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INFESTATION PATTERNS OF THE CAROB MOTH *ECTOMYELOIS CERATONIAE* (ZELLER) AND ASSOCIATED BIOCHEMICAL TRAITS IN SELECTED DATE PALM CULTIVARS IN THE TAFILALET REGION OF MOROCCO

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Abstract

This study aimed to determine the infestation levels of different Moroccan date palm cultivars by Ectomyelois ceratoniae in seven areas of the Tafilalet region, both under field conditions, where a total of 1900 dates at both Khalal and Tmar stages were sampled, and in four warehouses, where 210 Tmar fruits were examined. Infestation rates were determined from the collected samples, and associated biochemical traits, including total sugar content, total phenolic content, and moisture content, were evaluated to better understand their relationship with infestation patterns. Sampled dates were also analysed to determine their water, total sugar, and total phenolic content. Results showed that the infestation rate differed significantly by date stage and cultivar (stage: $p < 0.001$; cultivars: $p = 0.034$) with significant interaction between stage and cultivar ($p = 0.031$). Infestation rates were significantly lower during the Khalal stage compared with the Tmar stage. However, during the late Tmar stage, the rate ranged from 1.67% to 11.78% by area and from 3.25% to 11.33% by cultivar. As for stored dates, the level of infestation varied significantly by cultivar ($p = 0.004$), ranging from 0% to 5%. Regarding biochemical analyses, under field conditions, cultivar, fruit stage, and their interaction had a significant impact on moisture content ($p < 0.05$), fruit stage alone had a significant impact on total sugar content ($p < 0.05$), and fruit stage also had a significant impact on total phenolic content ($p < 0.05$). There was a significant difference in the hardness index between cultivars ($p < 0.05$). Total sugar, total polyphenol, and moisture content did not significantly differ between cultivars in dates that were stored. Results show that dates at the Khalal stage contain low levels of total sugars (from 24.42% to 37.54%). At the Tmar stage, all cultivars are rich in total sugars, with contents ranging from 69.66% to 79.39%. As for the water content, it is higher at the Khalal stage than at the Tmar stage for all the cultivars studied (from 77.17% to 81.39%). It decreases with maturation, reaching levels fluctuating between 9% and 30.8%. Based on these results, it appears that all cultivars, except for the "Maajouna" cultivar (semi-soft), were classified as dry and are more susceptible to attack than the semi-soft cultivar. The polyphenol content seems to be independent of the cultivar factor, but it was linked to the stage factor. Regression analyses indicated significant correlations between infestation rate and sugar, polyphenol, and water contents at the Tmar stage ($R^2 \approx 0.29$–0.35, $p < 0.05$), suggesting that biochemical factors affect infestation. The findings reveal the most attacked fruit stage and associated fruit biochemical traits, offering insights for improved pest management in the Tafilalet region.

Keywords
Ectomyelois ceratoniae, date palm, infestation rate, biochemical traits, Tafilalet, Morocco

Introduction

The date palm (*Phoenix dactylifera* L.) is the crop best adapted to the difficult climatic conditions of the Saharan and pre-Saharan regions, and is therefore an important agricultural crop in the Drâa-Tafilalet region. The Ministry of Agriculture has announced that this region contributes almost 73% of national date production, while the other producing regions, Souss-Massa, Oriental and Guelmim-Oued Noun, together account for 27% of production. For the 2024–2025 crop year, national date production is estimated at 103 thousand tonnes from a productive area of 51.6 thousand hectares, down 10% on production in the 2023–2024 crop year (115 thousand tonnes) (Le Matin, 2024), with water stress in these regions and fires affecting some traditional palm groves, particularly in the oases of Tinghir, Zagora and Tata, being the main factors behind this drop in production (Tridge, 2024). As regards the distribution of cultivars in the Tafilalet region, the main cultivars are Boufeggous (23%), Mejhoul (21%), Bouslikhène (15%), Boucérdoune (4%), Najda (3%), Bousekri (2%), Ras Tmar (2%), Bouyjou (2%) and Oum Nhal (1%); khalts account for 20% (El Bakouri et al., 2025).

In addition to the drought and fires that threaten date production, the marketing of dates is affected by the deterioration in quality caused by certain pests such as the date white scale insect (*Parlatoria blanchardi* Targ), the Boufaroua (*Oligonychus afrasiaticus* Mc Gregor), and the date moth (*Ectomyelois ceratoniae* Zeller) (Ouamane et al., 2017). The latter is considered to be one of the most devastating pests of date palms, given the losses it causes, which can reach 30% (Bouka et al., 2001). In palm groves in the Draa Tafilalet region, three species of moth have been identified: *Ectomyelois ceratoniae*, *Plodia interpunctella*, and *Ephestia figulilella* (Bouka et al., 2001). *E. ceratoniae* is considered to be the main moth species attacking dates with an infestation rate of 26.7%, followed by *Plodia interpunctella* with a lower infestation rate of no more than 1.61%. As for *Ephestia figulilella*, it is considered accidental given its negligible infestation rate. The *E. ceratoniae* species is also dominant in dates that have fallen to

the ground, with an infestation rate of 41.18% (Bouka et al., 2001). The bioecology of *E. ceratoniae* has been the subject of numerous investigations around the world, but results differ by location. According to Gothilf (1969), natural enemies dramatically decreased pest populations on substitute hosts like acacia and carob tree in Palestine. Dhouibi (1982) and Mediouni and Dhouibi (2007) discovered that host availability and local climate had a significant impact on infestation patterns in Tunisia. Warner (1988) and Nay (2006) highlighted that management practices were the primary factor influencing infestation in the United States. These comparisons show that different countries have different infestation drivers. A great deal of work is also being done throughout the world, particularly on the eco-biological aspects of *Ectomyelois ceratoniae*. In Morocco, however, few studies have examined *E. ceratoniae* infestation rates among date palm cultivars and localities. Moreover, no research has explored the biochemical traits associated with fruit susceptibility to infestation under field or storage conditions, which constitutes the gap this study aims to address. Accordingly, this study aimed to assess infestation rates of selected date palm cultivars in the Tafilalet region, both in the field and in warehouses, and to investigate factors, including fruit biochemical traits, explaining variations in infestation levels.

Materials and Methods

Presentation of the study region

This work was carried out at 20 sites in the seven date palm groves of Tafilalet (south-east Morocco): Errachidia, Aoufous, Erfoud, Errissani, Tinejdad and Boudnib. The plantations at the study sites are of two types: regular (Plantations where the palms are arranged in an orderly fashion and spaced at uniform intervals) (2 in Errachidia, 1 in Erfoud, 2 in Goulmima, 2 in Tinejdad, 1 in Boudnib) and irregular (Plantations where trees are placed without respecting a precise distance) (1 in Errachidia, 1 in Erfoud, 1 in Aoufouss, 3 in Goulmima, 2 in Tinejdad, 2 in Boudnib, 2 in Errissani).

Sampling of stored dates was carried out in 4 warehouses located in Aoufous, Errachidia, Tinejdad and Jorf (Figure 1).

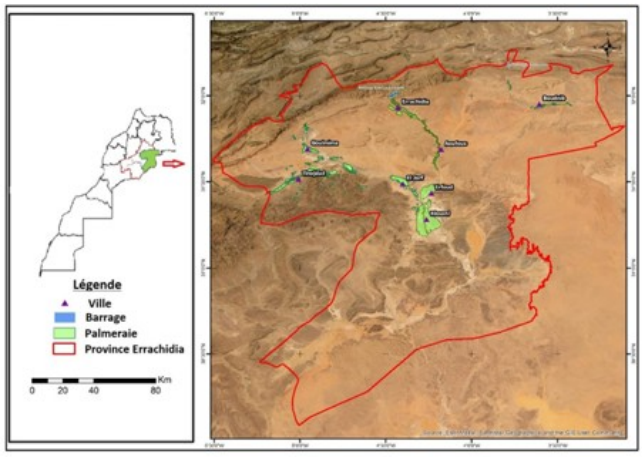

Figure 1. Location of date palm groves in Tafilalet (Khardi et al., 2024)

Coordinates and climatic conditions of the study area

Climatic data, corresponding to the study year (2022), were obtained from NASA POWER (NASA Langley Research Center (LaRC), 2024), while the geographical coordinates of the sampling area were determined using Google Maps (Google LLC, 2024). To ensure clarity and conciseness, only the representative coordinates of each study area are reported in this manuscript, even though GPS coordinates were gathered for each individual sampled plant in the field (Table 1).

Determining the infestation rate (IR) in open fields

The infestation rate was determined in two periods (2 different stages): during fruit enlargement (Khalal stage) and at the end of ripening (Tmar stage). A total of 364 date palms were sampled across the different study sites. At each site, between 6 and 12 palms were selected, depending on the size of the site and the availability of healthy plants. This variation was mainly due to differences in site surface and the presence of drought-affected palms that did not produce fruits. From each palm, 10 date fruits were collected during each sampling period. Within each study site, palms were first chosen using random sampling. However, some randomly chosen palms were excluded from the study because they were unproductive as a result of drought conditions. As a result, depending on plant availability, six to twelve palms were sampled per site. Each palm was located by GPS and numbered to make it easier to return during the second period. The dates collected were placed in kraft paper bags and labelled: the number of the plant, the site, the date of sampling and the cultivar. They were then taken back to the laboratory to be observed under a binocular magnifying glass in order to detect any possible form of infestation (eggs, larvae, pupae).

The infestation rate was calculated using the following formula (Stathers et al., 2020):

$$IR(\%) = \frac{\text{Number of infested dates}}{\text{Total number of dates observed}} \times 100 \qquad (1)$$

Determination of the infestation rate in warehouses

30 dates of each cultivar were sampled, placed in kraft paper bags and labelled with the warehouse, the cultivar, the storage temperature, and the treatment applied (generally phosphine fumigation). Samples were then observed with a magnifying glass and stored in the freezer. The infestation rate was calculated as above.

The experimental conditions for storage were not controlled. Storage facility managers provided information about phosphine treatment and storage temperatures (T1 = 4°C and T2 = –20°C). Consequently, these factors were regarded as observational variables rather than controlled treatments.

Biochemical analysis

Moisture content

Moisture content was determined by drying date samples, which were weighed and placed in dry Petri dishes in an oven

Table 1. Geographic coordinates and climatic conditions of the study area

Study Area	Latitude (°N)	Longitude (°W)	Temperature (°C)	Rainfall (mm)	Relative humidity (%)
Errachidia	31.94	4.46	18.09	23.06	41.44
Aoufous	31.69	4.18	21.33	226.2	33.77
Arfoud	31.43	4.23	21.33	226.2	33.77
Errissani	31.28	4.26	21.33	226.2	33.77
Boudnib	31.95	3.61	19.13	335.87	38.92
Tinejdad	31.51	5.03	19.66	278.31	35.25
Goulmima	31.69	4.96	19.66	278.31	35.25

at 70°C for 24 hours. After cooling, the samples were weighed again. The drying process continued until a constant mass was obtained. Moisture content (MC) was calculated using the following formula (Canet, 1988):

$$MC = \frac{M_i - M_f}{M_s} \times 100 \quad (2)$$

where MC is the water content expressed as a percentage (%), M_i is the mass of fresh sample (g), and M_s is the mass of sample after drying (g).

Total sugar content

0.1 g of dates was crushed in 4 ml of Ethanol (80%) and centrifuged at 5000 rpm for 10 min. The supernatant was collected, and the rest was resuspended by adding 2 ml of Ethanol to undergo a second centrifugation.

The two supernatants were used to determine the total quantity of soluble sugars using the method described by Du Bois et al. (1956): 1 ml of the supernatant was mixed with 1 ml of phenol solution (5%) and 5 ml of concentrated sulfuric acid. After 5 minutes, the optical density (OD) was measured at 485 nm using a UV spectrometer, and the sugar content was determined using glucose as the standard.

Figure 2 shows the calibration curve for glucose standards. Absorbance was measured at 485 nm, three replicates' mean values are used, and the graph displays the regression equation and coefficient of determination (R^2) (Figure 2).

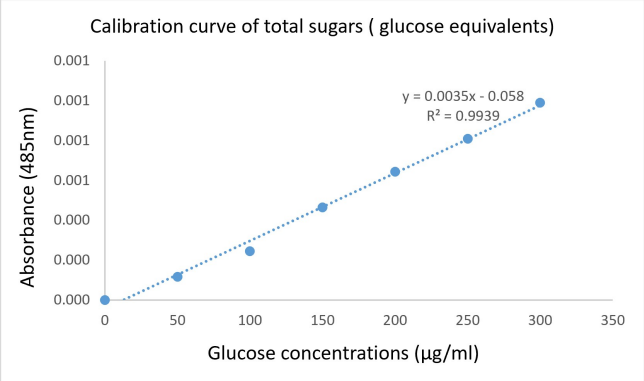

Figure 2. Calibration curve of total soluble sugars

Total phenolic content

0.5 g of dates were crushed in a mortar kept on ice with 2.5 ml of 80% methanol, the crushed material was collected in Eppendorf tubes and centrifuged for 15 minutes at 13,000 rpm, then the supernatant was collected and used for the assay.

The quantification method used involves the Folin-Ciocalteu reagent, which is based on the reduction of a mixture of phosphotungstic acid and phosphomolybdic acid during the oxidation of phenols, resulting in the formation of blue oxides of tungsten and molybdenum (Singleton and Rossi, 1965). The resulting colour, with a maximum absorption at 760 nm, is directly proportional to the concentration of polyphenols in the phenolic extract. The procedure is as follows:

In labelled tubes, 50 μl of phenolic extract or standard was added to 250 μl of Folin's reagent, 500 μl of sodium bicarbonate (20% $NaHCO_3$) and 2.5 ml of distilled water. The reaction mixture was vortexed and incubated at 40°C for 30 minutes in a water bath. The optical density (OD) was measured at λ = 760 nm, and the polyphenol content was expressed as mg of gallic acid equivalent per gram of fresh material. The calibration range was established in parallel under the same operating conditions using gallic acid. The assay was carried out according to the same protocol used previously for the assay of polyphenols in extracts. The calibration range was obtained in the form of optical density as a function of concentration.

Figure 3 shows the calibration curve for gallic acid standards. Absorbance was measured at 760 nm, and the mean values of three replicates are used, and the graph displays the regression equation and coefficient of determination (R^2) (Figure 3).

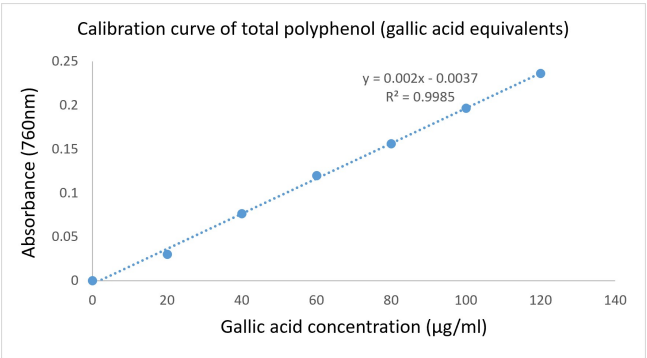

Figure 3. Calibration curve of total phenolic

Hardness index "r"

The hardness index "r" or the ratio of total sugars to water content was used to determine the consistency of the dates: soft, semi-soft and dry dates have an index r of less than 2, between 2 and 3.5 and greater than 3.5 respectively (Munier,

1961). Its calculation is based on the results of measuring total sugars and water content.

Statistical analysis

One-way and two-way ANOVA were used in statistical studies where the homogeneity of variances and normality criteria were satisfied. Welch's ANOVA was used as an alternative to one-way ANOVA when the assumption of homogeneity of variances was violated. The Scheirer–Ray–Hare test was applied as a non-parametric alternative to two-way ANOVA for factorial analysis of non-normally distributed data.

To assess the correlation between infestation rate and biochemical parameters, linear regression analyses were conducted between infestation rate and sugar content, polyphenol content, and water content at the mature stage. We used the coefficient of determination (R^2), the F-statistic, and p-values to assess the models' importance and usefulness. A p-value < 0.05 was used to determine statistical significance.

Statistical analyses were carried out using IBM SPSS Statistics and Microsoft Excel. SPSS was mainly used for ANOVA and regression analyses, while Excel was used to perform additional calculations for the Scheirer–Ray–Hare test (H and p-values) and to generate graphs and regression curves.

Results and Discussion

Results

Infestation rate of date moth in open fields

Infestation rates are higher at the Tmar stage, reaching up to 11.78 ± 8.85% in Errachidia, while remaining below 2% in other areas. In terms of khalal dates, the level of infestation was generally low across almost all areas (Figure 4). Statistical analysis showed that both locality and developmental stage significantly affected the infestation rate (area: F(6,26) = 3.486; partial η^2 = 0.163, p < 0.001; stage: F(1,26) = 94.877, partial η^2 = 0.218, p<0.001; Interaction: F(6,26) = 3.859, partial η^2 = 0.177, p<0.001). The level of infestation also varies according to cultivar and fruit stage. The results obtained at the Tmar stage indicate that the highest rate is for the Khalts (11.33 ± 7.77%), followed by the Bouslikhn cultivar (9.67 ± 5.18%). The lowest rate was for the Maajouna cultivar (3.25 ± 4.60%). As for the Mejhoul and Boufeggous cultivars, they have average rates ranging from 4.8 ± 4.05% to 6.92 ± 3.87%. At the 'Khalal' stage, infestation is generally very low for all cultivars, with rates of between 0% and 0.67 ± 0.94% (Figure 5).

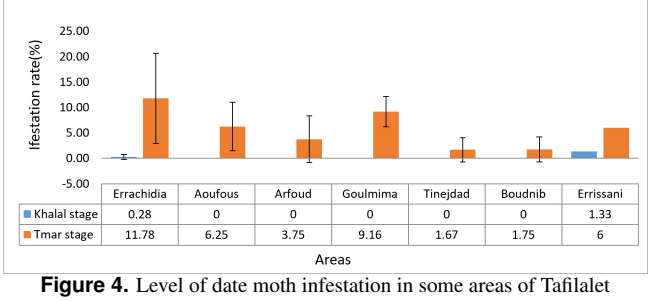

Figure 4. Level of date moth infestation in some areas of Tafilalet

Statistical processing of these results confirmed that the infestation rate by the date moth showed a highly significant difference according to cultivar and fruit stage (cultivar: H = 10.433, df = 4, ε^2 = 0.02, p = 0.034; stage: H = 76.66, df = 1, ε^2 = 0.2, p<0.001; Interaction: H = 10.637, df = 4, ε^2 = 0.005, p = 0.031). A pair-wise comparison of infestation rates revealed that Khalt plants differed significantly from Mejhoul, Boufeggous, and Maajouna cultivars (p<0.001, p = 0.007, and p = 0.033, respectively) (Figures 4 and 5).

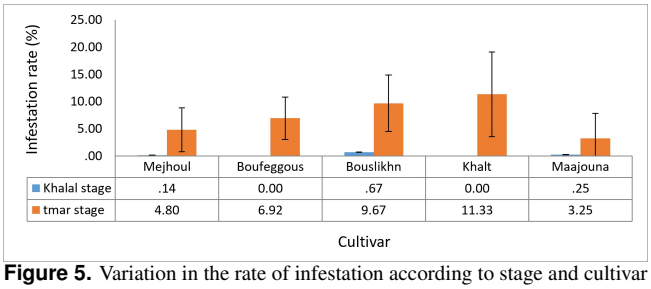

Figure 5. Variation in the rate of infestation according to stage and cultivar

Infestation rate of date moth in warehouses

The infestation rate of stored dates differs significantly from one cultivar to another (F(6,85) = 3.422, η^2 = 0.195, p = 0.004). The most susceptible cultivars are Khalts and Bouslikhn (5 ± 3.01% and 4.44 ± 3.85%), followed by Boufeggous and Mejhoul with moderate infestation rates (from 2.36 ± 3.86% to 3.06 ± 3.92%), whereas Tarzaoua, Laassyane and Rassltmar showed the lowest susceptibility, with rates ranging from 0% to 0.28 ± 0.96% (Figure 6). Post hoc analysis indicates that the cultivars Laassyane, Tarzaoua, and Rassltmar show significant differences with the cultivar Mejhoul (p = 0.017, p = 0.017, and p = 0.05, respectively). The difference is also significant between Khalt dates with Tarzaoua, Laassyane and Rassltmar (p = 0.003, p = 0.002 and p = 0.002 respectively). Bouslikhn also differs from these three cultivars with p-values varying from 0.034 to 0.05. The difference was also significant according to treatment (T) (treated (T) or not with phosphine (NT)) (H = 12.82, df = 1, ε^2 = 0.13, p<0.001), and storage temperature (TS) (T1=4°C, T2= –20°C) did not affect infestation (H = 1.15, df = 1, ε^2 = 0.001, p = 0.284). The interaction of these factors was significant (H = 4.3; df = 1, ε^2 = 0.01, p = 0.04). This is clearly illustrated in Figure 7, which shows reduced infestation levels in storage (0–5%) mainly due to phosphine fumigation.

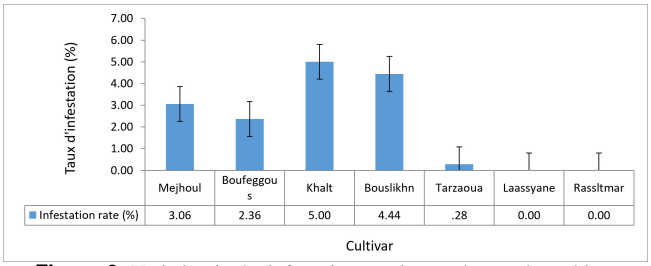

Figure 6. Variation in the infestation rate in warehouses by cultivar

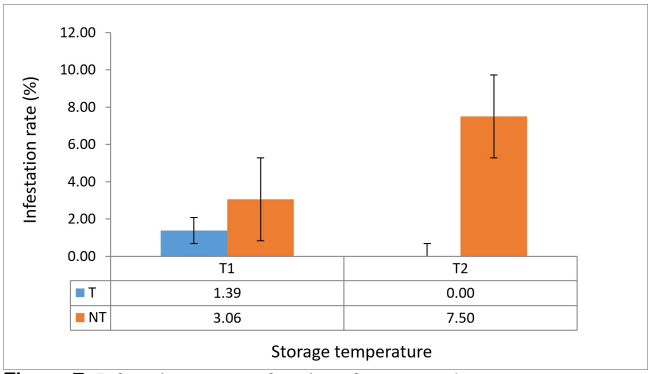

Figure 7. Infestation rate as a function of storage and treatment temperature

Stages of the pest observed

Examinations of sampled dates under both field and storage conditions indicated the existence of eggs, larvae, and pupae of *Ectomyelois ceratoniae* (Figure 8).

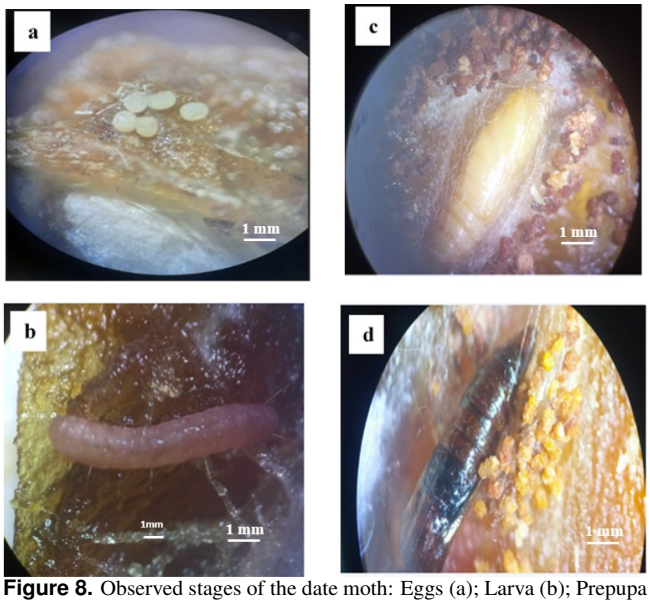

Figure 8. Observed stages of the date moth: Eggs (a); Larva (b); Prepupa (c); Pupa (d) (Personal photos, 2022)

Biochemical analysis

Moisture content of dates harvested from fields

Water content does not vary greatly from one cultivar to another at the Khalal stage (from 77.17 ± 1.64% to 81.39 ± 2.02%). As for the Tmar stage, the margin of difference is quite high: they vary from 9 ± 1.20% to 30.82 ± 1.81% (Figure 9). Statistical analysis shows that there are significant differences between cultivars ($F(4,46) = 6.58$, $\eta^2 = 0.5$, $p<0.001$), stages ($F(1,46) = 2555.26$, $\eta^2 = 0.98$, $p<0.001$) and their interaction ($F(4,46) = 3.96$, $\eta^2 = 0.38$, $p = 0.002$). A pairwise comparison of cultivars revealed significant differences between Maajouna dates and all other cultivars ($p < 0.001$).

Moisture content of dates stored in warehouses

A fluctuation in the water content of stored dates is observed among the cultivars, ranging from 9.49 ± 2.03% for the cultivar 'Rassltmar' to 12.56 ± 1.61% for the cultivar 'Laassyane'.

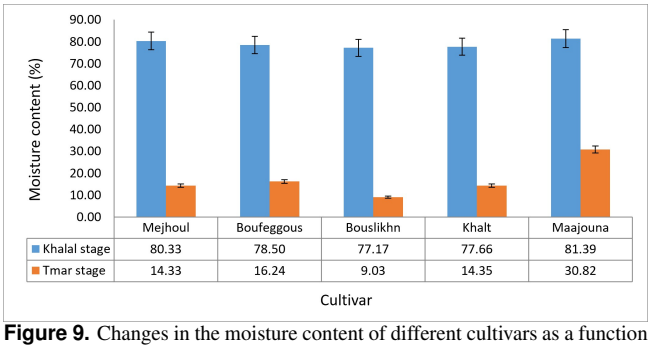

Figure 9. Changes in the moisture content of different cultivars as a function of fruit stage

The 'Boufeggous', 'Bouslikhn' and 'Tarzaoua', 'Mejhoul', and 'Khalt' cultivars have almost equal moisture contents (10.51 ± 1.64% to 11.22 ± 1.64%) (Figure 10). However, the statistical treatment of these data revealed that there was no significant difference between cultivars ($F(6,85) = 1.33$, $\eta^2 = 0.09$, $p=0.252$).

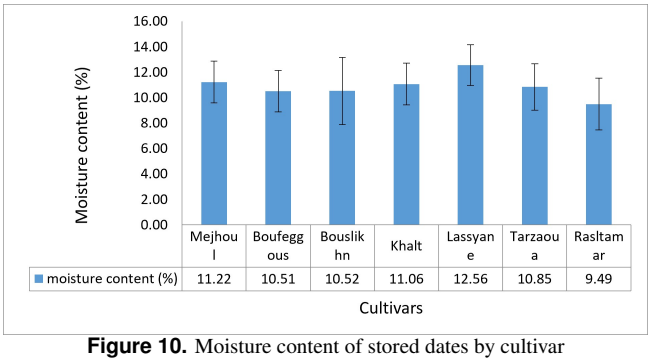

Figure 10. Moisture content of stored dates by cultivar

Total sugar content of dates collected in the fields

The total sugar content of Tmar dates is much higher than that of Khalal dates, whatever the cultivar. It does not vary considerably from one cultivar to another (from 24.42 ± 0.69% to 37.54 ± 2.31% for the Khalal stage and from 69.66 ± 1.98% to 79.39 ± 4.19% for the Tmar stage) (Figure 11). Statistical analysis showed a significant effect of the stage, whereas no significant effects were observed for the cultivar or the stage-cultivar interaction (stage: $H = 35.26$, $df = 1$, $\varepsilon^2 = 0.77$, $p < 0.001$; cultivar: $H = 1.17$, $df = 4$, $\varepsilon^2 \approx 0$, $p = 0.992$; interaction: $H = 8.32$, $df = 4$, $\varepsilon^2 \approx 0$, $p = 0.305$).

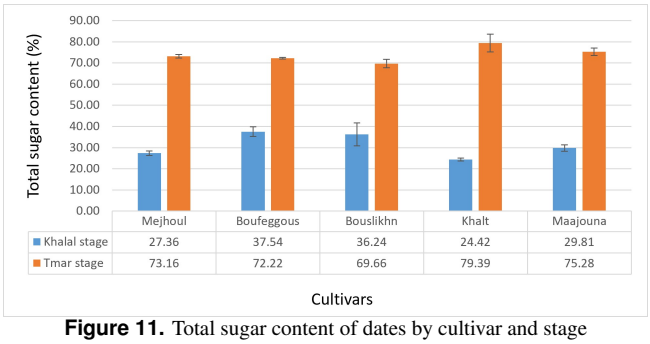

Figure 11. Total sugar content of dates by cultivar and stage

Total sugar content of dates collected in warehouses

The total sugar content does not vary greatly depending on the cultivar (Table 2). This is confirmed by analysis of variance ($F(2,21) = 1.38$; $\eta^2 = 0.12$, $p = 0.273$), which indicates that the difference between cultivars is not significant.

Total phenolic content of dates grown in the field

The total phenolic content of the Mejhoul, Bouslikhn, Khalt and Maajouna cultivars at the khalal stage exceeded that of dates at the Tmar stage, but was low at the khalal stage for the Boufeggous cultivar (Figure 12). Statistical analysis of these data indicates that the fruit stage has a significant influence on the total phenolic content of dates, and cultivar and the interaction were not significant (stage: $H = 35.27$, $df = 1$, $\varepsilon^2 = 0.74$, $p < 0.001$; cultivar: $H = 1.17$, $df = 4$, $\varepsilon^2 \approx 0$, $p = 0.992$; interaction: $H = 8.36$, $df = 4$, $\varepsilon^2 \approx 0$, $p = 0.302$).

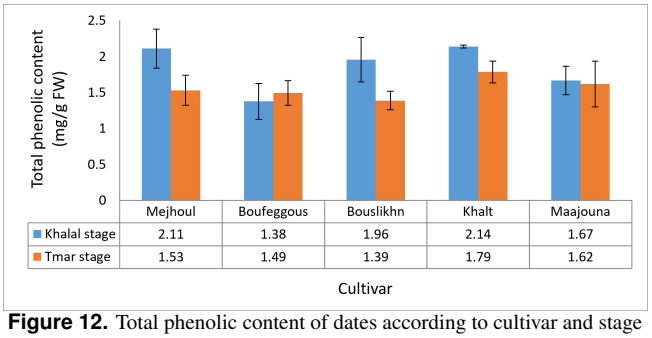

Figure 12. Total phenolic content of dates according to cultivar and stage

Total phenolic content of dates delivered to warehouses

The total phenolic content does not vary greatly across cultivars (Table 2). This is confirmed by analysis of variance using Welch's test ($F(2,21) = 0.85$, $\eta^2 = 0.05$, $p = 0.667$), which indicates that the difference between cultivars is not significant.

Total sugars/water ratio (hardness index)

The total sugar/water ratio or hardness index 'r' fluctuates according to cultivar (Figure 13): the 'Bouslikhn' cultivar has the highest ratio, followed by 'Khalt', 'Mejhoul' and 'Boufeggous'. The cultivar with the lowest ratio is 'Maajouna'. Welch's test for equality of means shows that this difference between cultivars is significant ($F(4,16) = 93.83$, $\eta^2 = 0.98$, $p<0.001$).

Based on the 'r' values, it was found that the dates of all the cultivars studied qualify as dry dates except for the cultivar 'Maajouna' whose dates are semi-soft. These results show that, in addition to sugar content, the water content of dates can influence their vulnerability to attack by the date moth, which favours dates that are high in sugars and low in moisture.

Relationship between infestation rate and biochemical factors

A linear regression analysis indicated a significant correlation between sugar content and infestation rate in the Tmar stage ($F(1,13) = 7.067$, $p = 0.02$), and the sugar content explained 30% of the variation in infestation ($R^2 = 0.352$) (Figure 14).

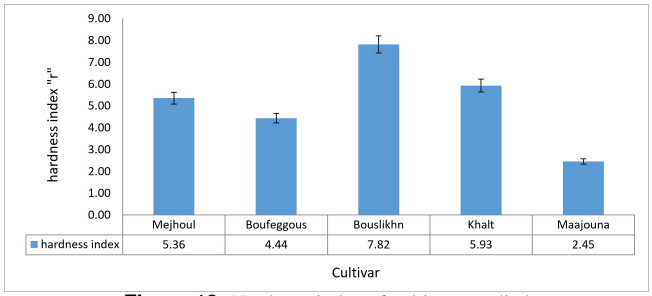

Figure 13. Hardness index of cultivars studied

A similar relationship was observed between total phenolic content and infestation rate, with comparable statistical results ($F(1,13) = 7.14$, $R^2 = 0.355$, $p = 0.019$) (Figure 15). This similarity is due to the very strong linear relationship observed between sugar and polyphenol contents ($F(1,13) = 5389.104$, $R^2 = 0.998$, $p < 0.001$).

A significant relationship was also observed between water content and infestation rate in the Tmar stage ($F(1,13) = 5.189$, $R^2 = 0.285$, $p = 0.04$) (Figure 16).

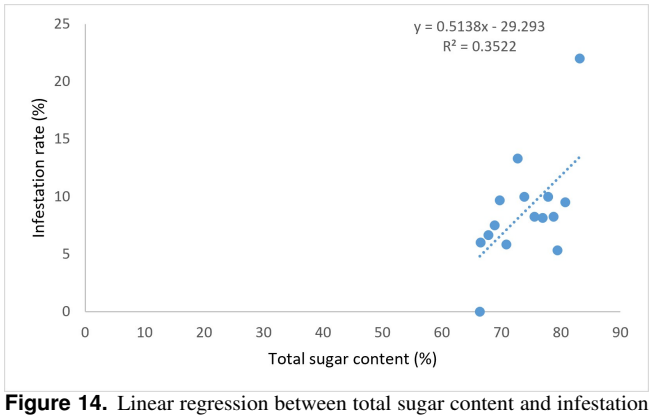

Figure 14. Linear regression between total sugar content and infestation rate in the Tmar stage

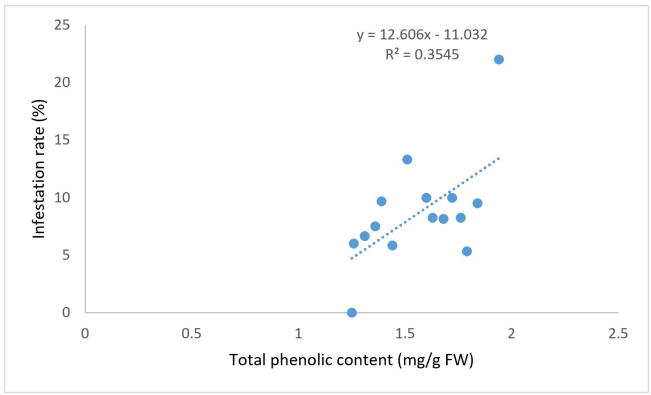

Figure 15. Linear regression between total phenolic content and infestation rate in the Tmar stage

Discussion

Variation in infestation rates was observed among different localities and developmental stages and is further discussed in comparison with previous studies. The infestation rates reported by Bouka et al. (2001) differ from those obtained in the

Table 2. Total sugars and phenolic content in stored date fruits

Cultivar	PC (mg/g MF) (mean ± SD)	SC (%) (mean ± SD)
Mejhoul	1.10 ± 0.08	61.38 ± 11.26
Boufeggous	1.25 ± 0.12	71.58 ± 12.36
Bouslikhn	0.96 ± 0.03	71.89 ± 18.5

Note: Values are expressed as mean ± SD (n=3). PC = total phenolic content; SC = total sugar content; MF = fresh material.

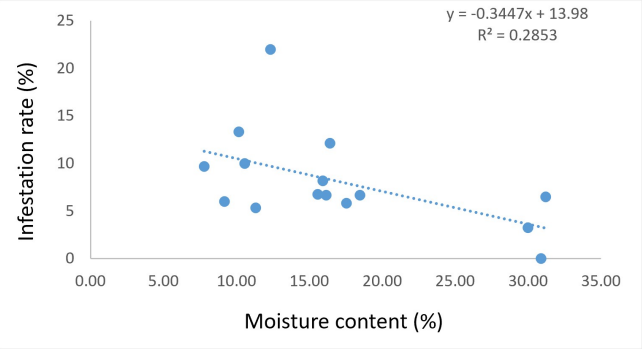

Figure 16. Linear regression between moisture content and infestation rate in the Tmar stage

present study. In their work, the lowest rate was recorded in Errachidia, not exceeding 3%, while the highest rate reached 26.7% in Aoufous. This difference may be due to several factors, such as the humidity generated by the summer rains: low humidity slows down the biological cycle and affects the level of infestation (Bouka et al., 2001). Our estimate of the infestation rate was made during the months of September and October of 2022, a year characterised by a hot, dry summer, which explains the low infestation rates compared with those obtained by Bouka et al. (2001).

The variations in infestation rates observed during this study can be attributed to the biology and behavior of *Ectomyelois ceratoniae*. During the dry season, females may lay their eggs on dates that fell to the ground during the previous season or on fruits in the early stages of development, which can lead to early infestation (Warner et al., 1990). Furthermore, orchard management techniques, such as palm grove maintenance and fruit bagging, have proven effective in significantly reducing infestation rates, highlighting the importance of cultural control methods (Idder et al., 2009; Krid et al., 2017; Roumani, 2020; Zizari and Ichir, 2010). Furthermore, the presence of alternative host plants such as pomegranate and fig trees can enable the pest to survive and reproduce throughout the year, thereby increasing the infestation pressure on date palms (Bouka et al., 2001).

The influence of the cultivar factor on the level of infestation by this pest has also been demonstrated in several date producing countries, including Algeria. Idder et al. (2009) reported that infestation levels of *Ectomyelois ceratoniae* in palm groves in the Ouargla region (south-east Algeria) varies significantly among cultivar. The cultivar 'Takermoust' showed the highest infestation rate, reaching up to 57%, whereas 'Ben-Azizi, Ghars' and 'Tafezouine' were the least susceptible with an infestation rate not exceeding 2–3%. Similarly, a study of the evolution of oviposition by female *E. ceratoniae* under natural conditions carried out by Nadji and Lombarkia (2025) revealed that the level of oviposition varied according to cultivar (Deglet Nour and Ghars) and fruit phenological stage. Differences in infestation rates among cultivars may be associated with several fruit characteristics, including epicarp thickness and ripening period. A thin epicarp facilitates penetration by neonate larvae into the fruit. In addition, early-maturing cultivars may coincide with the peak flight period of the second generation of the moth, thereby increasing the likelihood of infestation (Bouka et al., 2001).

Stored date infestation levels varied with cultivar and treatment conditions, indicating that host characteristics and post-harvest handling affect pest persistence during storage. In the present study, storage temperature did not appear to have a significant effect on level of infestation in the storage conditions observed in this study. These results may be explained by the effective protection measures applied in the field, particularly for dominant commercial cultivars such as Mejhoul and Boufeggous. Protection strategies typically involve agronomic practices such as bunch bagging to prevent moth attacks and the removal of fallen fruits from the plantation floor. Post-harvest pest management continues in storage facilities, where fumigation with phosphine and cold storage are commonly employed. Storage at temperatures around 4°C or –18°C has been shown to be effective in controlling eggs and larvae of the date moth after approximately 24 hours of exposure (Ben-Amor et al., 2019).

Moisture content did not vary among cultivars. However, comparisons with other studies conducted on Moroccan dates suggest that moisture content varies considerably depending on the production region. For instance, studies by Taouda et al. (2014), Elhoumaizi et al. (2023), and Hasnaoui et al. (2011) indicate that the moisture content of dates differs across regions. Elhoumaizi et al. (2023) reported that the moisture content of Mejhoul international dates originating from Jordan, Palestine, USA, and KSA ranged between 23.96% and 25.79%. In contrast, Mejhoul dates from Morocco (Figuig, Bouanane, Boudnib, Rissani, Zagora, Difat Ziz) exhibited higher moisture contents ranging from 31.08% and 35.66%. Similarly, Taouda et al. (2014) reported moisture contents of 26.7% and 27% for the Boufeggous and Bouslikhne cultivars, respectively, which contrasts with the lower values obtained in the present study (16.24% and 9.03%, respec-

tively). Hasnaoui et al. (2011) reported variability in moisture content for the same cultivars grown in different regions in Morocco (Figuig, Drâa and Tafilalet). For the cultivar Assiane, the moisture content in their study was between 10.2% and 14.5%, for Boufeggous it was from 11% to 34% and for Mejhoul it was from 9.3% to 13%. The variation observed suggests that prolonged exposure to high temperatures can enhance evapotranspiration and increase the water demand of the palm, thereby requiring adequate and regular irrigation. In this context, Al-Yahyai and Manickavasagan (2013) reported that under-irrigation (once a week) leads to higher dry matter content, whereas daily irrigation results in increased fruit water content. In addition, salt stress also affects water content and leads to a decrease in water content by slowing down the absorption of water by the roots (Krid, 2022).

Apart from moisture content, total sugar and polyphenol contents were also considered important biochemical characteristics of date fruits. Both parameters varied according to the phenological stage, showing little variation among cultivars. Sugar content increased during fruit maturation whereas polyphenol levels gradually decreased.

The total sugar contents obtained in the present study are in agreement with the results previously reported by Hasnaoui et al. (2010), Taouda et al. (2014), Alhyane et al. (2022), Bouhlali (2018) and Elhoumaizi et al. (2023) for the Mejhoul dates from Morocco and other date-producing countries such as the USA, Saudi Arabia, Palestine and Jordan.

Analysis of date total phenolic contents showed a general decrease in fruit ripening, consistent with the result obtained by Bensayah (2017). However, polyphenol level observed at the Tmar stage differ from those reported by Bouhlali et al. (2017), Ouamnina et al. (2024), and Arif (2021). The difference may be attributed to different types of stress that date palms undergo, which include water stress, thermal stress, salinity, light stress, biotic stress, and chemical toxicity by heavy metals. These factors can trigger the accumulation of polyphenols as secondary metabolites involved in protecting plants against environmental stress (Rao and Zheng, 2025; Šamec et al., 2021). Other factors can add to the stress, such as the growing season and storage temperature (Saafi-Bensalah et al., 2011).

The results of this study showed that as fruit ripening progresses, the total phenolic content and moisture content decreased while the infestation rate and total sugar content increased, suggesting that the levels of these compounds affect the infestation rate. This seems normal given that polyphenols are secondary metabolites that reduce infestation by intervening in the event of biotic and abiotic stress (Zaynab et al., 2018), and sugars are energy metabolites that are essential for the growth and development of living organisms. This relationship between these parameters was demonstrated by the linear regression test, which showed moderately significant correlations between infestation rate and all analyzed biochemical parameters (total sugar content, total phenolic content, and water content), suggesting that these factors influence infestation variability without fully explaining it. The moderate R^2 value shows that sugars, polyphenols, and moisture alone are not enough to accurately predict infestation levels. This shows that other factors are also important, and they are not independent predictors but rather represent a shared biochemical gradient linked to physiological changes in fruit. Consequently, their distinct contributions to infestation remain indistinguishable. The date cultivars studied are mostly dry dates, except for 'Maajouna' which is a semi-soft date. The r-values obtained in this study are higher than those reported by Taouda et al. (2014) who reported 3.10 for Boufeggous, 2.76 for Bouslikhn, 2.90 for Khalts, and 2.70 for Mejhoul. These differences may be related to differences in moisture content and total sugar concentration which are important determinants of fruit texture. In this context, previous studies as Zouioueche (2012) have shown that *Ectomyelois ceratoniae* prefer dates with lower moisture content and higher sugar levels, which could be a reason for the infestation pattern observed in this study. Furthermore, Idder Ighili (2008) reported that this pest preferentially attacks soft to semi-soft dates, and that this preference is more strongly related to high sugar content than to moisture content.

These factors together not only help to explain the observed patterns of infestation but also offer useful information for the improvement of pest management practices. Disparities in infestation levels in developmental stages and storage conditions indicate that both orchard sanitation and post-harvest management practices may influence the persistence of *Ectomyelois ceratoniae*. The removal of infested fruits, good management of palm groves, and appropriate storage practices may be useful in limiting infestation and may thus contribute to integrated pest management strategies.

Conclusion

The present study concluded that infestation by *Ectomyelois ceratoniae* depends on the developmental stage, cultivar, locality, and storage conditions, suggesting that the level of infestation may be related to several factors, including climatic conditions, fruit biochemical characteristics, and pest behavior. Significant differences in levels of infestation were observed, particularly among developmental stages and treatment conditions, indicating that fruit maturity and post-harvest management play an important role in pest development and persistence. Biochemical analyses also indicated that moisture, sugar, and polyphenol contents are associated with fruit maturation and may affect host susceptibility to infestation. In particular, sugar content increased during fruit ripening while polyphenol levels decreased, which may explain differences in infestation risk among stages.

The study points out the ecological role of climatic conditions, orchard maintenance and the presence of alternative host plants for the determination of infestation dynamics. These results underscore the need to include integrated pest management strategies including orchard sanitation, removal of infested fruits, fruit bagging, and proper storage and post-

harvest practices to reduce levels of infestation in the field and warehouse situation. Such measures could help to limit the survival of pests and to reduce the economic losses in date palm production systems.

This work generally contributes to a better understanding of the ecology of *Ectomyelois ceratoniae* and the factors associated with the risk of infestation of date palm groves in Morocco. Additional research is needed to study how environmental conditions and fruit biochemical traits interact to influence pest population dynamics under natural storage and field conditions, to help develop sustainable management strategies. Future studies should also monitor populations using trapping methods to better establish the relationship between insect abundance and infestation rates.

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