factor that, either directly or indirectly, affected the development of storage grain insect.

It has been widely known that relative humidity in the storage is positively correlated with the moisture content of the materials stored. Therefore increasing of the relative humidity will increase of the water content of the materials stored in the warehouse. The stored insect pests prefer high moisture content of grain stored and therefore the damage of the store product will be more extensive.

Rhyzopertha dominica would have a short developmental time and high population growth if there are suitable temperature and relative humidity conditions. Under these conditions this insect would be a potential and important pest of grain storage products. The change of climate conditions, therefore, would lead to a change the temperature and might affect the growth and development of stored product insect (Quarles, 2007).

With this in mind, the current study was aimed: (1) To study the population growth of *R. dominica* at different temperature and relative humidity and (2) To determine the optimum conditions for development with a few by calculating its theoretical optimum developmental time at each relative humidity levels on milled rice.

MATERIALS AND METHODS

Materials: The cultures used in this study was prepared by using the insects collected from the farmer's rough rice storage which has been infested by *R. dominica* at Rejoso village, Junrejo, Batu, East Java, Indonesia. These insects were reared in the pest laboratory using milled rice as stock culture.

The rice sample used was obtained from the farmer's where its seeds were supplied by local agriculture and estate, Malang-Indonesia. The rice sample was sterilized at-15°C for a week and then removed to 5°C for another week. Before used in the study, the rice samples were preconditioned at room temperature (27±2°C) for two weeks.

Methods: The study was conducted at Pest Laboratory, Department of Plant Protection, University of Brawijaya, Malang, Indonesia during June 2011 to June 2012. The treatments tested in this study were eight level of temperatures (20, 25, 30, 32, 34, 36, 38 and 40°C) and three levels of relative humidity (60, 70 and 80%). These 24 treatment combinations were arranged in a Randomized Complete Block Design with three replications. The temperatures of 20 and 25°C were provided by constant temperature rooms, while the temperature of 30, 32, 34, 36, 38, 40°C by thermostatically controlled cabinets. The relative humidity was achieved in desiccators at approximately 60, 70 and 80% by using saturated salt solutions (Greenspan, 1977).

Thirty grams of each sterilized milled rice were put in glass vials (7×4.5 cm). Then, the 15 pairs of 2 to 3 weeks old adults *R. dominica* were transfered from stock culture and covered with muslin cloth on top. The vials with milled rice sample and 15 pairs of adult *R. dominica* in it were placed in the conditions of required temperature and relative humidity as the treatment. Then the adult of *R. dominica* allowed to infest and oviposite for seven days. At the end of seven days oviposition period, the adult insects of *R. dominica* were discharged and the number of egg was recorded. Afterward, the rice samples with eggs of *R. dominica* were kept under the experiment conditions to assessed the number of larvae and the emergence of F_1 progeny. Emerging progeny was counted in each vial on each assessment day. This observation continued until all F_1 progeny was expected to have emerged before the F_2 generation starts (Bashir, 2002).

Separate cultures of egg on milled rice were run to record the egg period and also the total larval and pupal period was recorded as the most of the period spent in the rice kernel. The Growth Index (GI) was calculated using formula (Howe, 1971; Shires, 1979; Kumawat, 2007):

$$\text{Growth index} = \frac{\text{Log F}}{\text{D}} \times 100 \tag{1}$$

where, F is Adult emerged (%) and D is Developmental period.

Data analysis: The recorded data were analyzed under analysis of variance (ANOVA), while the significant means were compared by Least Significant Different at α = 5%. The non-linear regression model (Kutner *et al*., 2004; Easwood *et al*., 2008) were used to describe the relationship between temperatures and eggs, larvae and adult numbers at each different relative humidity. Statistical procedure analysis were accomplished using Genstat (1997). Selection of an equation to describe the data was based on the magnitude and pattern of residuals, R^2 and whether the curve had a shape that was reasonable for describing the data. The non-linear regression equation can be summarized as followed:

$$Y = a+(b+cX)r^X \tag{2}$$

where, a is constant; b is linear effect; c and r is non-linear effect (r>1).

RESULTS

It was observed that *R. dominica* could not survive at 40°C on 60-80% relative humidity and died at the first observation (7 days after incubation). At the temperature of 38°C with 60-80% relative humidity, the adult of *R. dominica* also died at the first observation even though there were still some eggs that were produced but none of them hatched. The statistical analysis showed that the interaction of temperature and relative humidity significantly influenced the eggs number of *R. dominica* (Table 1).

The results in Table 1 show that eggs number of *R. dominica* varied greatly at different temperature and relative humidity levels from 12.00 to 209.33. The minimum eggs number (12.00) was recorded at 38°C, 60% relative humidity, whereas the maximum eggs number (209.33) was recorded at 34°C, 80% relative humidity.

Table 1: Means number of eggs (from 15 females which were infested) of *R. dominica* (Coleoptera: Bostrichidae) at different temperatures (°C) and relative humidity (%)

	Relative humidity (%)		
Temperature (°C)	60	70	80
20	39.33bc	43.67cd	44.33cd
25	48.33d	58.33e	60.33e
30	87.67g	101.67h	107.00h
32	147.67i	164.00j	175.67k
34	174.33k	195.33m	209.33n
36	158.33j	175.33k	194.00l
38	120.00a	35.00b	70.67f

Means followed by the same letter are not significantly different at α = 0.05

Table 2: Means of larvae number and adult number of *R. dominica* (Coleoptera: Bostrichidae) at different temperature (°C) and relative humidity (%)

	Larvae No. at relative humidity (%)			Adult No. at relative humidity (%)		
Temperature (°C)	60	70	80	60	70	80
20	18.00a	20.00a	21.00b	21.00b	9.67b	10.67b
25	21.00b	41.00d	41.33d	41.33d	15.33b	18.00e
30	54.00g	72.33h	84.00g	84.00g	25.67d	28.67h
32	84.67j	93.67k	119.33m	119.33m	34.00k	39.67m
34	77.33i	103.00l	124.00n	124.00n	32.33j	37.00l
36	32.67c	46.33e	53.33f	53.33f	18.00e	21.00f

Means followed by the same letter are not significantly different at α = 0.05

In this study, the eggs produced at the temperature of 38°C did not hatch into larvae, so it was not included in the statistical analysis. The pattern of larvae number of *R. dominica* at six temperatures were not similar at the three different relative humidities, as the interaction of temperature and relative humidity which showed a significantly effect. The result presented in Table 2 shows that the temperature rise would cause greater increase in the number of larvae at high relative humidity level than at low relative humidity level. The effect of temperature on the rise in the number of larvae at the humidity of ≥70% still occurs up to 34°C. While at the humidity of 60%, the increase of larvae number was recorded at the temperature of 20°C to 32°C.

The results in Table 2 also show that interaction of temperature and relative humidity significantly influence the adult insect number. This result emphasized that, the pattern observed at the six temperatures was not always the same at each relative humidity level. The highest adult number (39.67) of *R. dominica* was recorded at 32°C, 80% relative humidity and the lowest (6.67) was at 20°C, 60% relative humidity.

The duration of eggs to adult developmental time was significantly influenced by the interaction between temperature and relative humidity (Table 3). The total developmental time from egg to adult vary at the various temperature and humidity levels. The fastest development time (25.00 days) was recorded at 36°C with 80% relative humidity and the slowest (106.33 days) was recorded at 20°C with 60% relative humidity.

The suitable of an environment for development usually is indicated by the developmental time. However, as developmental mortality is significantly variable, then Howe (1971) and Shires (1979)

Table 3: Means of the developmental time from egg to adult of *R. dominica* (Coleoptera: Bostrichidae) at different temperature (°C) and relative humidity (%)

	Relative humidity (%)		
Temperature (°C)	60	70	80
20	106.33^{k}	103.00^{j}	98.67^{i}
25	670.00^{f}	56.67^{g}	56.33^{g}
30	55.330^{g}	44.67^{f}	43.67^{f}
32	45.670^{f}	35.00^{d}	31.67^{c}
34	38.000^{e}	32.00^{c}	26.33^{a}
36	35.000^{d}	29.00^{b}	25.00^{a}

Means followed by the same letter are not significantly different at $\alpha = 0.05$

Table 4: Means Growth Index of *R. dominica* (Coleoptera: Bostrichidae) at different temperature (°C) and relative humidity (%)

	Relative humidity (%)		
Temperature (°C)	60	70	80
20	0.15^{a}	1.31^{ab}	1.40^{b}
25	2.08^{c}	2.56^{de}	2.62^{e}
30	2.40^{d}	3.15^{fg}	3.27^{g}
32	2.90^{f}	3.76^{h}	4.28^{k}
34	3.06^{f}	3.81^{j}	4.74^{l}
36	2.51^{de}	3.49^{i}	4.14^{k}

Means followed by the same letter are not significantly different at $\alpha = 0.05$

preferred the use of growth index. The results presented in Table 4 show that the interaction between temperature and relative humidity significantly influenced the growth index of *R. dominica* (Coleoptera: Bostrichidae). The maximum growth index (4.74) was recorded at 34°C with 80% relative humidity and the minimum growth index (1.15) was recorded at 20°C with 60% relative humidity.

DISCUSSION

The result presented in Table 1-4 show that the pattern of the development of *R. dominica* (Coleoptera: Bostrichidae) was influenced by the temperatures and relative humidity levels. It was noted that the effect of temperature on the eggs number was greater at the higher relative humidity. To determine the Optimum Temperature (OT), the regression analysis was performed and the resulted models follow the formula given in Eq. 2. The resulted equations for egg numbers, larvae numbers and the number of adult insects together with optimum temperature for each variable at each relative humidity are presented in Table 5.

The results in Table 5 show that the OT of *R. dominica* (Coleoptera: Bostrichidae) was around 33-35°C. Furthermore, it was found that the maximum eggs number (209.33), larvae number (128.64) and adult insect number (38.75) occurred at the relative humidity 80% with the temperature of 35.05, 33.59 and 33.27°C, respectively. At the relative humidity of 60%, the maximum egg number was only (180.17) at 34.77°C; the maximum larvae number was 80.69 at 33.39°C; and the maximum number of adult insect was 27.31 which occurred at the temperature of 33.09°C.

The experimental results discussed here emphasized that the maximum fecundity of *R. dominica* occurred at 35.05°C, 80% relative humidity. Furthermore, the adult of *R. dominica*

Table 5: Relations between number of eggs, No. of larvae and number of adult insect (Y) with temperatures (°C) in three different relative humidities (%)

*RH	Model $Y = a+(b+cX)r^X$	OT	Y_{max}	R^2
No. of eggs				
60%	Y = 29.14 +(0.1177-0.003110X)1.4095X	34.77	180.17	96.9
70%	Y = 32.60 +(0.0213-0.000560X)1.3880X	34.99	196.74	97.8
80%	Y = 31.52 +(0.0294-0.000769X)1.3762X	35.05	209.33	97.5
No. of larvae				
60%	Y = 11.03 + (0.00641-0.000177X)1.4258X	33.39	80.69	95.5
70%	Y = 18.35 + (0.01068-0.000293X)1.4096X	33.53	103.35	98.8
80%	Y = 16.64 + (0.01119-0.000307X)1.4191X	33.59	128.64	99.4
No. of adult insects				
60%	Y = 4.88 + (0.0078-0.000215X)1.3691X	33.09	27.31	89.6
70%	Y = 7.32 + (0.0127-0.000348X)1.3525X	33.23	32.39	95.7
80%	Y = 8.16 + (0.0153-0.000418X)1.3506X	33.27	38.75	96.9

*RH: Relative humidity, a: Constant, b: Linear effect, c and r: Non-linear effect (r >1), OT: Optimum temperature, significant at $\alpha<0.01$ (df_{error}: 17)

did not reproduce and could not survive at 40°C with the range of 60-80% relative humidity. This result differs from that obtained Kumawat (2007), who reported that at 75±5% relative humidity, *R. dominica* reaches its maximum fecundity at 30±1°C. On the other hand, Hagstrum and Milliken (1988) reported that could not survive and died at temperatures under 22.5°C and greater than 35°C. These differences might be due to the difference strain of *R. dominica* and the medium in this study (Edde, 2012). In this study it was noted that any increase in the temperature up to 34°C generally favor the development of *R. dominica* but further increase from 34°C has an adverse effect. Similarly an increase in the relative humidity levels usually benefits development although the response was considerably more variable. The significant effect of temperature and relative humidity on the insect growth and development has also been noted by Das and Chauduri (2005). Hagstrum and Milliken (1988) observed that the order of important of the growth factors that influence the development of *R. dominica* was temperature>relative humidity>quantity and quality of food. Furthermore, they noted that the temperature of near optimal development, the effect of moisture and food on the larval development was more pronounced than the effect of temperature.

Wang *et al.* (2009) noted that most insect could complete its development at the range of temperature between 20°C to 40°C. Furthermore, Wang *et al.* (2009) observed that *R. dominica* can still produce eggs at 3°C but none of them hatched. Baldasari *et al.* (2005) found that *R. dominica* capable of completing its reproduction at the temperature of >17°C. They observed that at the temperature between 7-27°C, *R. dominica* still had the ability to produce eggs. However, after they were incubated at 27°C for 50 days, only the eggs laid at the temperature of 27°C could hatch.

According to Wang *et al.* (2009), the survivorship of larvae stage would worst at extremely high or low temperature. Burk *et al.* (2000) found that at extremely high or low temperature, warehouse insect were killed. Furthermore, they observed that a moderate high or low temperature had a less lethal effect, but it decreased the population growth. Howe (1971) stated that the developmental time was a good indicator for studying the effect of environment conditions to the insect development. With this approach, Kumawat (2007) found that developmental time of *R. dominia* from egg to adult was affected by the temperature and relative humidity.

The regression analysis data presented in Table 3 found that there was a linear relationship between developmental time (DT, in days) with temperature (t, in°C), i.e.:

$$DT = 180-4.30\ t, \text{ for 60\% relative humidity } (R^2 = 94.0\%) \quad (3)$$

$$DT = 180-4.41\ t, \text{ for 70\% relative humidity } (R^2 = 89.2\%) \quad (4)$$

$$DT = 180-4.51\ t, \text{ for 80\% relative humidity } (R^2 = 92.6\%) \quad (5)$$

With these three Eq. 3-5, it could be concluded that increasing temperature would shorten the developmental time from egg to adult. Those equations also indicated that the increasing effect of the temperature on the developmental time was higher at a higher relative humidity level. This result can be seen by the regression linier coefficient (b = -4.51) that was at 80% relative humidity, while the regression linier coefficient (b = -4.30) was at 60% relative humidity.

This study emphasized that developmental time at all relative humidity levels decreased with the increase in temperature. On the other hand, at low temperature the time needed to complete development was considerably lengthened. Relative humidity appear to have a lesser effect, although high levels (e.g., 70-80% RH), were obviously beneficial. Speight *et al.* (1999) said that the body temperature of insect is a function of the surrounding temperature, therefore the inability to regulate that function affected its developmental time. According to Sousa *et al.* (2009) food availability and quality and environment factors such as temperature and moisture are the most factors for insect abundance. They found that those factors influence the insect abundance on insect developmental times, survival and fecundity. The significant effect of temperature and relative humidity on the survivability of the warehouse insect has also been demonstrated by Ileleji *et al.* (2007). Field (1992) found that most stored-grain insects has the optimum developmental time between 25-35°C.

Hagstrum and Subramanyam (2006) said that the most important factor affected to the time of insect development are both quantity and quality of food, temperature and moisture content of materials. Furthermore they found that the developmental time of *R. dominica* from eggs to adult vary from 58.8 days at 25°C and 31.1 days at 35°C and could not develop into an adult at the temperatures <22°C or above 35°C. The experimental result presented here also showed that the environmental suitability of *R. dominica* any increase in temperature to 34°C generally favour development, but further increase to 34°C has an adverse effect. Kumawat (2007) conducted study on wheat and found that *R. dominica* achieved the maximum growth index at 30.1°C. Again the different of those results could be caused by different of the strain of *R. dominica* and media used (Bashir, 2002; Edde, 2012). Generally, the temperature effect on growth index are different on each relative humidity level. In other words, the effect of temperature on growth index is higher on high relative humidity. This result can also be seen by looking at the number of eggs, larvae and adult data (Table 1, 2). These results clearly indicated that *R. dominica* would be able to develop successfully in humid tropical country such as Indonesia. However, some of biotic factors, as in competition with *S. oryzae*, may influence its distribution.

CONCLUSION

The experimental results discussed here showed that the development of *R. dominica* was influenced by temperature and relative humidity. At all levels of relative humidity tested, *R. dominica* did not survive at 40°C, whereas at 38°C some *R. dominica* produced eggs but none of them hatched. With the temperature-dependent equation it was found that the optimum temperature to produce egg number, larvae number and adult number were 35.05, 33.59 and 33.27°C, respectively. At those optimum temperature, the maximum predicted of egg number, larvae number and adult number occurred at 80% relative humidity, i.e.: 209.33 eggs, 128.64 larvae and 38.75 adult insect. The study also showed that *R. dominica* had the shortest (25.00 days) developmental time at 36°C with 80% relative humidity. The longest developmental time (106.33 days) was observed at 20°C with 60% relative humidity. At all relative humidity levels tested, the growth index of *R. dominica* increased with increasing the temperature up to 34°C and then it decreased with further temperature increase.

ACKNOWLEDGMENT

This research is a part of the first author's thesis for the Ph.D program at Brawijaya University, Indonesia. Thanks to the Rector and the Dean of Agriculture Faculty of University of Brawijaya for supporting and permission and to the PPKID University of Brawijaya for helping to finalize the manuscript.

REFERENCES

Baldasari, N., A. Martin, S. Cavicchi and P. Baronio, 2005. Effects of low temperatures on adult survival and reproduction of *Rhyzopertha dominica*. Bull. Insectol., 58: 131-134.

Bashir, T., 2002. Reproduction of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) on different host-grain. Pakistan J. Biol. Sci., 5: 91-93.

Burk, C.S., J.A. Johnson, D.E. Maler and J.W. Heaps, 2000. Temperature. In: Alternatives to Pesticides in Stored-Product IPM, Subramanyam, B. and D.W. Hagstrum (Eds.). Kluwer Academic Publishers, Massachusetts, pp: 73-104.

Das, M. and N. Chauduri, 2005. Life-fecundity table on incidence of *Spilosoma obliqua* on jute. Ann. Plant Protec. Sci., 13: 319-323.

Eastwood, D.C., A. Mead, M.J. Sergeant and K.S. Burton, 2008. Statistical modelling of transcript profiles of differentially rergulated genes. BMC Mol. Biol., Vol. 9 10.1186/1471-2199-9-66

Edde, P.A., 2012. A review of the biology and control of *Rhyzopertha dominica* (F.) the lesser grain borer. J. Stored Prod. Res., 48: 1-18.

Field, P.G., 1992. The control of stored-product insects and mites with extreme temperatures. J. Stored Prod. Res., 28: 89-118.

Genstat, 1997. Reference Manual (5) Release 3. Statistics Department Rothamsted Experimental Station, Oxford University Press, Oxford, New York, pp: 434-439.

Greenspan, L., 1977. Humidity fixed points of binary saturated aqueous solutions. J. Res. Natl. Bur. Stand. A: Phys. Chem., 81A: 89-96.

Hagstrum, D.W. and G.A. Milliken, 1988. Quantitative analysis of temperature, moisture and diet factors affecting insect development. Ann. Entomol. Soc. Am., 81: 539-546.

Hagstrum, D.W. and B. Subramanyam, 2006. Fundamental of Stored-Product Entomology. AACC International, Minnesota, USA., ISBN: 9781891127502, Pages: 323.

Hill, D.S., 2002. Pest of Stored Foodstuffs and their Control. Kulawer Acedemic Publisher, Netherlands.

Howe, R.W., 1971. A parameter for expressing the suitability of an environment for insect development. J. Stored Prod. Res., 7: 63-65.

Ileleji, K.E., D.E. Maier and C.P. Woloshuk, 2007. Evaluation of different temperature management strategies for suppression of Sitophilus zeamais (Motschulsky) on stored maize. J. Stored Prod. Res., 43: 480-488.

Kumawat, K.C., 2007. Effect of abiotic factors on biology of *Rhyzopertha dominica* on wheat. Ann. Plant Protec. Sci., 15: 111-115.

Kumawat, K.C., 2011. *Rhyzopertha Dominica* (Fab.) on Wheat: Bioecology and Management. LAP LAMBERT Academic Publishing, USA., ISBN: 9783845432090, Pages: 212.

Kutner, M.H., C.J. Nachtsheim and J. Neter, 2004. Applied Linear Regression Models. 4th Edn., McGraw Hill, New York, ISBN: 978-0256086010.

Munroo, J.W., 1966. Pests of Stored Products. Hutchinson and Co. Pub. Ltd., New York.

Navarro, S., R. Noyes and D.S. Jayas, 2002. Stored Grain Ecosystem and Heat and Moisture Transfer in Grain Bulks. In: The Mechanic and Physics of Modern Grain Aeration Management, Navarro, S. and R. Noyes (Eds.). CRC Press, United States of America, pp: 35-77.

Prakash, A. and J. Rao, 1995. Insect Pest Management in Stored-Rice Ecosystems. In: Stored-Grain Ecosystem, Jayas, D.G, N.D.G. White and W.E. Muir (Eds.). Marcel Dekker, New York. Hongkong, pp: 709-736.

Quarles, W., 2007. Global warming means more pests. IPM Practitioner, 29: 1-8.

Rees, D., 2004. Insects of Stored Products. CSIRO Publishing, Australia.

Shires, S.W., 1979. Influence of temperature and humidity on survival, development period and adult sex ratio in *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). J. Stored Prod. Res., 15: 5-10.

Sousa, A.W., L.R.D. Faroni, F. Rezende, M.A.G. Pimentel and G.N. Silva, 2009. Population growth of *Cathartus quadricollis* (Guerin-Meneville) (Coleoptera: Silvanidae) in products stored at different temperatures. Afr. J. Food Sci., 3: 347-351.

Speight, M.R., M.D. Hunter and A.D. Watt, 1999. Ecology of Insects: Concepts and Applications. 2nd Edn., Blackwell Science Ltd., UK., ISBN: 0-86542-745-3.

Wang, J.J., Y. Ren, X.Q. Wei and W. Dou, 2009. Development survival and reproduction of the Psocid *Liposcelis paeta* (Psocoptera: Liposcelidae) as a function of temperature. J. Econ. Entomol., 102: 1705-1713.