Bulletin of Pure and Applied Sciences
Vol.38A (Zoology), No.2,
July-December 2019: P.110-119
Original Research Article

Print version ISSN 0970 0765
Online version ISSN 2320 3188
DOI : 10.5958/2320-3188.2019.00012.3
Available online at www.bpasjournals.com

Population Dynamics of the Potato Tuber Moth *Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae) Upon Different Potato Varieties Grown in Northern Algeria

[1]Radhia Lamara Mahamed-Allahoum*
[2]Karima Khelfane-Goucem
[3]Nadia Lardjane
[4]Ferroudja Medjdoub-Bensaad

Author's Affiliation:
[1]PhD student of Biological Sciences, Laboratory of Production and Safeguarding of Endangered Species and Crops. Influence of Climatic Variations. Department of Biological Sciences and Agricultural Sciences. Mouloud Mammeri University, BP 17RP, Tizi-Ouzou, Algeria.
E-mail: radialamara@gmail.com
[2]Doctor of Biological Sciences, Laboratory of Production and Safeguarding of Endangered Species and Crops. Influence of Climatic Variations. Department of Biological Sciences and Agricultural Sciences. Mouloud Mammeri University, BP 17RP, Tizi-Ouzou, Algeria.
E-mail: kgoucem@yahoo.fr
[3]Doctor of environnemental engineering, Laboratory of Production and Safeguarding of Endangered Species and Crops. Influence of Climatic Variations. Department of Biological Sciences and Agricultural Sciences. Mouloud Mammeri University, BP 17RP, Tizi-Ouzou, Algeria.
E-mail: nadiaalar@yahoo.fr
4Professor of Biological Sciences, Laboratory of Production and Safeguarding of Endangered Species and Crops. Influence of Climatic Variations. Department of Biological Sciences and Agricultural Sciences. Mouloud Mammeri University, BP 17RP, Tizi-Ouzou, Algeria.
E-mail: medjdoubferroudja@yahoo.fr

***Corresponding Author:**
Radhia Lamara Mahamed-Allahoum. PhD student of Biological Sciences, Laboratory of Production and Safeguarding of Endangered Species and Crops. Influence of Climatic Variations. Department of Biological Sciences and Agricultural Sciences. Mouloud Mammeri University, BP 17RP, Tizi-Ouzou, Algeria.
E-mail: radialamara@gmail.com

Received on 19.09.2019
Accepted on 31.11.2019

Abstract:

Monitoring of population dynamics, varietal resistance and oviposition (depending on the foliar side and plant foliar layer) of the potato tuber moth *Phthorimaea operculella* Zeller were studied in the field, upon four potato varieties: Spunta, Kenza, Crisper and Désirée cultivated under the same growing conditions. Investigation results showed a positive correlation between flight of *P. operculella* adults and the increase in temperatures recorded from April to May 2016. A significant difference *(P* = 0.02) appeared between the four varieties for the number of males caught by pheromone traps; potato tuber moth showed a marked preference for the Spunta variety with an average of 6±1.46 adults per trap. Oviposition of potato tuber moth females was significantly higher on the lower sides of potato leaves compared to the upper sides, excepted for the Crisper variety where recorded differences were not significant (*P* = 0, 07) . Egg density laid upon the foliage did not show significant differences between the plant foliar layers (upper, middle and lower) in all the varieties studied. Combined with appropriate cultural practices and the rational use of chemical control, potato varietal resistance to *P. operculella* could be an essential tool in IPM programs for this pest insect.

Keywords: Oviposition, *Phthorimaea operculella,* population dynamics, *Solanum tuberosum*, varietal resistance.

INTRODUCTION

The potato, *Solanum tuberosum* L., is the fourth most widely grown food resource in the world, after wheat, rice and corn (Douches et al., 2004; Pelletier et al., 2011). In Algeria, this crop occupies a strategic place in terms of its importance as a food, the areas devoted to it, the employment it provides, and the financial volumes that are mobilized annually for local production and / or import; this sector in all its components, seeds and consumption occupies today (Omari, 2009).

Potato production in Algeria is steadily increasing, it is ranked 15th in the world, with a production of 4,673 516 tons (FAO, 2016). However, it does not satisfy the needs of the consumer; this generates dependence to foreign countries, especially for seeds production (Chauvin et al., 2008). Among the main causes of this low production, there are various phytosanitary problems, whether of vegetable or animal origin, including the potato tuber moth *Phthorimaea operculella* Zeller, a devastating lepidopterous insect. Some authors attribute the Mediterranean basin as a dispersal center for this species because, it was described by Boiduval in 1874, according to specimens captured in Algeria, but the tuber moth was described for the first time in Texas by Zeller, this seems more normal since the species feeds on the plant family Solanaceae and is specially known for being a major pest of potato crops which is native to America (Cohic, 1954).

This microlepidopteran from Gelechiidae family is one of the most destructive pests of potato in the tropics and subtropics (Veale et al., 2012; Golizadeh et al., 2014). *P. operculella* is mainly a potato pest, but attacks also several cultivated solanaceous plants such as eggplant (*Solanum melongena* L.), tomato (*S. lycopersicum* L.), pepper (*Capsicum annum* L.), tobacco (*Nicotina tabacum*) (Trivedi & Rajagopal, 1992; Rondon et al., 2007) and wild solanaceous plants like *Datura stramonium* L. (Alvarez et al., 2005). Larvae feed on potato leaves, stems, petioles, and, more importantly, potato tubers in the field and in storage. They prefer feeding on young foliage (Trivedi & Rajagopal, 1992). Typical damage results from larvae boring tunnels in tubers facilitating the introduction of pathogenic bacteria and fungi, which ultimately destroy the tuber. Larvae depositing their excreta make tubers unfit for consumption. Severe infestations result in yield and quality losses during storage where previously infested tubers are stored with healthy potato tubers (Malakar & Tingey, 2006; Alvarez et al., 2007; Rondon, 2010). Potato production losses caused by *P. operculella* are around 86% in Algeria, Tunisia and Turkey (Alvarez et al., 2005).

The most common control method for *Phthorimaea operculella* is the use of various insecticides. The development of pesticide resistance, resurgence of pest populations and potential detrimental effects of synthetic pesticides on non-target organisms has led to the adoption of integrated pest management (IPM) strategies. It is important to know the biology and distribution of a pest for an IPM program to be successful (Harisiman et al., 2014). The most effective management program combines cultural, biological, and chemical approaches (Rondon, 2007).

Despite the losses and damage caused by tuber moth on potato crops, few unpublished studies on the bioecology of this species are conducted in Algeria. The aim of the present work is to contribute to improving knowledge of *P. operculella* dynamics upon four potato varieties: Spunta, Kenza, Crisper and Désirée and thus to screen potato varieties for potential potato tuber moth resistance by tubers under field conditions during the period April-May 2016.

MATERIALS AND METHODS

Potato varieties

Four varieties of potato were used; Spunta and Désirée, which are widespread in Algeria and Kenza and Crisper, which are new varieties that are therefore not widely cultivated. Seed potatoes are provided by the Technical Institute of Vegetable and Industrial Crops (ITCMI), and are belonging to class E. Spunta variety is the most cultivated in the world and is mainly intended for consumption and is very sensitive to diseases and pests. Désirée variety is characterized by high yields, a high resistance to drought and is easier to store. Kenza variety is less known because it is the first time that

it is cultivated at ITCMI on a trial basis. Crisper is a variety intended for consumption with a moderate resistance to diseases (ITCMI, 2016).

The study was conducted in 2016, during the spring potato-growing season (from March 3rd 2016 until May 30th 2016) in experimental plot in Boumerdes region at a latitude and longitude of 36° 45' 0 N 3° 40' 0 E.

During the study, four plots were used and sown with a variety for each; the Spunta with 1254 m^2, the Kenza 951 m^2, the Crisper 750 m^2 and the Désirée 320 m^2.

The plots were separated by a distance of 120 cm and the ridges were at intervals of 60 cm and the distance between each plant in a ridge was 40 cm. The plot, with clay soil and a slope of 10%, is bounded in the north by onion and garlic crop, in the south by fallow, in the east by a wheat field and in the west by a plot of onion trials.

Monitoring of adult males

Monitoring of *P. operculella* adult males was performed using Delta-type pheromone traps (Producer Russell IPM) provided by the Regional Plant Protection Station. This trap consists of a stuck bottom and a roof made of durable water resistant material. Males attracted to female synthetic pheromones (PH-754-1RR) are fixed on the sticky background (Franck, 2008). One trap was set up for each variety and was suspended on a bar up to 50 cm from the ground. Pheromones were renewed at 3 week intervals during the study period. Traps were placed from March 28, 2016 until the end of May and were visited weekly and counts of adult males were made.

Evaluation of eggs density upon foliage

In order to follow potato tuber moth oviposition, leaf samples were taken every week from the elongation stage of *S. tuberosum* until plant wilt. A systematic sampling was carried out and 150 leaves were taken from each variety at the rate of 50 leaves per foliar stage (upper, middle and lower). Eggs laid by *P. operculella* females were counted on foliage sides (on the upper and lower) and foliage levels.

Statistical analysis

Variance analysis (ANOVA) were performed at 5% threshold for the number of adult males captured by pheromone traps and for the eggs number observed according to leaf sides and leaf stages for studied varieties. It was supplemented by means comparison using Scheffe test (Dagnelie, 1975). The statistical analysis was performed using the Origin software (version 7.5). Correlation between temperatures and adult numbers captured in pheromone traps was performed using a linear regression model.

RESULTS AND DISCUSSION

Adult males monitoring

During the first week of observation corresponding to 04 April 2016, *P. operculella* adults number caught by pheromone traps was low in all studied varieties recording one individual per trap in Spunta and Kenza, 3 individuals per trap in the Desiree and no individual was registered in Crisper trap. A gradual increase in the number of captured adults was recorded as early as the second week, reaching its peak in the 6^{th} week with 14; 5; 3 and 3 individuals / trap in Spunta, Kenza, Crisper and Désirée respectively (Fig. 1). Variance analysis for the number of adult males captured by pheromone traps indicated a significant difference ($P = 0.02$) between the 4 varieties (Table 1) and Spunta variety was the most attacked recording mean values of 6 ± 1.46 adults per trap.

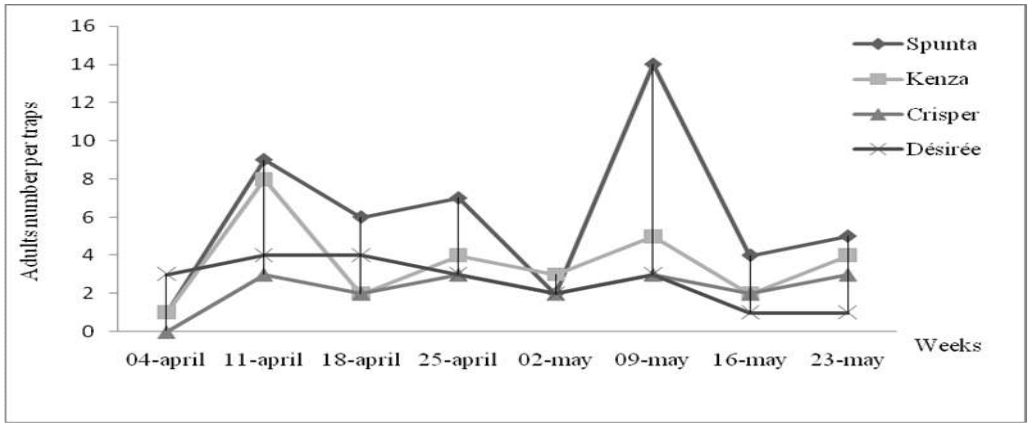

Figure 1: Distribution of *P. operculella* male adults caught by pheromone traps in four potato varieties (Spunta, Kenza, Crisper, Désirée) cultivated in Boumerdes during the period April-May 2016.

Table 1: Mean number (± SD) of male adults of *P. operculella* caught by pheromone traps in Spunta, Kenza, Crisper, Désirée varieties of potato grown in Boumerdes.

	Varieties				
	Spunta	**Kenza**	**Crisper**	**Désirée**	**P. Value**
Adults number	6±1,46 a	3,6±0,77 b	2,25±0,36 b	2,62±0,42 b	0,02 (*)

Means followed by different letters in the same line are significantly different using an ANOVA at α = 0.05. NS: not significant, (***) α = 0.001, (*) α = 0.01.

The present study showed a positive correlation between temperature and number of adult males (y = 0.805x + 0.211, R^2 = 0.253, r = 0.503), this suggest that temperatures directly affect the numbers of adult males caught in pheromone traps.

Eggs densities upon foliage

The density of eggs laid by females of *P. operculella* upon potato leaves of all studied varieties was evaluated on the lower and upper sides. The average number of eggs laid on the lower sides was greater than that laid on the upper sides for Spunta, Kenza and Désirée varieties. For the Crisper variety, *P. operculella* females laid their eggs on the underside throughout the experimental period with the exception of the third week where the average number of eggs laid was higher at the upper surface (Fig. 2). Variance analysis of the average number of eggs laid on the lower and upper sides showed highly significant differences in Spunta (P = 0.002) and Kenza (P = 0.007) varieties. A very highly significant differences (P = 0.0006) were recorded between the two leave sides in Désirée variety, whereas non-significant differences (P = 0.07) were registered for Crisper variety (Table 2).

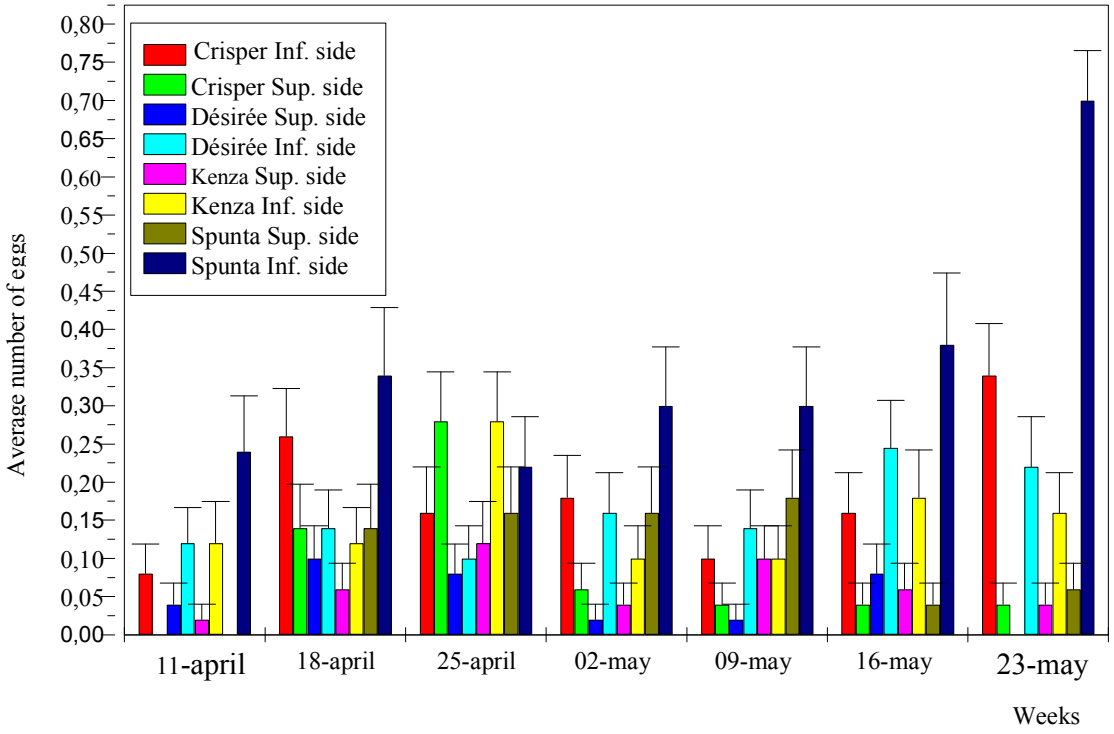

Figure 2: Average number of eggs laid by *P. operculella* females according to leaf sides (Upper and Lower) in Spunta, Kenza, Crisper, Désirée varieties of potatoes grown in Boumerdes.

Table 2: Egg distribution (mean ± standard deviation) of *P. operculella* according to leaf area sides (upper and lower) in Spunta, Kenza, Crisper, Désirée varieties of crop potato grown in Boumerdes.

	Foliage sides		
Varieties	**Sup. side**	**Inf. side**	**P. value**
Spunta	0,11±0,03 a	0,35±0,06 b	0,002(**)
Kenza	0,06±0,01 a	0,15±0,02 b	0,007(**)
Crisper	0,08±0,3 a	0,05±0,01 a	0,07 NS
Désirée	0,05±0,01 a	0,16±0,01 b	0,0006(***)

Means followed by different letters in the same line are significantly different using an ANOVA at α = 0.05. NS: not significant, (***) α = 0.001, (*) α = 0.01.

Variance analysis with two classification criteria (varieties and leaf sides) for *P. operculella* egg distribution indicated a highly significant difference between the four varieties (*P* = 0.0006). Potato tuber moth females showed a preference for Spunta variety with an average of 0.153 ± 0.04 eggs (Table 3).

Table 3: **Mean number (± standard deviation) of eggs laid by *P. operculella* females upon Spunta, Kenza, Crisper, Desiree potato varieties in Boumerdes.**

	Varieties				
	Spunta	Kenza	Crisper	Désirée	P. value
Mean number of eggs	0,153±0,04 a	0,073±0,03 b	0,089± 0,03 b	0,07±0,02 b	0,0006 (***)

Means followed by different letters in the same line are significantly different using an ANOVA at α = 0.05. NS: not significant, (***) α = 0.001, (*) α = 0.01.

Changes in the average number of eggs laid by *P. operculella* females were evaluated on four varieties according to the potato leaf stages. Eggs distribution in Spunta showed a preference for laying on the upper level with a maximum value of 0.4 eggs / leaf while in Kenza variety a maximum peak was recorded on the lower leaf stage with 0.16 eggs / leaf. The average number of eggs laid in the Crisper reached a maximum value of 0.26 eggs / leaf at the upper plant stage. Désirée variety showed two successive peaks of 0.14 eggs / leaf on the lower plant stage (Fig. 3).

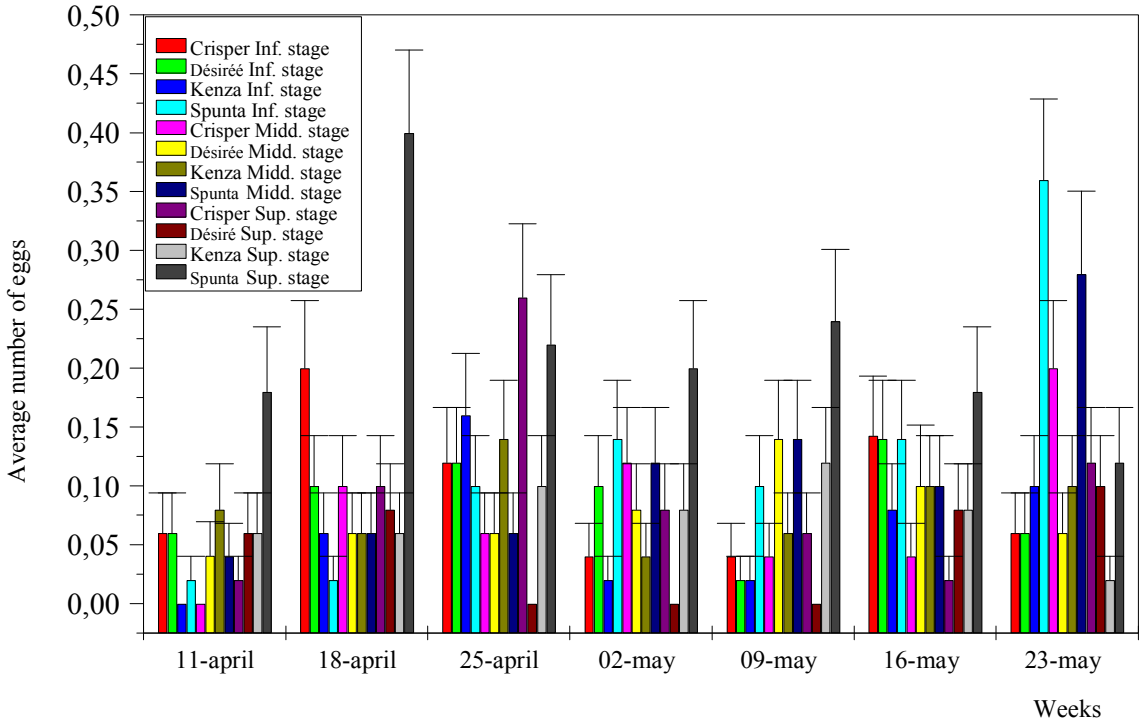

Fig. 3: Average number of eggs laid by *P. operculella* females according to foliage stage (upper, middle and lower) in Spunta, Kenza, Crisper, Desiree varieties of potato grown in Boumerdes.

Variance analysis of the average number of eggs laid on the different plant stages indicated that there was no significant difference between studied varieties (Table 4). Potato tuber moth females did not have a preference for a given leaf stage.

Table 4: *P. operculella* egg distribution (mean ± standard deviation) according to plant stages (upper, middle, lower) of four potato varieties at Boumerdes.

	Leaf stages			
Varieties	**Sup. stage**	**Midd. stage**	**Inf. stage**	**P. value**
Spunta	0,22±0,03 a	0,11±0,03 a	0,12±0,04 a	0,1 NS
Kenza	0,07± 0,01 a	0,08± 0,01 a	0,06± 0,02 a	0,67 NS
Crisper	0,09±0,03 a	0,08±0,02 a	0,09± 0,02 a	0,9 NS
Désirée	0,04±0,02 a	0,07±0,01 a	0,08±0,02 a	0,17 NS

Means followed by different letters in the same line are significantly different using ANOVA at α = 0.05. NS: not significant, (***) α = 0.001, (*) α = 0.01.

P. operculella infestation upon four potato varieties was studied at the Technical Institute of Vegetable and Industrial Crops of Boumerdes (Algeria), during the growing season March-May 2016. From the

number of male adults captured by pheromone traps for each variety, it could be deduced that out of the four varieties tested, Spunta is the most attacked variety, and therefore the least resistant to potato tuber moth, whereas Kenza, Crisper and Desiree varieties proved to be more or less resistant to this pest. These results confirm those obtained in a similar study carried out in 2014 in the same region (unpublished data), where the maximum number of *P. operculella* adults caught was 23 individuals in Spunta and 17 individuals in Désirée. Concerning Crisper and Kenza varieties, they are cultivated for the first time in 2016 in Algeria and consequently there is no previous works on these varieties.

Activity of *P. operculella* male adults upon four potato varieties showed that population numbers were low during the first week of April. From the second week of the same month, fluctuations in the number of males were observed until the first week of May and males numbers increased to reach their maximum in Spunta with a value of 14 individuals on May 9th. This trend is related to the increase in temperatures, which goes from 21.66°C in April to 24.8 °C in May. This shows that temperature plays a key role in the population dynamics of *P. operculella*. According to Kroschel & Koch (1994), temperature is the most important factor for the development of *P. operculella*. Within biological limits, it plays a major role in determining the variability and duration of all stages of *P. operculella* development (Al-Ali et al., 1975). Temperature is a key factor in the development, survival and longevity of *P. operculella* adults, with an optimum range of 17.5 to 27.5 °C (Andreadis et al., 2017) and an optimum of 28 to 30°C (Sporleder et al., 2004). Indeed, there is a positive correlation between temperatures and the number of adult males caught. Our results corroborate those obtained by many authors like Ndiaye (1997), in Senegal who found that *P. operculella* populations increase significantly from April and reach a maximum in May and June. This increase coincides with the transition from low temperatures to high temperatures. According to Foot (1979) who studied tuber moth dynamics in the field at Pukekohe, New Zealand, the activity of adult flight increases with increasing temperatures showing that the density of *P. operculella* is greater between mid-January and mid-May. Also, studies conducted by Giri et al. (2014) in Nepal gave similar results; they showed that *P. operculella* activity increases in May and reaches a maximum of captures of 480 ± 238 adults / month. Similarly Colle et al. (2000) noted, from 1995 to 1997, that the adult male population of *P. operculella* reached its maximum density in May and June with an average of 70.5; 24.5 and 63.2 adults / trap / night respectively.

According to obtained results, the average number of eggs laid by *P. operculella* females presents a very highly significant difference between the varieties. These results are not in agreement with those obtained by Fenemore (1980a) and those obtained in a similar study that we did in 2014 at the same station (unpublished data). These investigations showed that upon the foliage, the cultivar had no influence on the egg laying potential, whereas the texture of the tubers of the different cultivars and probably their odor, would influence *P. operculella* females oviposition. According to Medina et al. (2010), no fully recognized resistance cultivars have been found so far, few attempts have been made to identify plant cultivars resistant to potato tuber moth. Laboratory studies carried out by Gurr & Symington (1998) showed important differences recorded in *P. operculella* dynamics from egg to adult between several studied cultivars highlighting that Sequoia cultivar is less sensitive than Kennebec and Tarago cultivars.

Malakar & Tingey (1999) suggested in their study on the ovipositional behavior and developmental biology of *P. operculella* on the foliage of a wild potato species (*Solanum berthaultii* Hawkes) and that of potato cultivar Atlantic (*S. tuberosum*), that the foliage laying rate is very high in Atlantic cultivar with a value of 92%, whereas it is only of 11% in *S. berthaultii.*

Comparison of *P. opercullela* infestation on several potato cultivars performed by Abdallah et al. (2012) revealed that Nicola variety is the least susceptible to *P. operculella* infestation followed by Spunta and Simone, while Atlas variety was the most favorable for the development of the potato tuber moth. Golizadeh & Esmaeili (2012) reported that out of 10 varieties studied, the highest total fecundity was observed upon potato leaves and tubers of Arinda (78.3 eggs) and Ramus (154.8 eggs). A significantly smaller amount of eggs was laid on Marfona leaves (44.6 eggs) and tubers (72.9 eggs) compared to the other cultivars tested. The reproductive potential of females on potato leaves was significantly lower

than that of potato tubers. Golizadeh et al. (2014), also investigated the susceptibility of different *P. operculella* potato cultivars by measuring several parameters including the number of eggs laid, adult mortality, net reproduction rate upon potato leaves and tubers (Agria, Agata, Almera, Arinda, Baneba, Fiana, Marfona, Ramus, Satina and Volvox). Marfona is the cultivar with the lowest rates of reproduction, number of eggs laid, and adult mortality on both leaves and tubers, indicating that it is relatively less susceptible to this pest and could be used in integrated pest management programs for *P. operculella*.

The assessment of egg-laying activity on both the upper and lower leaf sides suggested that *P. operculella* females prefer to lay their eggs on the underside of the leaves in three varieties Spunta, Kenza and Désirée, while in Crisper, *P. operculella* females do not show preference for a given face. These results are consistent with those of Raman (1980) and those obtained in a study that we carried out in 2014 in the same region (unpublished data) and where *P. operculella* females showed a preference for eggs laying on the underside of potato leaves. This preference could be explained by the fact that females seek a suitable place to protect their eggs from external factors and on the other hand by the search for a rough substrate for a better eggs adhesion. Indeed, for Balachowsky (1966) and Rousselle et al. (1996), tuber moth females prefer to lay their eggs on rough surfaces such as leaf axils, and base limbs. Selection of plants by *P. operculella* for oviposition is determined both by the physical nature of their surfaces and by chemical factors that are detected only by contact (Fenemore, 1980b).

The study of the distribution of eggs by *P. operculella* females on the three leaf stages of the plant (upper, middle and lower) showed that females do not have a preference for a given foliar stage for all the varieties studied. These results are consistent with those obtained in a similar study that we carried out in the same region. Harsimran et al. (2014) also noted that *P. operculella* females do not have a preference and can use as a laying site different parts of the host plant such as the stems, the underside of the leaves. In the absence of foliage, potato tuber moths can even cross cracks in the soil in search of a tuber to enter. According to Rondon (2010), eggs can be widely distributed in the soil, but more are found at the base of potato plants. Indeed, Traynier (1975) stated that the number of eggs at the base of potato plants is greater than on the upper stages. However, maximum fertility is only achieved in the presence of appropriate host plant material and the physical properties of a substrate are extremely important in determining the egg laying location. Preferred substrates are those that provide just enough deep depressions to contain eggs (Fenemore, 1988).

CONCLUSION

The activity of *P. operculella* male adults on the studied potato varieties is influenced by temperature and their number increases with increasing temperatures. Potato tuber moth females have no preference for a given leaf stage, since they lay on the whole plant. On the other hand, they show a preference for laying underside the leaves. The temporal evolution of the number of eggs and adults is significantly different between the four varieties: Spunta, Crisper, Kenza and Désirée.

ACKNOWLEDEMENTS

The authors are grateful to the Technical Institute of Vegetable and Industrial Crops (ITCMI) of Boumerdes, Algeria for the facilities provided for conducting the study and the Regional Plant Protection Station of Draa Ben Khedda, Tizi-Ouzou, Algeria for providing pheromone traps.

REFERENCES

1. Abdallah, YEY, Abdel-Wahed, MS, Youssef, GHA. (2012). Life table parameters as indicator of potato Varieties susceptibility to infestation with *Phthorimaea operculella* (Zeller). Egypt. Acad. J. Biolog. Sci. 5(1):127-136
2. Al-Ali, AS, Al-Neamy, IK, Abbas, SA, Abdul-Masih, AME. (1975). Observations on the biology of the potato tuber moth *Phthorimaea operculella* Zeller (Lepidoptera, Gelechiiddae) in Iraq. J. Appl. Entomol. 79: 345-351.

3. Alvarez, JM, Barbour, J, Clough, GH, Debano, SJ, Dogramaci, M, Jensen, A, Rondon, SI, Schreiber, A, Thornton M. (2007). Biology and management of the potato tuberworm in the Pacific Northwest 594: 1-3.
4. Alvarez, JM, Dotseth, E, Nolte, P. (2005). Potato tuberworm a threat for Idaho potatoes. Educ Public University of Idaho 1125: 1-4. doi: 10.13140/RG.2.1.2283.9283
5. Andreadis, SS, Spanoudis, CG, Zakka, G, Aslanidou, B,Noukari, S, Savopoulou-Soultani, M.(2017). Effect of temperature on rate of development, survival and adult longevity of *Phthorimaea operculella* (Lepidoptera: Gelechiidae). Eur. J. Entomol. 114: 35–41. doi: 10.14411/eje.2017.006.
6. Anonyme. (2016). Fiche technique : variétés de pomme de terre. Institut Technique des Cultures Maraichères et Industrielles (ITCMI) Isser Boumerdes Algérie.
7. Balachowsky, AS. (1966). Traité d'entomologie appliquée à l'agriculture. Tome II volume I, Masson et Cie, Paris.
8. Chauvin, JE, Esnault, F. Ellissèche, D. (2008). Les recherches pour la filière pomme de terre; verrous et avancées, Ressources génétiques et innovation variétale chez la pomme de terre. Inra Parc des expositions de Paris.
9. Cohic, F. (1954). La Teigne de la pomme de terre. Revue Agricole de la Nouvelle-Calédonie 1(2), 6-11.
10. Coll, M, Gavish, S, Dori, I. (2000). Population biology of the potato tuber moth, *Phthorimaea operculella* (Lepidoptera: Gelechiidae), in two potato cropping systems in Israel. Bull. Entomol. Res. 90 : 309–315
11. Dagnelie, P. (1975). Théorie et méthodes statistiques. Vol. II. Les Presses Agronomiques de Gembloux. Gembloux, Belgique.
12. Douches, DS, Pett, W, Santos, F, Coombs, J, Grafius, E. (2004). Field and storage testing Bt potatoes for resistance to potato tuberworm (Lepidoptera:Gelechiidae). J. Econ. Entomol. 97: 1425-1431.
13. FAO. (2016). Principaux pays producteurs de la pomme de terre. www.fao.org/faostat/fr/
14. Fenemore, PG. (1980a). Susceptibility of potato cultivars to potato tuber moth, *Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae). N. Z. J. Agric. Res. 23(4), 539-546. https://doi.org/10.1080/00288233.1980.10417881
15. Fenemore, PG. (1980b). Oviposition of potato tuber moth, *Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae); identification of host-plant factors influencing oviposition response. N.Z. J. Zool. 7(3), 435-439. doi: 10.1080/03014223.1980.10423798.
16. Fenomore, PG. (1988). Host-plant location and selection by adult potato moth, *Phthorimaea operculella* (Lepidoptera: Gelechiida): a review. J. Insect. Physiol. 34: 175-177.
17. Foot, MA. (1979). Bionomics of the potato tuber moth, *Phthorimaea operculella* (Lepidoptera: Gelechiidae), at Pukekohe. N. Z. J. Zool. 6(4), 623-636. doi: 10.1080/03014223.1979.10428406.
18. Franck, A. (2008). Capture, conditionnement, expédition, mise en collection des insectes et acariens en vue de leur identification. La recherche agronomique pour le développement. Université de la réunion, Cirad.
19. Giri, YP, Aryal, S, Dangi, NPY, Pradhan, SB, Shrestha, SM, Sporleder, M, Thapa, B. (2014). Distribution and seasonal abundance of potato tuber moth: *Phthoremaea operculella* (Zeller) (Lepidoptera: Gelechiidae) in Nepal. Int. J. Appl. Sciences and Biotechnology, Nepal. 2(3), 270-274. doi: 10.3126/ijasbt.v2i3.10794.
20. Golizadeh, A, Esmaeili, N. (2012). Comparative Life History and Fecundity of *Phthorimaea operculella* (Lepidoptera: Gelechiidae) on Leaves and Tubers of Different Potato Cultivars. J. Econ. Entomol. 105(5), 1809-1815. http://dx.doi.org/10.1603/EC12144.
21. Golizadeh, A, Esmaeilib, N, Razmjouc, J, Rafiee-Dastjerdid, H. (2014). Comparative life tables of the potato tuberworm, *Phthorimaea operculella* on leaves and tubers of different potato cultivars. J. Insect Sci. 42 (14), 1-11.
22. Golizadeh, A., Zalucki, M.P. (2012). Estimating temperature-dependent developmental rates of potato tuberworm, *Phthorimaea operculella* (Lepidoptera: Gelechiidae). Institute of Zoology, Chinese Academy of Sciences. J. Insect Sci. 00:1–12. doi: 10.1111/j.1744-7917.2012.01503.x.

23. Gurr, GM, Symington, CA. (1998). Resistance to the potato tuber moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) in potato (*Solanum tuberosum* ssp. *tuberosum* L.) tubers. Aust. J. Entomol. 37: 49-51.
24. Harsimran, KG, Gurminder, Cl, Gaurav, G, Arshdeep, KG, & Gillett-Kaufman, JL. (2014). Potato Tuberworm *Phthorimaea operculella (Zeller)* (Lepidoptera: Gelechiidae)). Series of the Department of Entomology and Nematology 58: 1-6.
25. Kroschel, J, Koch, W. (1994). Studies on the population dynamics of the potato tuber moth (*Phthorimaea operculella* Zeller) (Lepidoptera, Gelechiidae) in the Republic of Yemen. J. Appl. Entomol. 118: 327-341.
26. Malakar, R, Tingey, WM. (1999). Resistance of Solanum berthaultii foliage to potato tuberworm (Lepidoptera: Gelechiidae). J. Econ. Entomol. 9(2), 497–502.
27. Malakar, R, Tingey, WM. (2006). Aspects of tuber resistance in hybrid potatoes to potato tuberworm. Entomol. Exp. Appl. 120:131–137
28. Ndiaye, I. (1997). Etude biologique de la teigne de pomme de terre *phthorimaea operculella (Zeller)* (Lepidoptera: Gelechiidae) et moyens de lutte. Thèse de doctorat, Université cheikh Anta Diop de Dakar.
29. Medina, RF, Rondon, SI, Reyna, SM, Dickey, AM. (2010). Population Structure of *Phthorimaea operculella* (Lepidoptera: Gelechiidae) in the United States. Environ. Entomol. 39(3), 1037-1042. doi: 10.1603/EN09286.
30. Omari, C. (2009). La filière pomme de terre en Algérie. Afrique agriculture. 381 : 26-30
31. Pelletier, Y, Horgan, FG, Ponpon, J. (2011). Potato resistance to insects. The American Journal of Plant Science and Biotechnogy 5: 37-52.
32. Raman, KV. (1980). La teigne de tubercule de la pomme de terre Bulletin d'information technique 3. International Potato Center Pérou.
33. Rondon, SI. (2010). the potato tuberworm: a literature review of its biology ecology and control. Am. J. Potato Res. 87: 149-166.
34. Rondon, SI, DeBano, SJ, Clough, GH, Hamm, PB, Jensen, A, Schreiber, A, Alvarez, JM, Thornton, M, Barbour, J, Dogramaci, M. (2007). Biology and Management of the Potato Tuberworm in the Pacific Northwest, PNW. 594: 1-7.
35. Rondon, SI, Brown, CR, Marchosky, R. (2013). Screening for Resistance of Potato Lines to the Potato Tuberworm, Phthorimaea operculella (Zeller) (Lepidoptera: Gelechiidae). Am. J. Potato Res. 90:71–82. doi : 10.1007/s12230-012-9278-8.
36. Rousselle, P, Robert, Y, Crosnier, JC. (1996). La pomme de terre. Production, amélioration, ennemis et maladies, INRA Paris.
37. Sporleder, M, Kroschel, J, Gutierrez Quispe, MR, Lagnaoui, A. (2004). A Temperature Based Simulation Model for the Potato Tuberworm, *Phthorimaea operculella* Zeller (Lepidoptera; Gelechiidae).Environmental Entomology 33(3), 477-486.
38. Traynier, RM. (1975). Field and laboratory experiments on the site of oviposition by the potato moth. Bull. Entomol. Res. 65: 391–398.
39. Trivedi, TP, Rajagopal, D. (1992). Distribution, biology, ecology and management of potato tuber moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) a review. Trop. Pest Manag. 38:279–285. doi: 10.1080/09670879209371709.
40. Veale, MA, Slabbert, MM, Van Emmenes L. (2012). Agrobacterium-mediated transformation of potato cv Mnandi for resistance to the potato tuber moth (*Phthorimaea operculella*).South African Journal of Botany. 80: 67–74. doi:10.1016/j.sajb.2012.02.007.