American Journal of Experimental Agriculture
11(6): 1-11, 2016, Article no.AJEA.24819
ISSN: 2231-0606

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Population Dynamics of the Mango Mealybug *Rastrococcus invadens* Williams (Homoptera: Pseudococcidea) in Western Burkina Faso

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Authors' contributions

This work was carried out in collaboration between all authors. Authors KN, DD, SN and LCO designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors KN and SN reviewed the experimental design and all drafts of the manuscript. Author KN managed the analyses of the study. Author KN performed the statistical analysis. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEA/2016/24819
Editor(s):
(1) Hugo Daniel Solana, Department of Biological Science, National University of Central Buenos Aires, Argentina.
Reviewers:
(1) A. Jeyasankar, Government Arts College (Autonomous), Coimbatore, India.
(2) Felipe Tafoya, Autonomous University of Aguascalientes, Mexico.
(3) K. K. Srikumar, UPASI Tea Research Institute, Tamil Nadu, India.
Complete Peer review History: http://sciencedomain.org/review-history/13884

Original Research Article

Received 1st February 2016
Accepted 18th March 2016
Published 26th March 2016

ABSTRACT

Aims: The study aimed at determining the periods of high pest population of the mango tree mealybug *Rastrococcus invadens* Williams with respect to biotic and abiotic factors.
Study Design: Semiweekly observations were performed on the mango trees with a view of assessing the density of alive, dead or parasitized *R. invadens*.

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Place and Duration of the Study: This study was conducted in Western Burkina Faso from May 2014 to April 2015.

Methodology: A set of mango trees was selected in each of the following locations: Toussiana, Bérégadougou and Orodara. The assessment was conducted on 20 leaves (five leaves per cardinal point) that were picked up from each mango tree at each observation date. The parasitized mealybugs were kept inside pill boxes for two weeks and the emerging parasitoids were collected and kept in alcohol 70°. Data were registered and processed with the Microsoft Excel 2010 and SPSS software.

Results: Results showed that *R. invadens'* populations were more abundant during the wet season (May-September 2014) than the dry season (November 2014-April 2015) in all study locations. In general, parasitism was low. Some peaks of abundance were recorded in both wet and dry seasons. The evolution of the mortality of the insect pest was the same in all locations and peaks were observed from December 2014 to April 2015. The density of living *R. invadens* was significantly correlated with temperature and relative humidity. Impact of the parasitism due to *Anagyrus mangicola* Noyes and *Gyranusoidea tebygi* Noyes were also assessed and discussed.

Conclusion: Periods of *R. invadens* populations' abundance are well known in Western Burkina Faso. The parasitoids *A. mangicola* and *G. tebygi* are well established. The level of parasitism could be improved by releasing of *A. mangicola* and *G. tebygi* to control *R. invadens* efficiently.

Keywords: Burkina Faso; mango; mealybug; population dynamics; parasitoids; biological control.

1. INTRODUCTION

The mango mealybug *Rastrococcus invadens* Williams (Homoptera: Pseudococcidea) was incidentally introduced in West Africa in the 1980s [1]. It was observed for the first time in Lomé (Togo) and in Cotonou (Benin) before spreading along the Western coast of Africa in Ghana, Côte-d'Ivoire and Eastern Nigeria. In the mid-1990s, it had almost invaded the whole Western and Central Africa, from Senegal to the Democratic Republic of Congo [2]. This insect pest was identified in French Guyana (South America) in September 2014, and was thus reported for the first time on the American continent [3]. As soon as it was incidentally introduced in Ghana, 80% of crop losses were reported in the infested mango orchards [4]. Losses inflicted by *R. invadens* were also reported on some other fruit crops such as citrus and guava trees [5]. Control methods (mechanical and chemical) that were implemented by farmers since the first years of infestation failed to contain the pest. To that effect, two species of parasitoids (*Anagyrus mangicola* Noyes and *Gyranusoidea tebygi* Noyes) were imported from India and were released in several West African countries from 1987 to 1990 [6]. Satisfactory results were reported on crop losses reduction and on the improvement of farmers' socio economic status [7-10]. According to [2], once the populations of the insect pest drastically dropped under the action of parasitoids, the mealybug restricted itself to mango trees as its major host plant. Nonetheless and despite the settlement of the parasitoids in countries that were not covered by the releases, the insect pest is still a major threat because of its devastating effect. Thus, 53% yield losses were reported on research stations in Korhogo-Lataha (Côte-d'Ivoire) by [11]. These losses at times rise to 100% in farmers' orchads. These same authors reported some constraints in mango production in Burkina Faso because of the mealybug.

Initially observed in the Far West of Burkina Faso, the mango mealybug then spread in all the Western region of the country. This region is the major mango production zone of the country. The insect pest was reported in 2009 in 29 locations distributed in the provinces of Comoé, Houet, Léraba and Kénédougou [12]. In the course of 2009, a short term monitoring (April to June) addressed the population dynamics of that insect pest within its distribution area (L.C. Otoidobiga, personal presentation). This testifies that the mango mealybug is still a major concern. More comprehensive knowledge is necessary to develop an efficient and sustainable control strategy of this insect pest. This study aimed at improving knowledge on the population dynamics of the insect pest within its distribution area. Its objective is to determine the abundance variation of the insect pest populations over time and space in relation with abiotic and biotic factors.

2. MATERIALS AND METHODS

The study was conducted in Western Burkina Faso, in the distribution area of the insect pest

[12]. The provinces of Comoé, Houet, and Kénédougou (Fig. 1) that are the most representative ones in mango production in that region were selected to host this study. Thus, a prospection was conducted from 14^{th} -16^{th} 2014 to set up a location for this study in each province. The selected locations were Bérégadougou (Comoé), Toussiana (Houet) and Orodara (Kénédougou). These three locations are circumscribed within a radius of 50 km and are part of the same agro-ecological zone. The climate of the region is tropical and Sudanian type with an alternation of two distinct seasons: a wet season that extends on five to six months (from May to October) with a yearly rain accumulation beyond 900 mm and a dry season [13]. The monthly mean temperatures are occasionally above 35°C. The vegetation is a savanna woodland with open woodland forest and islets of dry tropical rainforests and gallery forests. Fig. 1 indicates the geographical position of the three study locations.

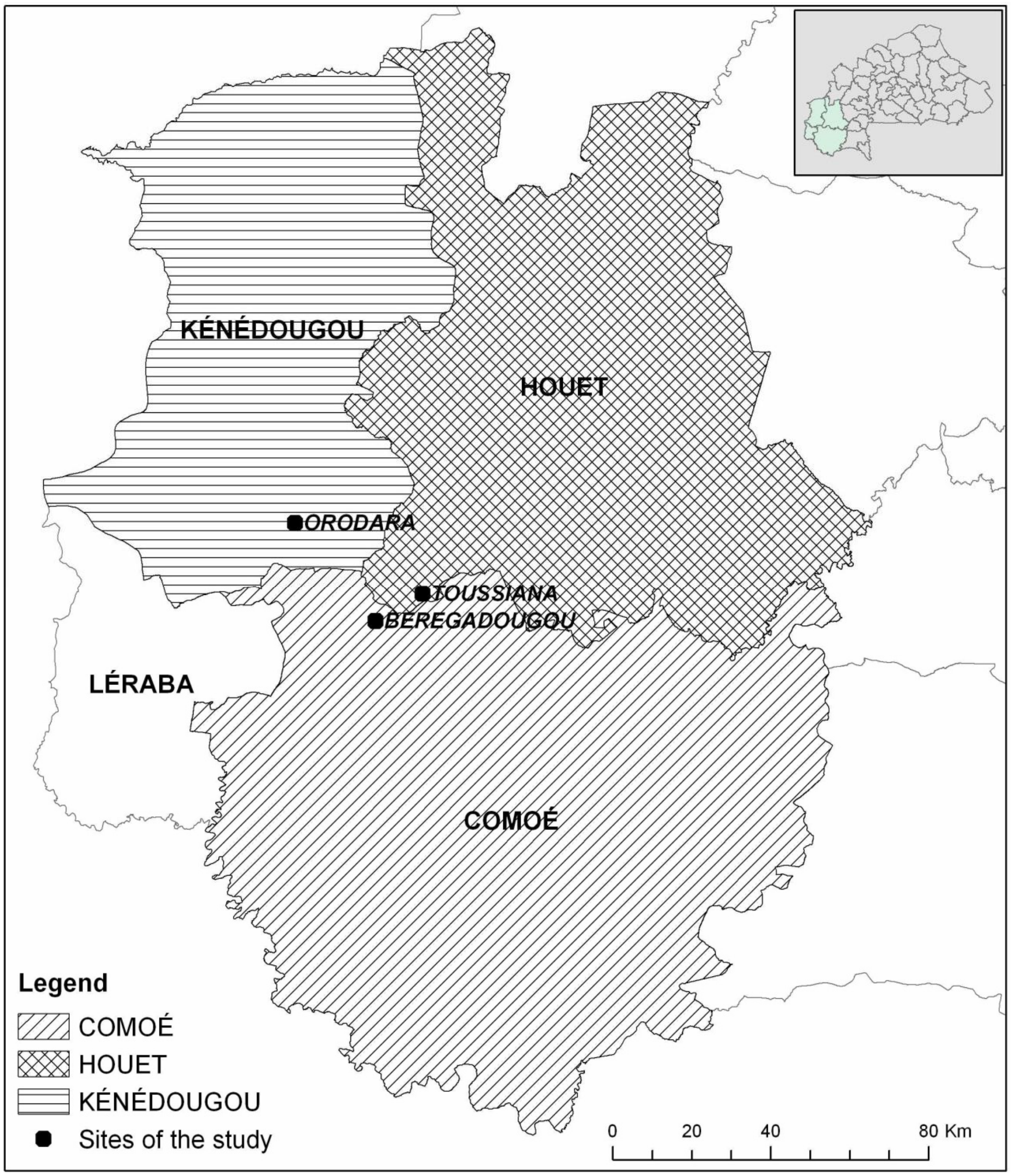

Fig. 1. Geographical situation of the study locations of *R. invandens* in Western Burkina Faso

2.1 Selection of Orchards for the Study

The selected orchards for the study equate to a stand of six mango trees infested by *R. invadens* in each location. *R. invadens*' infestations were confined to agglomerations and to the surroundings of highways and streets' facilities [12]. Mango trees that were selected in our study were in the agglomerations and were therefore not submitted to the rule of spacing that was applied in the orchards. On the Toussiana and Bérégadougou locations, the stand was composed of three varieties (that is 2 trees/variety) of mango trees. The varieties that were found in these locations included Amélie/Kent (Tousssiana/Bérégadougou), Lippens and green Mangot. On the Orodara site, the stand was solely composed of the green Mangot variety. All these mango trees were distributed within an area of two hectares. No chemical pesticides were applied throughout the duration of this study.

2.2 Data Collection and Climate Characteristics of the Study Locations

Weather data included temperature, relative humidity and rainfall recorded in the course of our study. In each location, rainfall data were recorded daily between 8 A.M. and 6 P.M. using a direct reading rain gauger (Brand S.P.I.E.A-Patented S.G.D.G N°1 269 277). Similar profiles of rain periods were recorded in all locations. The wet season was effective from May to October with a cumulated rainfall of 968.8 mm recorded in Bérégadougou; 1037.78 mm in Orodara and 1215.5 mm in Toussiana. Temperature was recorded using the thermographer PRECIS-MECANIQUE, 95870 BEZONS-FRANCE and relative humidity was recorded using the hygrographer make. These two tools recorded on daily basis the hourly changes of temperature and hygrometrics, under shelter, on charts that were specifically conceived for that purpose. Daily means were computed according to the following formula:

$$\frac{mini+maxi}{2}$$

Mini being the minimal temperature or minimal relative humidity and maxi being the maximal temperature or maximal relative humidity recorded on that day. From the computed values, monthly means were determined. Relative humidity was high (81-87%) from June to October and low (39 to 41%) from December to March. As for temperature, it was low from December to January (25 to 26°C) and high from February to April (29 to 32°C).

2.3 Monitoring *R. invadens*' populations

Rastrococcus invadens' population's densities, living insects, dead ones and parasitized ones were assessed during the in situ study. These data were collected every 15±1 days in all three locations. During these observations, leafed small branches were collected outside the frondescence of each tree respective the four cardinal points (East, West, North, South). Then five leaves were randomly sampled (three old leaves + two young leaves and vice versa) on each young branch according to the method used by [14] and [15]. All leaves were removed and carefully examined under magnification in order to register the values in line with the above mentionned parameters. After these observations, the parasitized insects were collected and put inside pillboxes. The sampled leaves were incubated inside A4 format enveloppes: approximatively 8½ by 11 inches (one enveloppe per tree) to allow the insects to complete their developmental cycle. Four weeks afterwards the emerged insects were collected and were identified using a make.

2.4 Entry and Statistical Analysis of Data

Data were entered on the Excel software and were organized per tree for each variable. The values that were entered were divided by 120 (20 leaves per tree for six trees) in order to get the overall means expressed in number of insects per leaf, wether they were alive, parasitized or dead. Parasitism and mortality were expressed in percentage according to the formula used by [8] and [14]. *Rastrococcus invadens* populations' fluctuations and parasitism and mortality evolution were translated by curves using the coresponding total means. All data collected from the three study sites were grouped and submited to multivariate analysis with SPSS (Statistical Package for the Social Sciences) 19.0.1 software.

3. RESULTS AND DISCUSSION

3.1 Fluctuation of *R. invadens*' Populations and of Parasitism Level in Toussiana

The evolution of the population density of and parasitized *R. invadens* in Toussiana is illustrated in the Fig. 2. The alive insect pest's populations increased from mid-May to mid-September 2014 with a mean of 31 to 132 individuals per leaf of mango tree. After two first peaks that were observed at the end of May (60 living insect pest per leaf) and at the end of June 2014 (80 living insect pest per leaf), the insect pest's populations' density gradually reached a maximum of 132 individuals per leaf at the end of August 2014. The populations decreased as from mid-September until mid-November 2014 with a density varying from 102 to 12 individuals per leaf. A slight increase in populations density (18 to 49 individuals per leaf) was then observed between the end of November 2014 and the end of April 2015.

The peaks of abundance of parasitized *R. invadens* were generally similar to those of living mealybugs. Thus, a first peak (6% of parasitized *R. invadens* per leaf) was observed in mid-June 2014. After this first peak, parasitism ratio moved from 3.61 to 1.39% between June and August 2014. A gradual increase in parasitism (3.38 to 8.04%) was recorded between mid September and mid-November 2014. Then parasitism ratios decreased (3.70 à 2.90%) until end of December 2014 before fluctuating between 2.81 to 4.40% between mid-January and the end of April 2015.

3.2 Fluctuation of *R. invadens* Populations and Parasitism Level in Bérégadougou

The evolution of the population density of and parasitized *R. invadens* in Bérégadougou is illustrated in the Fig. 3. A first peak was observed amidst *R. invadens*' populations at the end of May 2014 with a mean of 50 living insects per leaf. Other populations peaks appeared in August and September 2014. During these periods, a mean of 57 to 102 living *R. invadens* were recorded per leaf. The density of the insect pest's populations dropped after mid-September (5 to 40 living individuals per leaf) between the end of September 2014 and the end of April 2015.

A mean parasitism of 2.5 to 8.6% was registered between May 2014 and April 2015. The first peak of abundance was observed at the end of June with 8.54% of parasitized scale insects per leaf. Three other peaks were observed in mid December 2014 (5.9%), mid-January (6.8%) and mid-April 2015 (6.2%).

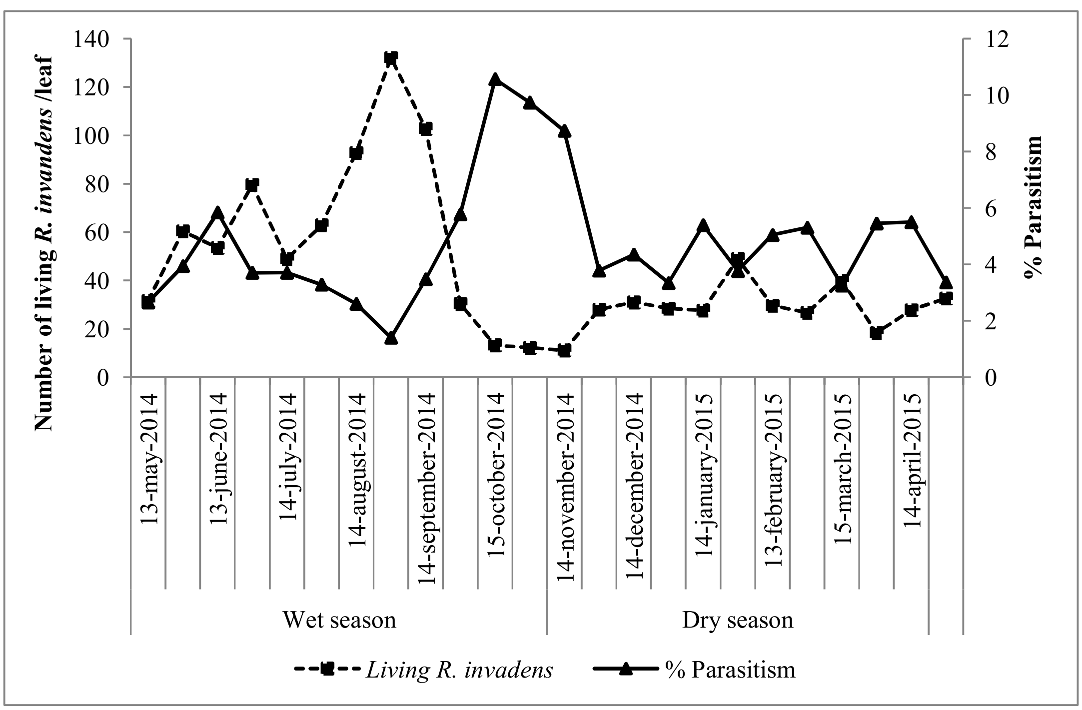

Fig. 2. Fluctuation of living *R. invadens*' populations and parasitism level in Toussiana, Western Burkina Faso

3.3 Fluctuation of *R. invadens*' Populations and of Parasitism Level in Orodara

A first peak of abunbance of the insect pest' populations was observed at the end of May 2014 with a mean of 51 individuals per leaf (Fig. 4). As from the ending of June 2014 (51 living insects per leaf), the insect pest's populations increased gradually and reached maxima numbers of 164 and 159 individuals per leaf at the end of August and at mid-September 2014. Afterwards, a continuous decrease of the populations (82 to 40 living individuals per leaf) was observed between September and November 2014. Three peaks of abundance (85, 48 and 21 living individuals per leaf respectively) were recorded at the end of December 2014, mid-February and mid-March 2015. The parasitism level varied from 1.7 to 6.9% from May 2014 to April 2015. Two first peaks were observed during the wet season, at the end of June (6.9%) and at the end of July (6.8%) 2014. These were followed by a decrease of 6.3 to 1.7% parasitism between mid-August 2014 and the end of September 2014. Four other peaks were observed at the end of November 2014 (4.15%), end of January (4.33%), mid-March (5.62%) and mid-April (5.02%) 2015.

The populations of *R. invadens* evolved in a saw tooth pattern as from May 2014 moving towards peaks of abundance which highest were observed during the wet season in all study locations. The lowest population densities of the insect pest were observed during the dry season. These results are similar to [15]'s findings in Northern Côte d'Ivoire where climate conditions are close to those of our study zone. A contrario, in Southern Benin where the climate is of the bimodal type, the highest densities of the insect pest were observed during the dry season [8]. The parasitism was low (≤11%) meaning the failure of parasitoids *G. tebygi* and *A. mangicola* to control *R. invadens*. Author [14] observed a mean parasitism ratio of 11.9% on sites that were highly polluted by smoke. The insect pest being mostly confined into agglomerations, parasitoids are less efficient because of air pollution due to human activities. In addition to the negative impact of pollution, hyper parasitoids like *Chartocerus hyalipennis* Hayat and *Marietta leopardina* Motschulsky were suspected of being limiting factors for *A. mangicola* and *G. tebygi* in some studies [15].

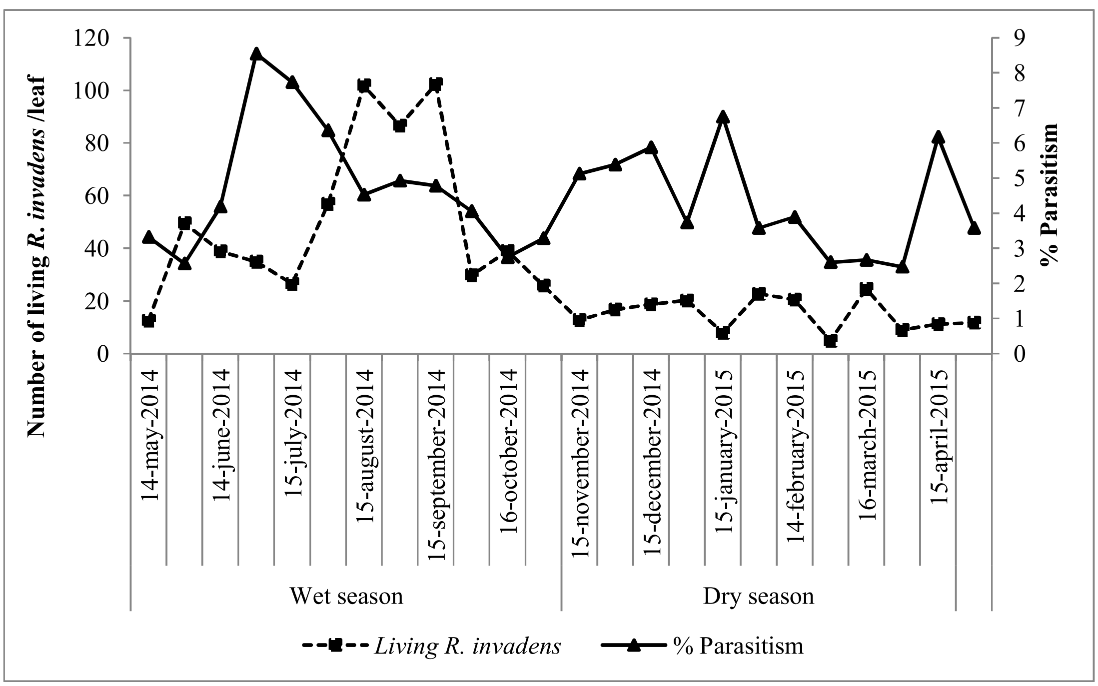

Fig. 3. Fluctuation of living *R. invadens*' populations and parasitism level in Bérégadougou, Western Burkina Faso

3.4 Fluctuation of *R. invadens*' Populations' Mortalities in the Study Locations

Rastrococcus invadens' populations mortalities were found low in all three locations from mid-May to mid September 2014 (Fig. 5). During that period, these mortalities varied from 0.7 to 5.6%. A peak of mortality was observed in each location in mid October in Toussiana (44%) and Bérégadougou (18%) and at the end of October in Orodara (18%). After that period, a decrease (31.92 to 1.82%) in the populations' mortalities of the insect pest was observed between September and November 2014. In Toussiana, the mortality ratio varied from 13.33 to 27.01%. These ratios were observed around four peaks of abundance that appeared between mid-December 2014 and end of April 2015. The same period of decrease was observed in Bérégadougou where the mortality ratio dropped from 15.43 to 6.65%. Mortality ratio then increased from 7.79 to 33.6% including three peaks between mid-December 2014 and the end of April 2015. In Orodara, a 15-day period of decrease (2.4%) was observed. After that period, the mortality ratio fluctuated around 5 to 30.52% with 2 peaks observed between the end of November and the end of April 2015. The increase of temperature from the last months of wet season and during the dry season could be the cause of the high mortalities observed from October 2014 to April 2015.

3.5 Impact of Abiotic Factors and Parasitism on *R. invadens*' Populations in Study Locations

Multivariate analysis by Wilks Lambda model showed that environmental factors (location, temperature, rainfall) and parasitism had a highly significant effect (P<.001) on the density of living and dead *R. invadens*. The Inter-subjects effects Tests have revealed that the relative humidity affected significantly the density of living mealybugs (Table 1). The effect of this abiotic factor was not significant on the density of dead mealybugs. A significant and positive correlation was observed between density of living *R. invadens* and relative humidity (Table 2). This positive effect that was observed could therefore explain that an increase of relative humidity induces a high fecundity of the insect pest. With the cassava mealybug, *Phenacoccus manihoti*

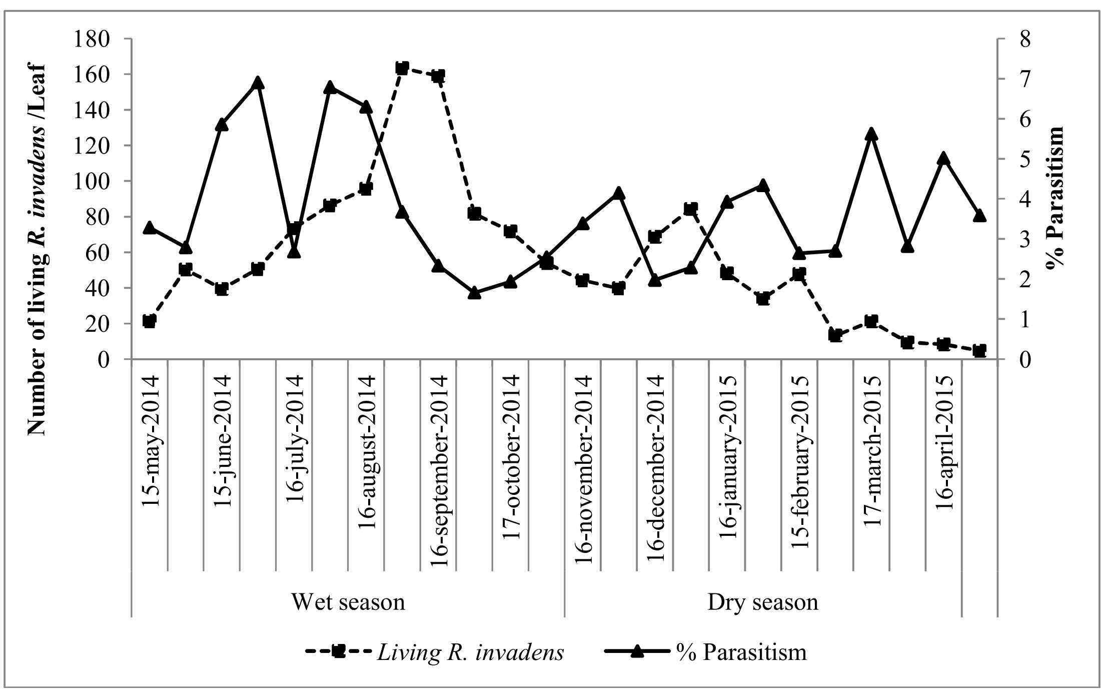

Fig. 4. Fluctuation of living *R. invadens*' populations and parasitism level in Orodara, Western Burkina Faso

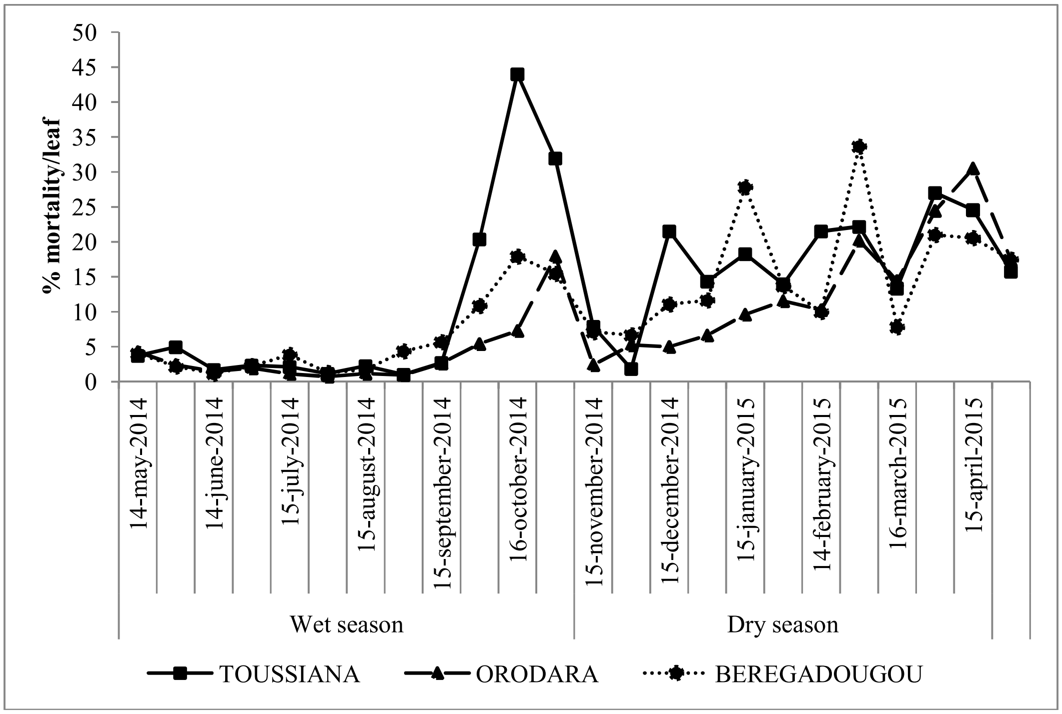

Fig. 5. Fluctuation of *R. invadens*' mortalities in all three study locations, Western Burkina Faso

Matile-Ferrero, [16] observed an increase in the number of laid eggs at different increasing relative humidity (respectively 60, 65 and 95%) with a constant temperature of 27°C. In a previous study, [17] reported that extreme values of relative humidity inflict high mortality to larval stages of *P. manihoti*. The correlation was significant but negative between living *R. invadens* and temperature. A contrario with [15]'s findings, the impact of temperature was not significant on *R. invadens*' populations. The negative coefficient of correlation for this abiotic factor could mean a decrease in the population density of living *R. invadens* as from a specific temperature level and vice-versa. This phenomenon was evidenced by [18]'s work which observed in the laboratory a drop of fecundity of *R. invadens* when temperature rises above 30°C. Besides, they concluded that temperatures between 20 and 30°C are supportive of the insect's development. In the field, [19] also observed a high fecundity of *R. invadens* in September; a period when temperatures varied between 26 and 30°C and relative humidity from 82 to 90%. That trend was observed during the wet season in our study. No significant relationship was evidenced between the density of living *R. invadens* and rainfall. But relative humidity was significant and positively correlated with rainfall. According to [15], rainfalls can negatively or positively impact the populations of the insect pest. The positive effect results in the origination of new leaves which present interesting physicochemical traits for the insects. But rainfalls can have a negative effect through a mechanical action which displaces the insect's young larvae on the leaves. In this study, the negative effect of rainfall on *R. invadens* was significant because there was an increase in their populations during periods of heavy rains. The level of dead mealy bugs was significant and negatively correlated with density of living *R. invadens*. Temperature and relative humidity were significant and respectively positively and negatively correlated with density of dead *R. invadens*. The highest mortalities are therefore observed in dry season which presents high temperature and low relative humidity. The parasitism developed by *G. tebygi* and *A. mangicola* was significant and negatively correlated with living *R. invadens*. The decrease of living *R. invadens* was observed after the increase of parasitism and vice-versa during the study period. That could explain a well establishment of these parasitoids with their host *R. invadens*.

Table 1. Results of inter-subjects effects tests

Source	Dependent variate	∑ of square type III	ddl	Mean square	F	Signification	Partial Eta-square
Corrected Model	Living *R. invadens*	384388.870[a]	6	64064.812	58.849	.000	.454
	Dead *R. invadens*	25399.642[b]	6	4233.274	23.677	.000	.251
Constant	Living *R. invadens*	61852.479	1	61852.479	56.817	.000	.118
	Dead *R. invadens*	27.009	1	27.009	.151	.698	.000
Localities	Living *R. invadens*	20315.606	2	10157.803	9.331	.000	.042
	Dead *R. invadens*	1464.552	2	732.276	4.096	.017	.019
Temperature	Living *R. invadens*	49070.724	1	49070.724	45.075	.000	.096
	Dead *R. invadens*	966.464	1	966.464	5.405	.021	.013
Relative Humidity	Living *R. invadens*	5047.232	1	5047.232	4.636	.032	.011
	Dead *R. invadens*	380.709	1	380.709	2.129	.145	.005
Rainfall	Living *R. invadens*	53714.487	1	53714.487	49.341	.000	.104
	Dead *R. invadens*	5909.729	1	5909.729	33.053	.000	.072
Parasitism	Living *R. invadens*	81903.911	1	81903.911	75.235	.000	.150
	Dead *R. invadens*	3105.772	1	3105.772	17.371	.000	.039
Error	Living *R. invadens*	462669.888	425	1088.635			
	Dead *R. invadens*	75987.559	425	178.794			
Total	Living *R. invadens*	1714749.760	432				
	Dead *R. invadens*	181857,619	432				
Corrected Total	Living *R. invadens*	847058.758	431				
	Dead *R. invadens*	101387.201	431				

a. R-two = .454 (R-two adjusted = .446); b. R-two = .251 (R-two adjusted = .240)

Table 2. Correlation matrix between the density of *R. invadens* (living and dead) and abiotic and biotic factors

Variates	Living mealybugs	Dead mealybugs	Parasitism	Relative humidity	Rainfall	Temperature
Living mealybugs	**1**					
Dead mealybugs	**-0.684**	**1**				
Parasitism	**-0.632**	0.333	**1**			
Relative Humidity	**0.632**	**-0.654**	-0.248	**1**		
Rainfall	0.295	-0.461	0.081	**0.845**	**1**	
Temperature	**-0.610**	**0.645**	0.222	**-0.999**	**-0.870**	**1**

Bold values are different from 0 to a level of significance alpha = 0.05

4. CONCLUSION

This study determined the variations in the abundance of *R. invadens*' populations in time and space in Western Burkina Faso. The populations of the insect pest were more during the wet season than the dry one and were significantly influenced by the effect of temperature, relative humidity and rainfalls on all study locations. Parasitoids *A. mangicola* and *G. tebygi* are well established but their action remained low on all study locations. The knowledge of the ecology of *R. invadens* supports the formulation of a sustainable control strategy with a view of improving mango production in Burkina Faso. In that perspective, the two associated parasitoids, *A. mangicola* and *G. tebygi* could be mass reared and released for the biological control of *R. invadens*.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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