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Resistance of *Opuntia ficus-indica* cv 'Rojo Pelon' to *Dactylopius coccus* (Hemiptera: Dactylopiidae) under greenhouse condition

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Abstract. *Opuntia ficus-indica* (L.) Mill.), is called "beles" in the Tigray region of Ethiopia, where it is used for multiple purposes, such as food, fodder, and fences; however, in recent years the introduction of the cochineal (*Dactylopius coccus* Costa) to this region has caused it to become a plague that has affected thousands of hectares, causing an economic and social problem. Six cultivars: three from *Opuntia ficus-indica* ('Atlixco', 'Chicomostoc', and 'Rojo Pelón') and three others *O. cochenillifera* ('Nopalea' and 'Bioplástico') and *O. robusta* ('Robusta') were tested for resistance to *D. coccus* in completely randomized design (CRD) experiment with six replications under greenhouse conditions, for two seasons (cycles). Matured cladodes were infested by attaching a paper bag with ten ovipositing female *D. coccus*. The number of insects at different stages and yields were recorded, log transformed (insect count data), and subjected to statistical analysis. The number of nymphs (stages I and II) was significantly different in both cycles (P=0.0000). The insects died at the nymph I stage at 'Rojo Pelón' and 'Robusta', in contrast, they completed their life cycle at 'Atlixco', 'Chicomostoc', and 'Nopalea' cultivars. Insects at 'Bioplástico' cultivar remained in the nymph I stage the whole experimental period; the molting was hampered. Although some crawlers started settling (nymph I) at 'Rojo Pelón', they couldn't survive and developed, and this confirms that this *O. ficus-indica* cultivar is resistant to *D. coccus.*

Keywords: *Beles, cactus pear, cochineal, resistant cultivar*

Introduction

Opuntia ficus-indica (L.) Miller (cactus pear) is among the Cactaceae family, which has about 127 genera of which 1750 are identified species of the order Caryophyllales (Christenhusz and Byng, 2016). During the XVI century, *O. ficus-indica* was an important commodity in Mexico (Reyes-Agüero *et al*., 2005), and because of the different benefits this species had, like morphological peculiarities, anti-scurvy properties, sweet edible fruits, and ability to host the cochineal insect, from which an important commodity called cochineal dye was gained, the Spanish took it to their homeland. Later it was expanded to other regions of the world, including the Mediterranean area (Barbera *et al*., 1992; Griffith, 2004). It was also introduced to Tigray, around the middle XVIII century (Neumann 1997; cited in Gebretsadik *et al*., 2013). The cactus pear, locally called beles in the Tigirigna Language of Ethiopia, is a crop that is used in some parts of Tigray, as a source of human food for 4 or 5 months and for livestock feed, and it is considered an emergency crop. Although it can grow in different areas, it is obvious that beles can grow better in specific areas (Lemma *et al*., 2010). It is appreciated for its various benefits, which include high biomass yield, growth in sandy soils, staying greenthroughout the year, and resistance to drought; this suggests a high potential for use for different other purposes (Brutsch, 1997). In Mexico this plant is known as “nopal”, but in other countries is “tuna”, “cactus pear”, “prickly pear”, “green jewel” “green gold”, “fruit for the poor”, “treasure under its thorns”, “world plant dromedary”, “future plant”, “sacred plant”, and “monstrous tree” (Arias-Jimenez, 2013).

Cactus pear in North Africa, Brazil, and the Middle East is at risk from the wild cochineal (*Dactylopius opuntiae* (Cockerell)) (Bouharroud *et al.,* 2016; Mazzeo *et al*., 2019; Torres and Giorgi, 2018). In Ethiopia, the fine cochineal insect (*D. coccus* Costa) has caused damage in several areas of the Tigray region (Belay, 2015; Berhe *et al*., 2020). Due to the aforementioned reasons, it is necessary to carry out research to combat this problem with some options including the utilization of resistant varieties.

Dactylopius species or biotypes prefer specific species of *Opuntia* as a host and parasitize only cacti (Volchansky *et al*., 1999; Hoffmann *et al*., 2002: Campana *et al*., 2015; Portillo and Vigueras, 2006). The breeding of *D. coccus* is carried out in a small number of nopal species, it has been reported that only 10% of the total number of opuntias are used; among these species, *O. ficus-indica* is with its different cultivars, which is preferred by producers due to its ease of handling (few spines), larger cladodes, in addition to being used for other purposes such as the food and forage (Campana *et al*., 2015; Van Dam *et al*., 2015; Vigueras and Portillo, 2014). *D. coccus* is a species cultivated worldwide (Portillo and Vigueras, 2006; Van Dam and May, 2012), which produces the pigment called carminic acid and which is processed in different presentations such as lacquers and carmine (Piña, 1979; Vigueras and Portillo, 2014). This dye is one of the most demanded and has replaced artificial dyes (red); it is used as an additive for food, medicines, cosmetics, and textiles (Arroyo-Figueroa *et al*., 2016; Torres-Ponce *et al*., 2015; Arroyo-Figueroa *et al*., 2009); and it is preferred for its high stability to light and temperature, in addition to being harmless to human health (Vigueras and Portillo, 2014).

But it became invasive and a pest of the host *O. ficus-indica* in Tigray, because of different reasons; like the absence of natural enemies, dense plant populations, and in-proper management (Belay, 2015). Having long and short-term management plans are important to control insect and integrated pest management (IPM) gives more emphasis on environmental pollution and the well-being of human being. Resistant varieties are an important component of the IPM to manage the infestation in Tigray (Berhe *et al*., 2020).

Although the development or evaluation of resistant cultivars of *O. ficus-indica* to *D. coccus* is rarely reported, the utilization of pest resistant crop varieties is important for the economy, environment, and ecology. The economic advantages are reducing crop loss due to insects and minimizing the cost of insecticides. It is also easily available to small-scale growers, especially in developing countries. Mostly, the seed of insect-resistant varieties are a little more expensive than the cost of the susceptible varieties or sometimes can be equal (Teetes, 1996; Huang *et al*., 2013). More importantly, farmers don’t require any special skills or techniques of application (Sharma and Ortiz, 2002). It also helps to reduce the use of chemicals and indirectly related risk of environmental pollution and human health (Munhame *et al*., 2021; Reinert *et al*., 2003; Vigueras y Portillo, 2014). The genus *Opuntia* has higher diversity and distribution in the Americas than the other Cactaceae (Reyes-Agüero and Valiente-Banuet, 2006). There is a high genetic similarity between *O. ficus-indica* and *O. megacantha* and it indicates *O. ficus-indica* that could be a domesticated type of *O. megacantha* (Kiesling and Metzing, 2017). *O. ficus-indica*, *O. albicarpa*, and *O. megacantha* possibly share an ancestry (Valadez-Moctezuma *et al*., 2015). Some of the wild species are resistant to *D. coccus* and the genetic similarity of *O. ficus-indica* with the different species implies that; there could be genetic sharing hence some *O. ficus-indica* cultivars may have resistance capability. Plants have evolved a whole arsenal of defense strategies against pests, including morphological structures that form the first line of protection to capacity in synthesizing an enormous array of chemical compounds (War *et al*., 2020).

Tovar *et al.* (2005) reported that *D. coccus* yield obtained from var. Villanueva is higher than varieties tested in Mexico. Méndez-Gallegos *et al*. (2010) explained that 'Blanco Moscatel' and 'Colorado Moscatel' cultivars might have defense means for *D. coccus*, since the colony development on those hosts showed a high mortality rate and failed to reproduce. This behaviour may be associated with the presence of phytochemicals (such as terpenoids, flavonoids, tannins, and polyphenols) (Akroud *et al*., 2021; Guevara-Figueroa *et al*., 2010; Matos *et al*., 2021) and morphological-histological characteristics (epidermis and cuticle thickness and density of calcium oxalates) (da Silva *et al*., 2010). Host resistance should be considered in cochineal control (Vigueras and Portillo, 2014). Thus, it can be possible to find resistant cultivars which may have similar properties to resistant wild species, and exploration and verification are required. Identification of resistant varieties and a deeper understanding of the levels and mechanisms of resistance is vital for integrated pest management strategies (War *et al*., 2020). It is also imperative paramount to study the genetics of *O. ficus-indica* such as identifying the morphological resistance characteristics of genotypes and finding the genes that control resistance to cochineal (Felker and Inglese, 2003). Resistant varieties can be used either as the main method or as a supplement to other strategies of insect control, based on their resistance level (Jayaraj and Uthamassamy, 1990). Therefore, the research was conducted to assess the cultivar 'Rojo Pelon' of O. *ficus-indica* resistance to *D. coccu*s for further utilization and breeding purposes.

Materials and Methods

The experiment comprised six *Opuntia* cultivars collected from different production farms and locations in Mexico: three *O. ficus-indica* ('Rojo Pelón', 'Atlixco', and 'Chicomostoc'), two *O. cochenillifera* ('Nopalea' and 'Bioplástico') and one *O. robusta* ('Robusta') (Table 1). For the infestation of the cladodes, females ovipositing was used (where nymphs were observed), this material was obtained from cochineal breeding in greenhouse. It was carried out at the University of Guadalajara, Center of Biological and Agricultural Sciences (CUCBA), Zapopan, Jalisco, Mexico, under greenhouse conditions and with a completely randomized design (CRD) replicated six times (cladodes as an experimental unit) in two seasons/cycles (Cycle 1: October-January 2020/2021 and Cycle 2: January-April 2021), since these two seasons have different climatic conditions. At Cycle 1 temperatures were 10 to 38.05ºC and relative humidity between 36.95 to 56.77%; meanwhile, for Cycle 2 the records ranged from 12.3 to 45.82ºC and relative humidity 10 to 66.95%.

The climatic conditions from where the hosts were collected: Ojuelos, Jalisco has an average annual temperature of 13.9ºC, and 594 mm rainfall (IIEG, 2021). Guadalajara has an average temperature of around 20.9ºC and 900 mm rainfall; Villanueva, Zacatecas has an annual temperature of 17ºC, annual mean rainfall of 510 mm (INEGI, 2022).

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Table 1. Identity and cladode characteristics (cultivar name, species name, national ID, source, and presence of spines) of the six *Opuntia* cultivars evaluated.

Cultivar name	Species name	National ID	Source	Spininess
Rojo Pelón	*O. ficus-indica*	NOP-022-221104	OjJ	Spineless
Atlixco	*O. ficus-indica*	NOP- 018-221104	VNZ	Spineless
Chicomostoc	*O. ficus-indica*	NA	VNZ	Spineless
Bioplástico	*O. cochenillifera*	NA	VNZ	Very few
Nopalea	*O. cochenillifera*	NA	GDLJ	Spineless
Robusta	*O. robusta*	NOP-060-090617	OjJ	Spiny

Note: OjJ-Ojuelos, Jalisco, VNZ-Villanueva, Zacatecas, GDLJ-Guadalajara, Jalisco. Source: CNVV, 2020.

All selected matured cladodes were one-year-old, vigorous, and free of plagues and diseases. Cladodes were thoroughly washed with pure water for cleaning from any wild cochineal (*D. opuntiae*), their length, width, and thickness were measured with a vernier caliper and a weighing balance was used to measure their weight. Then, the cladodes were labelled and marked for repeat counts, hanged in reverse position, in such a way that they were pierced at their base with wire and placed on a metal barrel. For the infestation of the cladodes, females close to oviposition were used (when nymphs were observed), from this material was obtained from the cochineal breeding in the greenhouse. The adult females were collected (Figure 1a) from the source host cladodes with a fine brush and kept in small paper bags which were fixed with spines (Figure 1b) containing ten adult females each. Infested cladodes were covered with nylon clothing bags (60 cm x 30 cm size) to protect them from uncontrolled infestation and pests (Figure 1c). The paper bags remained attached to the cladodes for 7 days and then removed (Gusqui Mata, 2013). After the females started oviposition (matured), they were harvested with a fine brush to take the yield data.

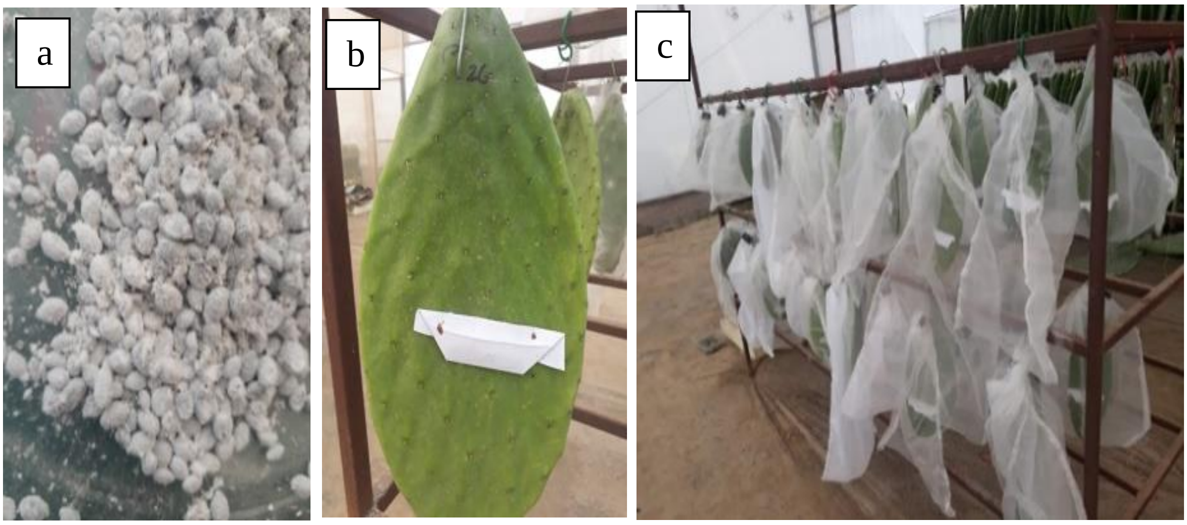

Figure 1. Infestation of cladodes. a) female ovipositing cochineal ready for infestation, b) fixing paper bags that contain female ovipositing cochineal to the cladodes, c) infested cladodes covered with nylon clothing bags.

Data were collected on insect counts including the number of crawlers (mobile nymph I), nymph I established, nymphs II, cocoons, and female adults; total fresh and dry weight per cladode (g); the fresh and dry weight of individual adult female (mg) from each experimental unit (cladode). To take the individual weight, ten samples were randomly weighted, and the average was recorded. Dry weights were measured after the insects were dried in an oven at 60°C for 3 h. Data were checked for homogeneity, transformed with log (count data) and square root (number of cocoons), and an analysis of variance (ANOVA) was performed using the statistical package R.4.1.0. Tukey test at (0.05) was applied to compare means among treatments if significant differences were detected.

Results and Discussion

Cladode characteristics of the cultivars used

Cultivars used in cycle 1 and 2 had significant differences (P = 0.0000 both) in cladode weight (g), width (cm), and thickness (cm), and (P = 0.0173 and P = 0.0011) in length (cm) (Table 2). In line with this finding, Peña-Valdivia *et al*. (2008) reported differences in morphological characteristics of *opuntias*, and presence of spines on the surface of cladodes, and cladodes' width and length. Adli *et al*. (2019) also observed significant differences in cladode length, width, and thickness among four *O. ficus-indica* accessions. Cladode shapes may be considered important parameters for taxonomic classification even to differentiate forage cacti (Lucena *et al*., 2019). Morphological characteristics of cladodes (height, width, weight, and thickness) can have effects on the yield of cochineal (Arroyo-Figueroa *et al*., 2020).

Table 3. Means of cladode weight (CWt) in g, length (CL) in cm, width (CW) in cm, and thickness (CT) in cm in cycle 1 (C1) and cycle 2 (C2).

CV	CwtC1	CwtC2	CLC1	CLC2	CWC1	CWC2	CTC1	CTC2
RP	1128.33^{d}	932.5000^{c}	30.67^{b}	27.8333^{bc}	17.33^{b}	16.3333^{bc}	3.50^{d}	3.3333^{c}
A	467.50^{a}	705.0000^{bc}	30.67^{b}	31.3333^{c}	12.83^{a}	14.1666^{ab}	2.04^{ab}	2.2500^{ab}
C	741.67^{b}	591.6667^{bc}	31.33^{b}	29.5000^{bc}	18.50^{b}	17.8333^{c}	2.04^{ab}	1.9583^{ab}
B	476.67^{ac}	375.0000^{ab}	28.67^{ab}	26.3333^{bc}	12.50^{a}	11.0000^{a}	2.42^{bc}	2.2916^{ab}
N	247.50^{a}	238.3333^{a}	31.17^{b}	24.6666^{ab}	10.50^{a}	11.1666^{a}	1.46^{a}	1.8333^{a}
R	836.67^{c}	594.1667^{bc}	22.33^{b}	23.0000^{a}	19.33^{b}	17.1666^{bc}	2.96^{cd}	2.5416^{b}

Means sharing the same letter are not significantly different.
CV-cultivar,RP='Rojo Pelón', A='Atlixco', C='Chicomostoc', B='Bioplástico', N='Nopalea', and R='Robusta'.

D. coccus survival and development

Statistically, a significant difference was observed among the cultivars in the number of crawlers/mobile nymph I (NC) in cycle I (P = 0.0398), but not in cycle 2 (P = 0.1520), where the number was higher in 'Chicomostoc' but statistically similar with 'Atlixco' and 'Nopalea'. The number of nymphs I (NI) indicated a significant variation at both cycles (P=0.0000). Additionally, for both cycles, there was a statistically significant difference in the number of nymph II (NII) (P=0.0000). At cycle 2, a lower number of nymphs I was observed on 'Rojo Pelón', and a higher number was observed on 'Atlixco' (but statistically like 'Chicomostoc'). The number of nymphs I was significantly similar within the resistants ('Robusta', 'Rojo Pelón', and 'Bioplástico'). The number of nymphs II was statistically similar among the susceptible cultivars, but there was no nymph II observed in the resistant cultivars (Figure 2).

The similarity of *Opuntia* cultivars in the number of crawlers is an indication of the insects' non-preference for oviposition. The difference in development among different cultivars is similar to previous reports. Passos da Silva *et al*. (2007) found a difference in resistance among *Opuntia* clones to *D. opuntiae*. Sbaghi *et al*. (2019) also reported that seven resistant ecotypes out of 241 tested proved to be resistant to *D. opuntiae* pest in Morocco.

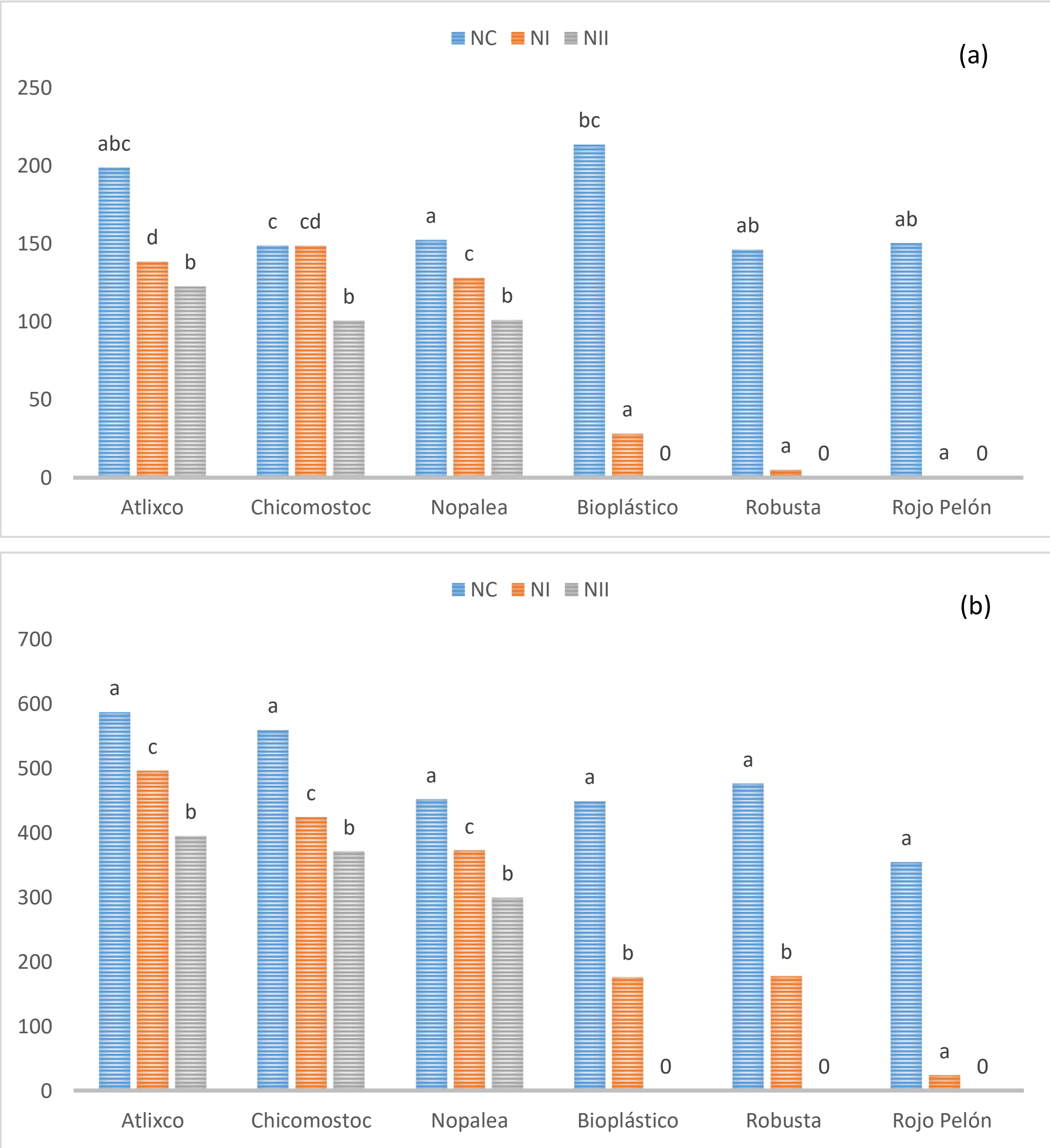

Figure 2. Development of *Dactylopius coccus* on six *Opuntia* cultivars. The number of crawlers (NC), nymphs I (NI), and nymphs II (NII) at cycle 1 (a) and cycle 2 (b). Means sharing the same letter are not significantly different.

It was noted that the insects died at the nymphs I stage, after 21 days of infestation on two resistant cultivars (‘Robusta’ and ‘Rojo Pelón’) (Figure 2). Growing nymphs II with white wax on ‘Atlixco’ (Figure 3a) and insect-free on ‘Rojo Pelón’ (Figure 3b).

(a) Atlixco (b) Rojo Pelón

Figure 3. Status of insects in *Opuntia* cultivars after 21 days after infestation. a) susceptible cultivar (‘Atlixco’) with *Dactylopius coccus* showing covered with white wax, b) resistant cultivar (‘Rojo Pelón’) without *D. coccus*.

Opuntia cultivars also showed statistically significant differences (P=0.0000) in the percentage of crawler mortality and nymph I mortality at both cycles at p≤0.05. Crawlers’ mortality was higher in the resistant cultivars (86 % to 96%) than in susceptible cultivars (28% to 35% in cycle 1). In cycle 2, crawlers’ mortality was higher at ‘Rojo Pelón’ (100%) followed by ‘Robusta’ (94%), and ‘Bioplástico’ (63%). Similarly, nymph I mortality was higher (100%) in resistant cultivars, ‘Rojo Pelón’, ‘Bioplástico’, and ‘Robusta’ (Figure 4). In agreement with this finding, nymph mortality of *D. opuntia* was high, ranging from 40 to 60% at different cultivars, during the first 24 days of development (Méndez-Gallegos *et al*., 2010). Akroud *et al*. (2021) found that mortality of *D. opuntiae*, started on the 7th day after infestation and maximum mortality on the 28th day. The authors also discussed that the mortality might be due to the abnormalities that could be caused by the ingestion of compounds (secondary metabolites like alkaloids, carotenoids, diterpenes, amines, etc.), which are either insufficient or anti-nutrition for the insect’s development. At the two resistant cultivars, all nymphs died at first instar which may be due to the cultivars possessing antibiosis mechanisms of resistance. This finding can suggest that ‘Rojo Pelón’ is a resistant cultivar to *D. coccus*. Similarly, Sbaghi *et al*. (2019) and Passos da Silva *et al*. (2007) concluded that five cultivars proved to be immune to the *D. opuntiae*, since there has been no insect development.

Adult and cocoon populations showed a significant difference across cultivars (P=0.0000) at both testing cycles, but there was no statistical difference among susceptible cultivars (Table 3). Cultivars had no significant difference in total insect fresh weight at both cycles (P=0.5540 and 0.0744), total dry weight at cycle 1 (P=0.7860), individual fresh weight at cycle 2 (P=0.3680), and individual dry weight at cycle 2 (P=0.3320). However, there were statistically significant differences in individual insect fresh and dry weight (P=0.0003 and P=0.0007) at cycle 1 and total dry weight at cycle 2 (P=0.0475) (Figure 5). ‘Atlixco’ followed by ‘Chicomostoc’ cultivars were superior to ’Nopalea’ in insect performance, measured by the above parameters (Table 3 and Figure 5). These results support the conclusions made by Tovar *et al*. (2005) who noticed significant differences among cultivars. Similarly, Méndez-Gallegos *et al*. (2010) reported differences in the carminic acid percentage of *D. coccus* among different cultivars. Arroyo-Figueroa *et al*. (2020) also reported the effect of morphological characteristics in cladodes of different ages, such as length, width, and weight affected *D. coccus* yield; which can be also different intra and inter-species (Peña-Valdivia *et al*., 2008; Adli *et al*., 2019).

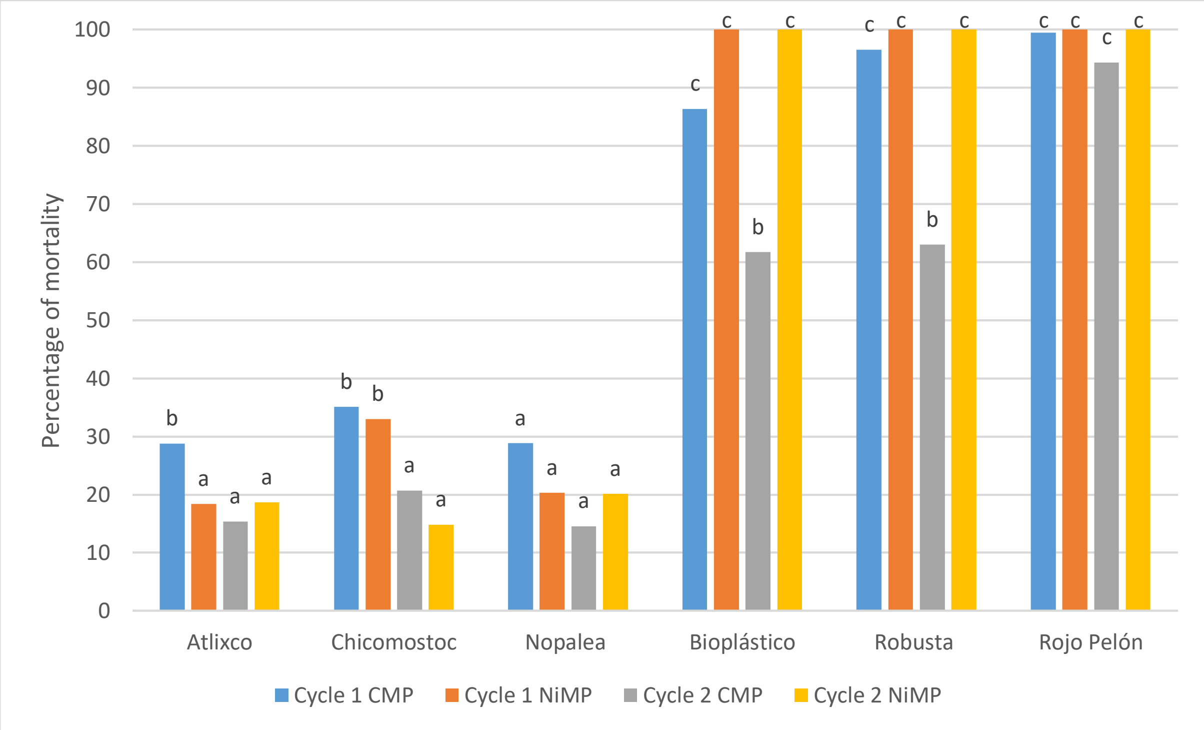

Figure 4. Mortality of nymphs (percentage) on six *Opuntia* cultivars. Mortality of crawlers at cycle 1 (cycle 1 CMP) and cycle 2 (Cycle 2 CMP), mortality of nymph I at cycle 1 (Cycle 1 NiMP) and cycle 2 (Cycle 2 NiMP) at p≤0.05. Means sharing the same letter are not significantly different.

Table 3. Means of the number of adults (females) and cocoons of *Dactylopius coccus* on six *Opuntia* cultivars at cycle 1 (C1) and cycle 2 (C2).

Cultivar	Adults C1	Cocoons C1	Adults C2	Cocoons C2
'Rojo Pelón'	0[a]	0[a]	0[a]	0[a]
'Atlixco'	49.17[b]	14.83[b]	255.83[b]	66.33[b]
'Chicomostoc'	49.00[b]	18.00[b]	201.50[b]	54.17[b]
'Bioplástico'	0[a]	0[a]	0[a]	0[a]
'Nopalea'	55.67[b]	14.50[b]	148.17[b]	37.50[b]
'Robusta'	0[a]	0[a]	0[a]	0[a]

Note: Means sharing the same letter are not significantly different.

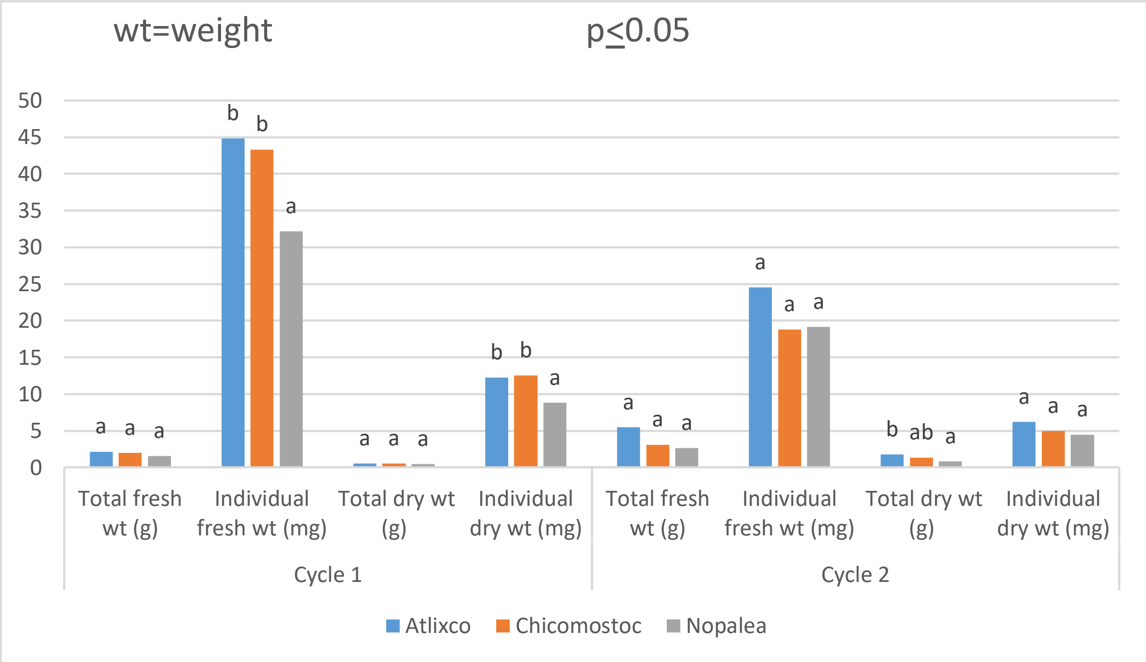

Figure 5. Insect fresh and dry weight total (g), fresh and dry weight individual (mg), at cycles 1 and 2.

The number of days to complete the female life cycle of the insect (harvesting) showed a statistically significant difference among the susceptible cultivars (P=0.0000). *D. coccus* completed its life cycle earlier at 'Atlixco' followed by 'Chicomostoc', and 'Nopalea' (Figure 6). Overall, the days taken to maturity are in the range of the life cycle of the insect. In accordance with this, Arroyo-Figueroa *et al*. (2020) explained that *D. coccus* needs 90 to 120 days to complete its life cycle. Méndez-Gallegos *et al*. (1993) also support that the period to maturity of *D. coccus* is around 90 days.

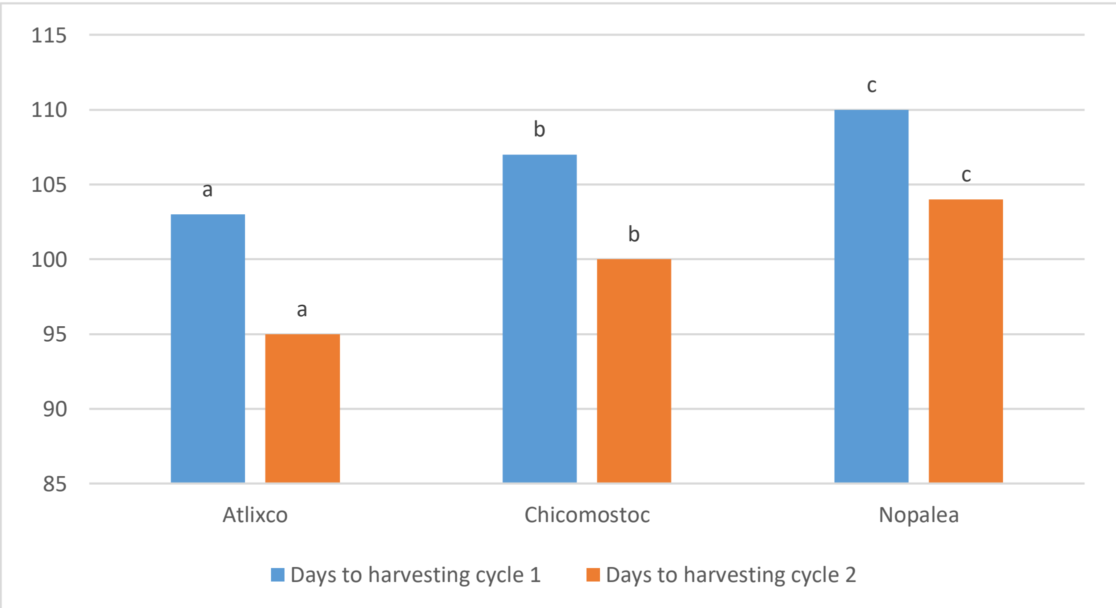

Figure 6. Days to harvesting of *Dactylopius coccus* under three susceptible cultivars ('Atlixco', 'Chicomostoc', and 'Nopalea'). Means sharing the same letter are not significantly different.

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Insects completed their life cycle on the three susceptible cultivars (‘Atlixco’, ‘Chicomostoc’, and ‘*Nopalea*’). In ‘Bioplástico’ the insects remain in nymph I (Figure 7). At cultivars (‘Robusta’ and ‘Rojo Pelón’) the insects died during the first instar (nymph I) (Figures 4 and 7). The susceptible hosts are members of *O. ficus-indica* which are the commonly used hosts for cochineal production (Campana *et al*., 2015). The mechanism of resistance could be the presence of secondary metabolites (War *et al*., 2020) or physical barriers like calcium oxalates (Nakata, 2015; Molano-Flores, 2001). López-Palacios and Peña-Valdivia (2020) observed higher levels of hydroxycinnamic acid in the cladodes of wild species. Tovar-Puente and Pando-Moreno (2010) high concentration of calcium oxalate crystals stated that prevents the nymph from inserting the stylet and settling in the cladode. Oxalates are more concentrated on matured cladodes (Contreras-Padilla *et al*., 2011).

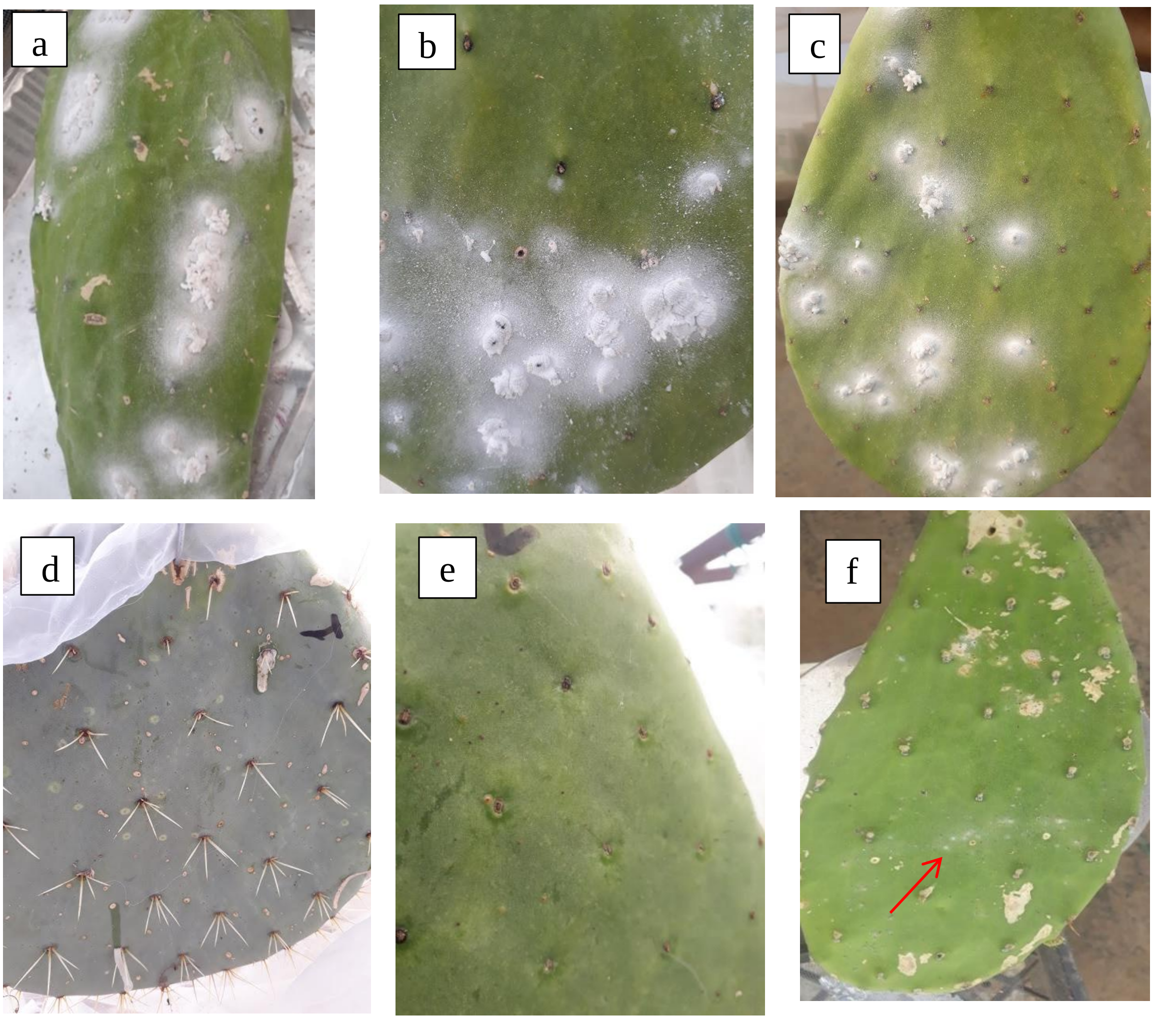

Figure 7. Infestation status of all six cultivars at the end of the experiment periods. a=‘Nopalea’, b=‘Atlixco’, c= ‘Chicomostoc’, d=‘Robusta’, e=‘Rojo Pelón’, and f= ‘Bioplástico’. Susceptible cultivars a, b, and c with matured *Dactylopius coccus* and resistant cultivars d and e free of insects and f with nymphs (arrow).

Generally, the findings are supported by previous works. Tovar *et a*l. (2005) and Méndez-Gallegos *et al*. (2010) reported differences in *D. coccus* performance among cultivars in Mexico and suggested the possibility of resistance. Sbaghi *et al*. (2019) also found seven ecotypes shown to be resistant to *D. opuntiae* in Morocco. Since there has been no pest establishment, a cultivar could be resistant; hence, our results confirm that ‘Rojo Pelón’ is a promising resistant cultivar of *O. ficus-indica* to *D. coccus*. The host and the insect have obviously been in continuous adaptations and many wild species are resistant to these insects; so, it is inferred that this domesticated cultivar may share some genetic characteristics with some of the wild species.

The ‘Rojo Pelon’ cultivar probably originated from Northern Guanajuato and Southern San Luis Potosi (Central highlands of Mexico). Characterized by an elliptical shape, bright red fruit colour, and sweet export quality fruit that matures during the summer season. The tender and spineless cladodes it has been important for vegetable and livestock feed (Cervantes-Herrera *et al*., 2006).

Remaining the insects in the nymph I stage throughout the experimental period of the complete life cycle on ‘Bioplástico’ cultivar (Figure 6) implies moulting was hindered, probably by some Phyto-ecdysones (terpenoids) (War *et al*., 2020). Moulting growth can be continuous, as in hemimetabolous insects (e.g., aphids, cockroaches, grasshoppers, and locusts) or resting pupal stage, when the larval organs are completely changed to adult level (holometabolous insects, e.g., beetles, moths, flies, and ants) (Morgan and Poole, 1977). It is under the control of the brain (the corpus cardiacum) (Veelaert *et al*., 1998) that stimulates the prothoracic gland to secrete moulting hormone or its precursor (Krishnakumaran and Schneiderman, 1968; Kobayashi and Yamazaki, 1974; Ishizaki and Suzuki, 2002).

Conclusions

The evaluated cultivars belong to three species of *Opuntia*, three *O. ficus-indica* cultivars, one *O. robusta* cultivar, and two *O. cochenillifera* cultivars. These cultivars are different in resistance to *D. coccus*. It was also observed that there is sharing of characteristics among species in relation to resistance to *D. coccus*. Three cultivars from different species are resistant to the insect.The resistance characteristics could be shared among species since there is a genetically interlinked among the *Opuntia* spp. During the two cycles experiments, ‘Rojo Pelón’ was found to be resistant against *D. coccus* among the *O. ficus-indica* cultivars, because the insects could not develop and complete the life cycle but died at the nymph I stage. This is the first report on *D. coccus* resistance, which can be considered as an element of integrated pest management intervention or practice in Tigray and other areas having similar problems. It can be used for direct utilization and/or genetic improvements for the *D. coccus* resistance breeding programs for beles. Mechanisms of resistance or characteristics of the plants related to *D. coccus* resistance are also important subjects of study to use as a selection/improvement marker in resistant breeding. And it could be physical barriers, tissue structures, and secondary metabolites or combinations which lead to antibiosis (restricting growth or killing) resistance. Differently from the other cultivars, moulting of the insect was restricted in the ‘Bioplástico’ cultivar, this could be probably due to presence of unique secondary metabolites, and these phenomena of resistance are an important area of study.

Ethics statement

Not applicable

Consent for publication

Not applicable

Disclosure statement

The authors declare that they have no conflict of interest.

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Author contributions

All authors participated in the conceptualization of the project, made the investigation for the background of the manuscript, and wrote part of the original draft. The second and third authors participated in the application and development of the experiments; executed part of the administration of the project. They reviewed and edited all versions of the manuscript.

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