



Article

Influence of Some Fruit Traits on Codling Moth (*Cydia pomonella* L.) Preference among Apple Varieties in Two Contrasted Climatic Conditions

Dina Akroute ^{1,2}, Ahmed Douaik ¹ , Khaoula Habbadi ¹ , Ahmed ElBakkali ¹, Abdellatif BenBouazza ¹, Rachid Benkirane ² and Salma El Iraqui El Houssaini ^{1,*}

¹ Regional Center of Agricultural Research of Meknes, National Institute of Agricultural Research, Av. Annasr, Rabat 10000, Morocco

² Laboratory of Plant, Animal and Agro-Industry Productions, Faculty of Sciences, University Ibn Tofail, Kenitra 14000, Morocco

* Correspondence: salma.eliraqui@inra.ma

Abstract: Codling moth, *Cydia pomonella* L., is a major pest of pome fruits and walnuts worldwide. Screening the susceptibility of apple varieties to *C. pomonella* infestation is an important step to develop a sustainable management program against this pest. Therefore, the present study aimed to explore potential correlations between pest damage and several physical (firmness, weight, and diameter), chemical (pH, SSC, and TA), and biochemical (polyphenols) fruit properties collected from two sites with distinctively twelve and seven commercial apple varieties. The study was conducted in two distinct Moroccan regions to highlight whether the traits influencing the insect's preference could be similar for different varieties under contrasted climates. In both regions, results revealed that the pest damage varied significantly across apple varieties as well as between observation dates. The late and medium maturing varieties had similar damage patterns and were heavily attacked compared to early maturing ones. The preferred varieties were Galaxy Gala, Obro Gala, Golden Smoothee, Black Staymen, and Idared, while the least preferred ones were Anna, Dorsett, and Stark Delicious. Some physical and chemical fruit properties seemed to be associated with the insect behavior, in particular, firmness and pH were positively correlated to pest damage. Moreover, the research suggested that infestations might be influenced by diameter, weight, and polyphenol content of fruits.

Keywords: apple varieties; *Cydia pomonella*; preference; physical; chemical and biochemical properties; susceptibility



Citation: Akroute, D.; Douaik, A.; Habbadi, K.; ElBakkali, A.; BenBouazza, A.; Benkirane, R.; El Iraqui El Houssaini, S. Influence of Some Fruit Traits on Codling Moth (*Cydia pomonella* L.) Preference among Apple Varieties in Two Contrasted Climatic Conditions. *Horticulturae* **2023**, *9*, 788. <https://doi.org/10.3390/horticulturae9070788>

Academic Editor: Yuepeng Han

Received: 7 March 2023

Revised: 26 May 2023

Accepted: 28 May 2023

Published: 11 July 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The codling moth, *Cydia pomonella* (L.), is an important pest of pome fruits (apples and pears) and walnuts worldwide [1–4]. Its presence causes substantial economic losses to production and fruits become unmarketable. Several management strategies have been adopted to control *C. pomonella*, but most of them rely on intensive and frequent use of chemical treatments. This approach has led to the development of pest resistance to various groups of insecticides [5–11]. *C. pomonella* is also known for its multivoltine life cycle, which can vary widely from one geographic region to another [12] depending on several factors, mainly temperature, photoperiod, and food availability. A study conducted in Morocco has shown that this pest can have two to four generations per year depending on the prevalent climatic conditions of the season, especially the temperature factor [9]. These facts complicate the control of *C. pomonella*, and thus there is a need to develop alternative and sustainable methods for its management.

Codling moth has a highly evolved relationship with its host plants, expressed through its ability to select suitable hosts for oviposition and larvae development [13]. In fact, its oviposition behavior differs between host plants and varieties, such as pear [14], quince [15],

and walnut [16]. However, experiments suggested that apple varieties are the preferable hosts for codling moth females [17,18] and certain apple varieties might be more susceptible to codling moth infestation than others [19,20]. Moreover, it is reported that codling moth females could rely on physical, biochemical, and phytochemical fruit traits [18] as well as olfactory cues [21] in the selection of egg-laying hosts and adult-feeding preferences. Studies have shown that apple varieties can produce different patterns and amounts of volatile compounds including E, E- α farnesene, an important stimulant implicated in host selection by adults (females) and neonate larvae of codling moth [22–24], which can lead to different levels of susceptibility to *C. pomonella* infestations.

In addition to volatile emissions, the chemical and physical structure of fruits can play a role in pest's infestation as demonstrated in different studies and other insects. Research has shown that the sugar content of apples can affect the behavior of the green apple aphid (*Aphis pomi*) in terms of oviposition [25]. It was also stated that firmness, weight, and fatty acid composition of olives could influence the oviposition of olive fly *Bactrocera oleae* and its selection of olive varieties [26]. Phytochemical composition of fruits can also have a significant effect on the behavior of the pest. Studies revealed that certain secondary metabolites, such as phenols could serve as a crucial defense mechanism against insect development [27–29]. Additionally, it has been demonstrated that these compounds vary substantially between apple varieties and during different stages of fruit development [30–32], which might impact the vulnerability/resistance of some varieties toward pest infestations.

Effective management of codling moth requires an exploration of the relationship between this pest and its host plants, especially apple varieties. To investigate this, our study aimed to screen the susceptibility of different apple varieties to *C. pomonella* infestations by assessing the damage caused by the pest and examining various physical, chemical, and biochemical traits of fruits that could influence its preference in two distinct regions of Morocco. By analyzing the data collected from contrasted climatic conditions, different localities and varieties, we aimed to highlight the factors that contribute to the susceptibility/resistance of apple varieties to *C. pomonella* infestations and verify whether they are the same, which could help in reducing the impact of this pest on apple productions in upstream stages of the apple chain.

2. Materials and Methods

2.1. Study Sites

The research was conducted over the year 2022 and analyzed two apple collections from the National Institute of Agricultural Research (INRA) in Morocco. The first one is located in Lannoceur region (33°41'03" N 4°51'11" W) in the mountains of the Middle Atlas (1350 m asl), which is characterized by cold winters and dry summers with high temperatures (max. 40°; min. −7°). The second one is located in Ain Taoujdade region (33°55'59.9" N −5°12'60.0" W) in the Saïss Plain (500 m asl), which is characterized by a semi-arid Mediterranean climate with hot, dry summers and cool winters (max. 37°; min. 2.8°) (Figures 1 and A1).

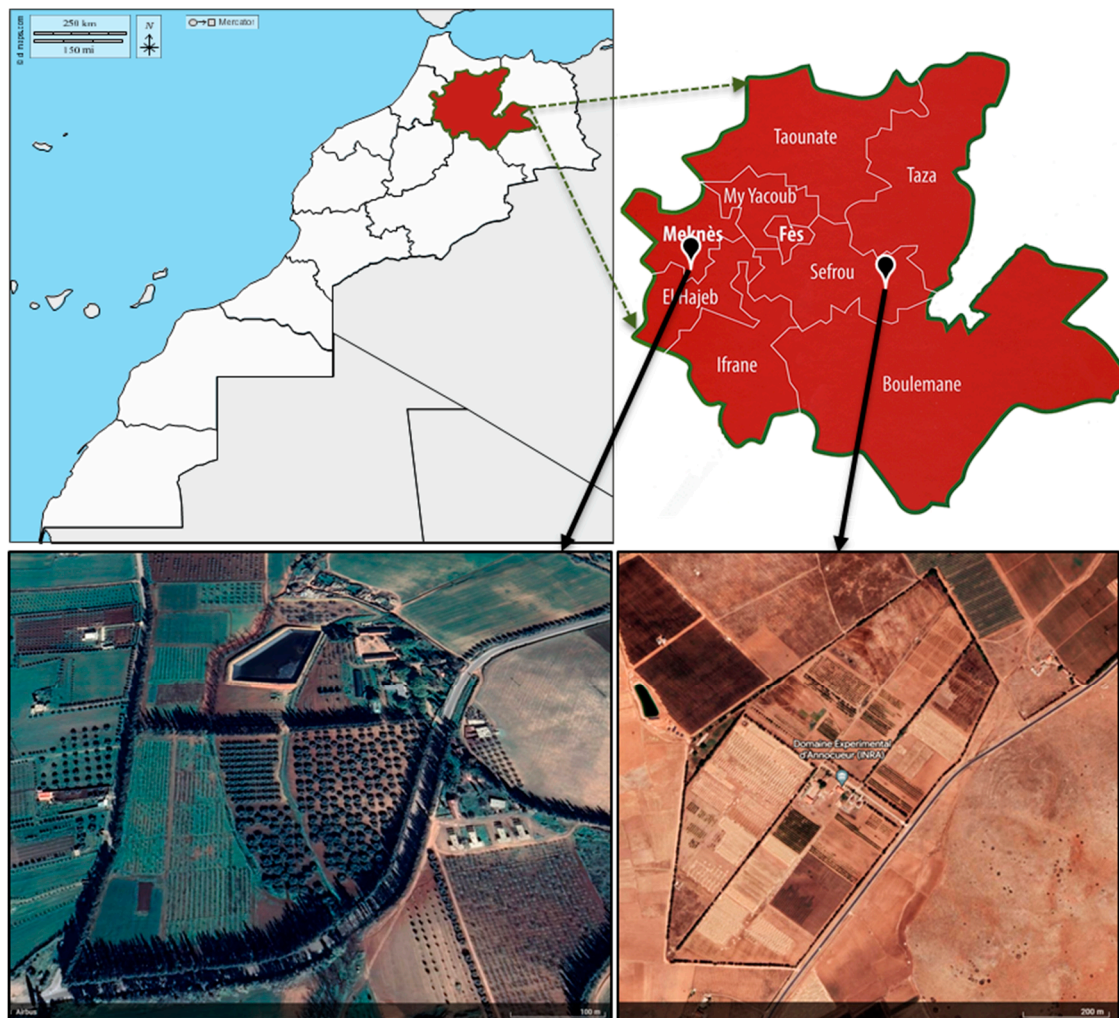


Figure 1. Experimental stations of the National Institute of Agricultural Research. <https://earth.google.com/web> (accessed on 20 February 2023).

2.2. Codling Moth Monitoring

In order to determine the flight dynamic of codling moth adults, pheromone traps were deployed in this study in both experimental stations. Seven traps were placed in Lannoceur on 1 April 2022 and four traps were placed in Ain Taoujdate on 20 April 2022. The lures used for each trap (E8, E10-dodecadienol, Univers Horticole) were changed every 4/6 weeks. The sticky boards were replaced according to the amount of impurities deposited on them. The control of catches was carried out two times per week. When moth catches exceeded the economic threshold level (three males/week), chemical treatments were applied for pest management.

2.3. Insect Damage Assessment

The study focused on two main apple collections. In Lannoceur station, the collection has 12 commercial apple varieties: Red Chief, Stark Delicious, Obro Gala, Brookfield, Early Red One, Washington Spur, Golden Smoother, Cherry Gala, Galaxy Gala, Golden Delicious, Anna and Dorsett. While the apple collection in Ain Taoujdate station contains 7 apple varieties: Vistabella, Ein Sheimmer, Black Stayman, Idared, Stark Delicious, Anna and Dorsett. There are 10 trees/varieties and they are arranged in rows.

Fruit damage assessment was carried out at four sampling dates in Lannoceur station (9 June, 7 July, 1 August, 1 September) and three dates in Ain Taoujdate station (25 May, 26 June, 27 July). The observation dates were scheduled according to the flight dynamic of

C. pomonella adults and different ripening stages of apple fruits. Infestation of fruits was visually assessed for the total of fruits/trees/varieties in both stations. The infestation level was expressed as the percentage of infested apple fruits over the total of examined fruits.

2.4. Fruit Characterization

The characterization of fruits concerned the varieties mentioned above in each collection. Twenty fruits/varieties were randomly handpicked from each sampling station during all observation dates. The sampled fruits were stored in plastic bags at 4 °C until required for physical traits characterization. The determination of chemical and biochemical properties required fruit freeze-drying.

2.4.1. Extract Preparation

Samples extraction was based on adding separately 10 mL of distilled water (for chemical analysis) and 10 mL of ethanol 80% (for biochemical analysis) to 0.5 g of freeze-dried apple powder. The homogenate was then centrifuged for 20 min at 3000× *g*. The supernatants were collected in 10 mL volumetric flasks, sealed tightly, and stored at −20 °C for further analysis.

2.4.2. Physical and Chemical Properties

Fruits samples were weighed and measured. Then, fruit firmness was determined with a penetrometer (Force Gauge; PCE-FM 200; PCE Instruments, Strasbourg, France). Soluble sugar content (SSC), titratable acidity (TA), and pH were systematically measured on apple samples according to AOAC methods and each measurement was performed in triplicate [33]. The SSC content was determined with a portable refractometer (Milwaukee; MA 871; Milwaukee Instruments, Rocky Mount, United States). The TA was determined as grams of malic acid in one liter of apple extract by titration with 0.1 M NaOH.

2.4.3. Biochemical Properties

Total phenolic content (TPC) was determined by means of Folin–Ciocalteu method [34] using gallic acid solution as a standard. Briefly, 40 µL of apple extract was mixed with 3 mL of distilled water, 200 µL of diluted Folin–Ciocalteu reagent, and 600 µL of 20% sodium carbonate. After incubation in the dark for 30 min at 40 °C, the absorbance was measured at 765 nm. The results were expressed as grams of gallic acid equivalent per liter of apple extract (g GAE/L).

2.5. Statistical Analysis

Data were processed with SPSS software to analyze pest damage and fruit characteristics. Analysis of variance (ANOVA) was used to study the significance of difference between varieties, their maturing stages, and observation dates. In the case of significant differences, the Duncan post-hoc test was used to identify groups of similar varieties, maturity stages, or observation dates. The correlation between physicochemical and biochemical characteristics and damage rates was determined by the Pearson correlation coefficient.

3. Results

3.1. Pest Damage Investigation in Both Apple Collections

3.1.1. Lannoceur Station

In Lannoceur station, trap catches attested the massive presence of the insect throughout the campaign and usually exceeded the economic threshold of three males/trap/week (Figure 2).

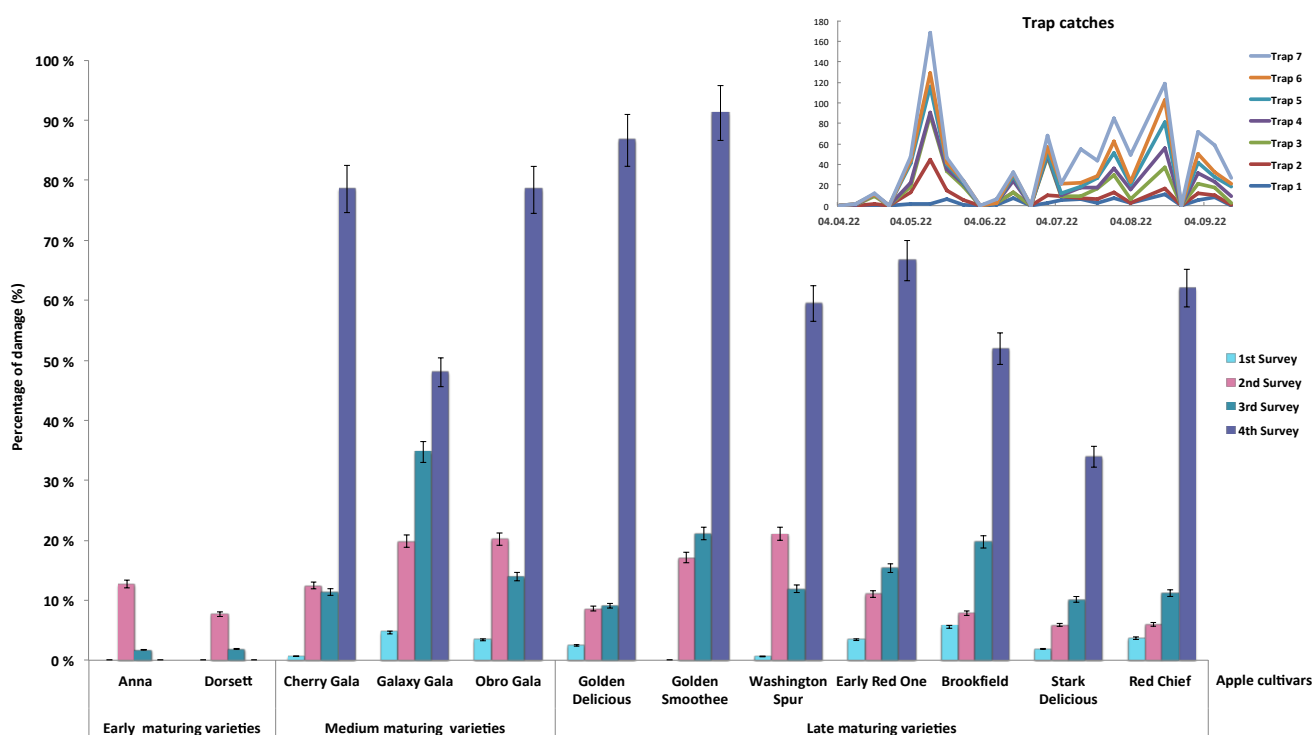


Figure 2. Trap catches and percentage of damaged apples in each sampling date in Lannoceur station (1st survey: 9 June, 2nd: 7 July, 3rd: 1 August, 4th: 1 September) (n = 5 replicates/bar).

The damage rate caused by *C. pomonella* differs significantly among the apple varieties ($p < 0.001$). Moreover, the pest infestations varied considerably between sampling dates ($p < 0.001$) with a noticeable increase in damage rate from one sampling date to another. The maturity factor had not significantly influenced the pest host selection and it was observed that medium and late maturing varieties had similar patterns in terms of pest damage (Table 1). During this campaign, considering all observation dates, the varieties Galaxy Gala, Golden Smoothee, and Obro Gala were distinguished as the most susceptible ones to the pest compared to the other varieties, while early maturing varieties (Anna and Dorsett) were the least damaged. It was also noticed that Stark Delicious showed less susceptibility to *C. pomonella* attacks throughout the season.

Table 1. Analysis of variance (ANOVA) for studied factors at Lannoceur station.

Source	DF	Type III SS	Mean Square	F-Value	Pr > F
Sampling Date	3	16.26316134	5.4205378	310.52	<0.0001
Variety	11	0.89688824	0.08153529	4.67	<0.0001
Maturity	2	0.12535089	0.06267544	5.36	0.0057

In June, the highest damage was observed for the varieties Brookfield (6%) and Galaxy Gala (5%), while the varieties Golden Smoothee, Anna and Dorsett were not infested (Figure 2). In July, the most infested varieties were Washington Spur (21%), Galaxy Gala (20%), and Obro Gala (19.80%) and the less infested ones were Stark Delicious (6%) and Red Chief (5.91%) varieties. Observations on the third survey date (August) showed that the most attacked fruits were observed for the varieties Galaxy Gala (35%), Golden Smoothee (21%), and Brookfield (20%), whereas fruits of the early maturing varieties (Anna and Dorsett), Golden Delicious (9%), and Stark Delicious (10%) were the least damaged. In the last date of prospection (September), most of the varieties were remarkably attacked by the pest. The varieties Golden Smoothee, Golden Delicious, and Obro Gala recorded the

highest damage rates (91%, 87%, and 78%, respectively), while the variety Stark Delicious recorded the lowest infestations (34%).

Based on Duncan's test classification, apple varieties could be categorized into three clusters according to the intensity of damage caused by *C. pomonella*: Highly attacked varieties with Obro Gala, Galaxy Gala, and Golden Smoothee; moderately attacked ones with Golden Delicious, Early Red One, Washington Spur, Cherry Gala, and Brookfield; and the less attacked group with the varieties Stark Delicious, Red Chief, Anna and Dorsett (Table A1).

3.1.2. Ain Taoujdate Station

Similarly to the first site, at Ain Taoujdate station, the population of *C. pomonella* was abundant and trap catches exceeded the economic threshold of three males/trap/week (Figure 3). The damage caused by *C. pomonella* varied significantly across apple varieties ($p < 0.001$) as well as between observation dates ($p < 0.001$) (Table 2). The varieties Idared and Black Stayman were the most attacked by codling moth during the campaign (considering the three survey dates). Conversely, the early maturing variety Anna was distinctively not infested by the pest throughout the campaign. In May, the fruits of Stark Delicious were not available (not fully developed) for damage inspection, which led to the absence of data in this date. During this survey, the early maturing varieties had lower infestation rates compared to the other varieties, notably Black Stayman and Idared; although among this group, Vistabella and Ein Sheimmer were the most infested. In June, the variety Black Stayman was the most infested across all varieties of the collection. Meanwhile, during this survey, Vistabella recorded the highest damage rate among the early maturing varieties group and was similarly attacked as Idared and Stark Delicious. In the last observation occurring in July, the damage rate increased significantly for the varieties Idared (90%), Ein Sheimmer (50%), and Dorsett (40%), recording the highest rates (Figure 3).

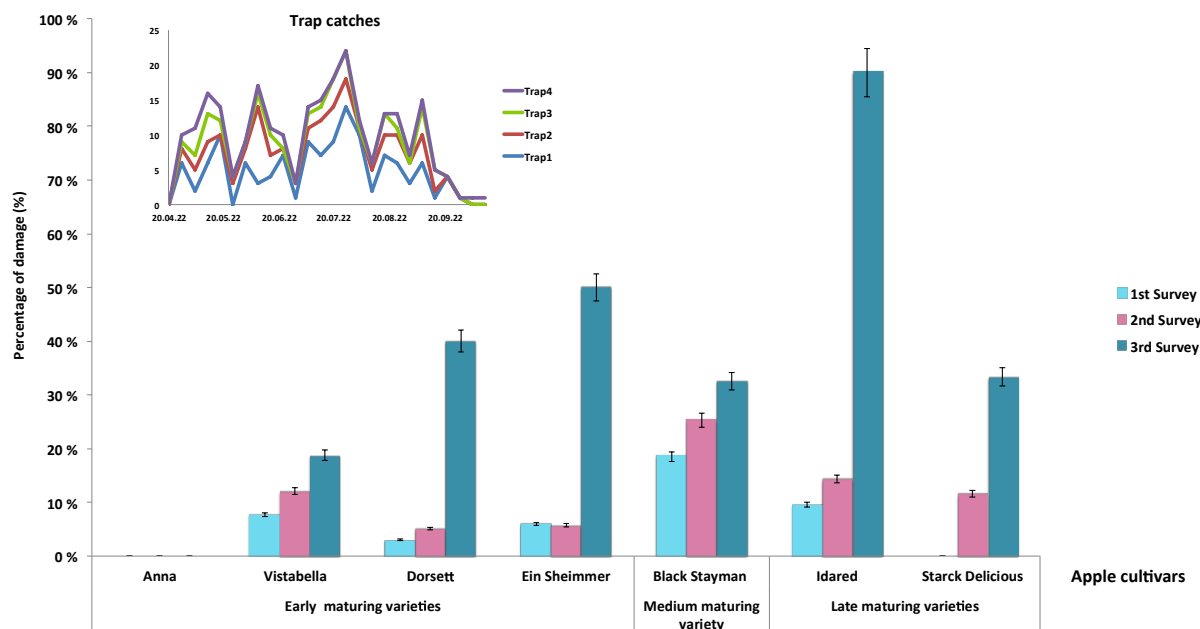


Figure 3. Trap catches and percentage of damaged apples in the three sampling dates in Ain Taoujdate station (1st survey: 25 May, 2nd: 26 June, 3rd: 27 July) (n = 5 replicates/bar).

According to the intensity of pest damage in all sampling dates, the studied varieties could be categorized into the highly susceptible varieties group represented by Idared and Black Stayman, and the moderately attacked varieties with Stark Delicious, Ein Sheimmer, Vistabella, and Dorsett. Finally, the variety Anna can be qualified as the less susceptible variety in the collection (Table A2).

Table 2. Analysis of variance (ANOVA) for studied factors at Ain Taoujdate station.

Source	DF	Type III SS	Mean Square	F-Value	Pr > F
Sampling Date	2	0.56046308	0.28023154	56.70	<0.0001
Variety	8	1.29831612	0.16228951	13.88	<0.0001
Maturity	2	0.18160597	0.09080298	18.37	<0.0001

3.2. Physicochemical and Biochemical Characteristics of Fruits and Percentage of Damaged Apples

3.2.1. Lannoceur Station

On each sampling date, fruits were characterized based on their physical traits (firmness, weight, and diameter), chemical properties (pH, SSC, and TA), and biochemical parameters (polyphenols) and were correlated to pest damage to exhibit the factors influencing varieties preference (Table 3).

Table 3. Average values of physicochemical and biochemical parameters and percentage of damaged apples in Lannoceur station during four sampling dates (June, July, August, and September).

Varieties	Sampling Dates	Damage %	Weight (g)	Diameter (mm)	Firmness (kg/cm ²)	SSC (°Brix)	pH	TA (g/L)	TPC (g/L)
Anna	9 June	0% ± 0.0	43.3 ± 3.6	43.0 ± 3.6	8.6 ± 0.5	10.4 ± 0.5	3.3 ± 0.1	9.0 ± 1.6	38.9 ± 5.9
	7 July	13% ± 0.1	133.2 ± 20.3	66.4 ± 4.6	5.8 ± 0.5	11.7 ± 1.1	3.4 ± 0.1	6.5 ± 0.8	13.9 ± 3.3
	1 August	2% ± 0.0	141.9 ± 30.7	69.0 ± 6.1	5.1 ± 1.0	15.6 ± 2.6	3.6 ± 0.1	4.8 ± 0.9	18.4 ± 4.1
	1 September	-	-	-	-	-	-	-	-
Brookfield	9 June	6% ± 0.0	20.9 ± 5.8	35.4 ± 4.2	8.4 ± 1.5	8.9 ± 1.0	3.5 ± 0.0	7.5 ± 0.5	61.0 ± 6.1
	7 July	8% ± 0.0	54.1 ± 10.5	48.0 ± 4.9	7.6 ± 0.5	8.8 ± 0.5	3.6 ± 0.1	5.3 ± 0.5	28.5 ± 7.1
	1 August	20% ± 0.1	91.4 ± 32.5	58.1 ± 8.7	7.2 ± 0.6	11.0 ± 1.1	3.8 ± 0.1	3.8 ± 0.1	29.1 ± 2.1
	1 September	52% ± 0.2	127.4 ± 28.0	68.1 ± 4.1	6.4 ± 0.9	15.0 ± 0.9	3.7 ± 0.1	4.0 ± 0.1	21.0 ± 4.6
Cherry Gala	9 June	1.4% ± 0.0	13.2 ± 5.1	28.9 ± 4.7	8.5 ± 1.1	9.5 ± 0.8	3.4 ± 0.1	9.4 ± 2.3	68.8 ± 1.0
	7 July	12% ± 0.1	38.3 ± 10.0	43.3 ± 4.7	7.0 ± 0.5	8.8 ± 0.1	3.5 ± 0.1	7.5 ± 0.9	29.8 ± 3.7
	1 August	11% ± 0.1	65.7 ± 10.7	53.6 ± 3.0	7.4 ± 0.9	11.7 ± 0.4	3.7 ± 0.1	5.5 ± 0.2	21.3 ± 0.7
	1 September	79% ± 0.2	98.0 ± 16.1	67.4 ± 14.5	6.3 ± 0.6	13.7 ± 1.3	3.6 ± 0.1	3.8 ± 0.3	15.7 ± 4.2
Dorsett	9 June	0% ± 0.0	57.8 ± 21.0	50.4 ± 6.4	8.5 ± 0.8	11.3 ± 0.9	3.3 ± 0.1	6.6 ± 1.1	101.0 ± 6.6
	7 July	8% ± 0.0	104.7 ± 30.1	62.8 ± 7.7	6.6 ± 0.8	13.4 ± 2.4	3.4 ± 0.1	7.0 ± 0.8	14.0 ± 4.7
	1 August	2% ± 0.0	84.8 ± 30.7	59.2 ± 7.5	5.6 ± 1.4	12.1 ± 3.7	3.7 ± 0.1	4.5 ± 0.9	11.7 ± 3.5
	1 September	-	-	-	-	-	-	-	-
Early Red One	9 June	3% ± 0.0	25.1 ± 5.6	36.4 ± 3.4	10.4 ± 0.5	9.5 ± 0.5	3.5 ± 0.1	6.0 ± 0.8	70.7 ± 5.7
	7 July	11% ± 0.1	63.8 ± 11.6	50.7 ± 3.5	7.2 ± 0.4	8.4 ± 0.5	3.7 ± 0.1	4.9 ± 0.6	44.5 ± 3.3
	1 August	15% ± 0.1	94.7 ± 17.9	60.4 ± 4.1	7.3 ± 0.8	10.2 ± 0.6	3.9 ± 0.1	3.6 ± 0.2	38.4 ± 2.1
	1 September	67% ± 0.3	130.8 ± 22.6	67.6 ± 4.6	6.5 ± 0.4	12.2 ± 1.7	3.8 ± 0.1	3.9 ± 0.2	23.3 ± 3.1
Galaxy Gala	9 June	5% ± 0.0	12.8 ± 7.1	29.4 ± 6.1	9.0 ± 1.6	9.7 ± 1.0	3.5 ± 0.1	7.2 ± 0.3	67.6 ± 2.8
	7 July	20% ± 0.1	62.5 ± 13.8	51.1 ± 4.8	8.0 ± 1.4	10.0 ± 0.5	3.6 ± 0.1	5.0 ± 1.0	25.3 ± 2.9
	1 August	35% ± 0.2	77.0 ± 15.1	54.9 ± 4.0	9.0 ± 0.7	12.9 ± 1.6	3.9 ± 0.1	3.6 ± 0.3	25.2 ± 2.1
	1 September	48% ± 0.1	111.7 ± 14.6	64.3 ± 3.5	6.8 ± 1.0	16.5 ± 1.4	3.8 ± 0.1	3.8 ± 0.1	24.2 ± 1.0
Golden Delicious	9 June	2% ± 0.0	11.7 ± 4.2	27.8 ± 3.4	7.0 ± 0.9	9.4 ± 0.5	3.3 ± 0.1	9.5 ± 1.1	67.8 ± 4.8
	7 July	9% ± 0.1	37.9 ± 7.5	42.8 ± 3.0	8.2 ± 0.8	9.3 ± 0.5	3.4 ± 0.1	7.4 ± 1.0	34.3 ± 0.8
	1 August	10% ± 0.1	61.4 ± 13.9	51.9 ± 4.1	6.9 ± 0.7	11.0 ± 0.8	3.7 ± 0.1	4.8 ± 0.6	27.5 ± 2.8
	1 September	87% ± 0.1	102.1 ± 25.3	62.1 ± 5.2	5.71 ± 0.5	12.6 ± 1.1	3.5 ± 0.1	4.7 ± 0.5	12.8 ± 2.7
Golden Smoothee	9 June	0% ± 0.0	15.3 ± 2.4	30.5 ± 1.7	10.9 ± 0.6	10.0 ± 0.5	3.3 ± 0.1	10.2 ± 1.1	69.9 ± 1.7
	7 July	17% ± 0.1	51.3 ± 9.9	47.6 ± 2.9	7.0 ± 0.6	9.4 ± 0.7	3.5 ± 0.1	7.7 ± 0.8	31.2 ± 1.3
	1 August	21% ± 0.0	75.0 ± 24.1	54.9 ± 6.4	7.3 ± 0.8	11.8 ± 0.9	3.7 ± 0.1	5.7 ± 0.6	27.5 ± 2.8
	1 September	91% ± 0.1	126.9 ± 12.1	66.4 ± 2.5	5.9 ± 0.5	14.0 ± 1.4	3.6 ± 0.1	3.9 ± 0.2	14.0 ± 1.7
Obro Gala	9 June	3.2% ± 0.0	14.5 ± 6.6	29.8 ± 4.8	11.5 ± 2.2	9.3 ± 1.1	3.5 ± 0.1	7.3 ± 0.5	99.4 ± 3.9
	7 July	20% ± 0.1	71.6 ± 10.2	47.3 ± 3.4	9.5 ± 0.9	9.2 ± 0.7	3.7 ± 0.1	5.9 ± 1.2	27.0 ± 3.5
	1 August	14% ± 0.1	73.6 ± 19.7	55.7 ± 5.0	7.3 ± 1.2	11.4 ± 0.9	3.7 ± 0.1	5.0 ± 0.1	24.0 ± 4.0
	1 September	78% ± 0.1	131.9 ± 32.0	67.1 ± 5.3	6.5 ± 0.5	15.2 ± 1.1	3.7 ± 0.1	3.6 ± 0.2	16.7 ± 1.5
Red Chief	9 June	4% ± 0.0	20.6 ± 6.2	33.1 ± 4.8	8.3 ± 2.2	10.2 ± 1.1	3.4 ± 0.1	7.5 ± 0.5	73.9 ± 4.8
	7 July	6% ± 0.0	62.3 ± 1.7	50.3 ± 4.7	7.6 ± 0.8	7.9 ± 0.9	3.6 ± 0.1	4.6 ± 0.3	48.0 ± 3.3
	1 August	11% ± 0.1	97.6 ± 3.9	61.1 ± 7.5	7.1 ± 0.6	10.2 ± 1.4	3.9 ± 0.1	3.4 ± 0.4	47.0 ± 7.1
	1 September	62% ± 0.2	121.5 ± 40.5	66.0 ± 8.1	6.0 ± 0.6	12.5 ± 1.1	4.0 ± 0.1	3.4 ± 0.1	26.1 ± 1.9

Table 3. Cont.

Varieties	Sampling Dates	Damage %	Weight (g)	Diameter (mm)	Firmness (kg/cm ²)	SSC (°Brix)	pH	TA (g/L)	TPC (g/L)
Stark Delicious	9 June	2% ± 0.0	20.2 ± 4.9	34.0 ± 3.1	10.5 ± 0.6	9.6 ± 0.7	3.5 ± 0.1	6.1 ± 0.8	71.4 ± 4.3
	7 July	5.4% ± 0.0	64.8 ± 22.9	52.5 ± 7.3	8.4 ± 0.6	7.9 ± 0.7	3.7 ± 0.1	4.4 ± 0.5	65.7 ± 4.2
	1 August	10% ± 0.1	90.8 ± 24.8	60.1 ± 5.8	7.1 ± 0.8	10.0 ± 0.9	3.9 ± 0.1	3.0 ± 0.2	37.5 ± 4.4
	1 September	34% ± 0.2	127.2 ± 18.7	67.6 ± 3.9	6.3 ± 0.6	12.7 ± 1.0	3.9 ± 0.1	3.0 ± 0.1	22.1 ± 6.3
Washington Spur	9 June	1% ± 0.0	21.0 ± 4.0	34.2 ± 2.4	10.6 ± 0.9	9.4 ± 0.4	3.5 ± 0.1	4.6 ± 2.8	71.6 ± 7.0
	7 July	21% ± 0.1	51.9 ± 11.3	48.6 ± 3.7	7.7 ± 1.3	7.8 ± 0.6	3.7 ± 0.1	5.0 ± 1.1	52.0 ± 4.0
	1 August	12% ± 0.1	84.7 ± 19.0	58.3 ± 5.0	7.0 ± 0.6	10.6 ± 1.9	3.9 ± 0.1	4.6 ± 0.3	42.9 ± 4.9
	1 September	59.1% ± 0.1	160.8 ± 30.0	73.7 ± 4.6	5.6 ± 0.6	11.8 ± 1.5	3.9 ± 0.1	2.6 ± 1.0	33.3 ± 1.9

SSC: Soluble sugar content, TA: Titratable acidity, TPC: Total polyphenol content.

During this campaign, early maturing varieties (Anna and Dorsett) were particularly recognized by their large and high weight fruits (an average of 106.1 and 82.5 g, respectively). Relatively, they were the least damaged compared to the other varieties until the first of August, which generally corresponds to their last ripening stage. In contrast, the lowest weights were recorded for the varieties Cherry Gala and Golden Delicious (average of 53.8 and 35.3 g, respectively).

Fruit firmness generally decreased from one sampling date to another as the apples ripened. Throughout the campaign, measurements showed that the firmest varieties were Obro Gala and Galaxy Gala, particularly toward the end of the season. In the first survey, the least firm variety was Golden Delicious, while in the second and third surveys, the least firm ones were Anna and Dorsett. During the third inspection in August, Obro Gala, Galaxy Gala, and Golden Smoothee, being the firmest varieties, recorded the highest damage rates.

Chemical and biochemical traits (pH, SSC, and TA) varied markedly among the different apple varieties and during all prospection dates. In the first periods of sampling, high levels of sweetness content were measured for the varieties Dorsett and Anna. In the later periods, in August/September, the sweetest fruits were the varieties Galaxy Gala and Obro Gala.

On the other hand, the varieties Anna, Golden Delicious, and Golden Smoothee were the most acidic (lowest pH) and recorded the highest content of malic acid during June, July, and August. These varieties were the least infested by the pest during the first survey conducted in June.

The concentration of phenolic compounds differed remarkably between the apple varieties during all sampling dates. It was noticed that the concentration of polyphenols decreased as the apples matured. During the first survey, total phenolic content was elevated for the whole varieties studied, with Dorsett and Obro Gala mainly recording the highest levels (100.9 and 99.4 g/L, respectively). In the second survey, the variety Stark Delicious showed the highest total phenolic content value of 65.7 g/L among the sampled fruits. In the later periods, the highest values of phenolic content were found for Washington Spur and Red Chief.

3.2.2. Ain Taoujdate Station

Data on the measurements of fruit properties collected from Ain Taoujdate station are represented in Table 4. In contrast to previous measurements undertaken in Lannoceur station, physicochemical and biochemical traits of fruits changed remarkably according to the different maturity stages of varieties.

During the three sampling dates, the variety Anna had the largest fruits among the studied varieties and recorded the least damage rates. On the other hand, Idared, which was the most attacked, had the lowest fruit weight and diameter compared to the other varieties.

In the first survey, the firmest varieties were Vistabella, Idared, and Black Stayman. In June, these varieties remained the firmest along with Stark Delicious. In the last observation date, Idared was the firmest variety (8.0 kg/cm²) and the most infested one (90%).

Table 4. Average values of physicochemical and biochemical parameters and percentage of damaged apples in Ain Taoujdate station during three sampling dates (May, June, and July).

Varieties	Sampling Dates	Damage %	Weight (g)	Diameter (mm)	Firmness (kg/cm ²)	SSC (°Brix)	pH	TA (g/L)	TPC (g/L)
Anna	25 May	0.0% ± 0.0	72.2 ± 28.2	50.0 ± 8.2	7.0 ± 1.0	9.6 ± 0.3	3.3 ± 0.1	8.8 ± 2.0	48.6 ± 1.2
	22 June	0.0% ± 0.0	127.2 ± 26.8	64.5 ± 6.0	5.1 ± 0.8	12.3 ± 2.2	3.5 ± 0.1	6.9 ± 1.0	24.8 ± 3.0
	26 July	0.0% ± 0.0	125.6 ± 25.8	54.7 ± 6.2	5.9 ± 0.3	14.8 ± 0.1	3.6 ± 0.1	5.2 ± 1.0	19.0 ± 2.7
Black Stayman	25 May	19% ± 0.1	40.0 ± 13.6	43.4 ± 5.4	8.6 ± 1.3	10.6 ± 1.0	3.3 ± 0.1	12.5 ± 3.9	48.5 ± 0.3
	22 June	25% ± 0.2	75.6 ± 21.5	55.8 ± 6.3	6.7 ± 0.7	13.5 ± 1.1	3.4 ± 0.3	8.1 ± 0.4	33.5 ± 5.1
	26 July	33% ± 0.1	74.0 ± 26.3	55.8 ± 7.8	4.9 ± 0.7	17.2 ± 1.2	3.5 ± 0.1	4.9 ± 0.2	25.2 ± 3.2
Dorsett	25 May	3% ± 0.0	61.8 ± 23.2	50.1 ± 6.4	7.5 ± 0.9	10.4 ± 1.1	3.4 ± 0.1	6.8 ± 1.1	30.5 ± 0.6
	22 June	5.6% ± 0.0	112.7 ± 22.4	61.8 ± 4.0	6.0 ± 1.1	12.6 ± 0.7	3.6 ± 0.1	5.8 ± 0.7	26.3 ± 3.7
	26 July	40% ± 0.1	60.7 ± 31.6	43.3 ± 23.2	5.3 ± 0.3	17.9 ± 0.2	4.0 ± 0.1	4.3 ± 0.2	17.3 ± 10.1
Ein Sheimmer	25 May	5.8% ± 0.0	47.1 ± 21.0	45.6 ± 7.2	7.7 ± 1.0	10.0 ± 1.1	3.3 ± 0.1	10.4 ± 1.2	57.2 ± 8.1
	22 June	9.4% ± 0.0	72.6 ± 22.2	53.9 ± 5.8	6.0 ± 1.3	12.9 ± 1.4	3.3 ± 0.1	7.7 ± 1.1	21.5 ± 1.7
	26 July	50% ± 0.1	78.4 ± 28.2	55.5 ± 7.7	5.6 ± 1.0	17.3 ± 1.0	3.5 ± 0.1	4.7 ± 2.1	19.5 ± 2.6
Idared	25 May	9.5% ± 0.1	22.6 ± 7.1	36.4 ± 3.6	9.2 ± 0.7	9.7 ± 1.1	3.4 ± 0.1	9.5 ± 0.4	65.2 ± 6.3
	22 June	14.3% ± 0.2	29.9 ± 17.1	40.0 ± 9.5	6.8 ± 0.6	12.9 ± 1.0	3.4 ± 0.1	7.3 ± 0.4	49.4 ± 3.1
	26 July	90% ± 0.1	45.8 ± 18.1	39.7 ± 9.4	8.0 ± 0.8	18.0 ± 2.1	3.5 ± 0.1	6.5 ± 0.5	38.8 ± 3.7
Stark Delicious	25 May	-	-	-	-	-	-	-	-
	22 June	12% ± 0.2	23.9 ± 9.9	36.9 ± 5.7	7.3 ± 0.4	7.2 ± 0.7	3.8 ± 0.1	8.1 ± 2.4	74.9 ± 3.1
	26 July	33% ± 0.1	55.4 ± 16.1	49.7 ± 5.3	7.8 ± 0.9	13.2 ± 1.9	3.9 ± 0.1	6.7 ± 1.6	42.0 ± 3.2
Vistabella	25 May	7.9% ± 0.1	23.7 ± 10.9	36.2 ± 5.7	10.7 ± 0.4	9.0 ± 0.3	3.3 ± 0.1	12.2 ± 1.8	79.5 ± 1.6
	22 June	11.7% ± 0.1	41.9 ± 15.4	45.6 ± 7.3	7.6 ± 0.4	12.5 ± 0.8	3.5 ± 0.1	6.6 ± 0.4	45.3 ± 5.9
	26 July	18.8% ± 0.1	53.3 ± 20.8	49.6 ± 6.3	5.7 ± 1.4	19.0 ± 1.1	4.0 ± 0.1	4.0 ± 1.1	43.3 ± 4.4

SSC: Soluble sugar content, TA: Titratable acidity, TPC: Total polyphenol content.

The sweetness level changed between the apple varieties depending on the sampling dates. During May and June, the highest soluble sugar content was found in the varieties Ein Sheimmer and Black Stayman. However, in July, the sweetest varieties were Vistabella, Idared, and Dorsett.

During the first sampling date, the varieties Anna, Vistabella, and Ein Shiemmer had the most acidic fruits and recorded the highest values of malic acid content. These varieties were the least attacked in this date. In the later periods, in June and July, the most acidic fruits and the highest titratable acidity values were recorded for the varieties Idared and Black Stayman.

Similarly to Lannoceur station measurements in the first survey, most of the varieties showed elevated levels of phenolic content. The variety Vistabella displayed the highest phenolic content (79.5 g/L) in this date. In the later periods, in June and July, Stark Delicious and Vistabella recorded the highest phenolic content among the other varieties.

3.3. Correlation between Fruit Traits and Pest Damage

In both locations, correlations between the studied parameters and pest damage were analyzed to exhibit the factors influencing the insect's preference toward apple varieties (Table 5). In the initial survey, conducted in June at Lannoceur and May at Ain Taoujdate stations, it was observed that the pH parameter was positively correlated with pest damage (0.645 * and 0.682 *, respectively). Similarly, in the third survey conducted in late July/early August, it was found that fruit firmness was positively correlated with pest damage in both sites (0.788 ** and 0.613 * for Lannoceur and Ain Taoujdate stations, respectively). Interestingly, in Ain Taoujdate, the survey conducted in July showed a negative correlation between pest damage and fruit weight and diameter (−0.680 * and −0.663 *, respectively).

Table 5. Correlations between measured parameters and pest damage.

	Lannoceur Station				Ain Taoujdate Station		
	Damage% 6 June	Damage% 7 July	Damage% 1 August	Damage% 1 September	Damage% 25 May	Damage% 22 June	Damage% 26 July
Weight (g)	−0.344	−0.069	−0.356	−0.084	−0.551	−0.501	−0.680 *
Diameter (mm)	−0.272	−0.135	−0.462	0.121	−0.470	−0.388	−0.663 *
Firmness (kg/cm ²)	0.021	0.272	0.788 **	−0.205	0.474	0.423	0.613 *
SSC (Brix%)	−0.482	−0.017	−0.008	0.439	0.199	0.362	0.236
pH	0.645 *	0.137	0.406	−0.445	0.682 *	−0.507	−0.184
TA (g/L)	−0.334	0.151	−0.137	0.362	−0.445	−0.538	−0.189
TPC (g GAE/L)	−0.019	−0.012	0.032	−0.447	0.173	0.088	0.640

SSC: Soluble sugar content, TA: Titratable acidity, TPC: Total polyphenol content. *: Significant, at the 5% level, correlation between the studied parameters and damage rate. **: Highly significant, at the 1% level, correlation between the studied parameters and damage rate.

4. Discussion

In the present study, we investigated the susceptibility of different apple varieties to *C. pomonella* in two different regions. Fruit inspections were programmed according to fruit maturity stages and the presence of the insect whose abundance was recorded throughout trap catches. Furthermore, pest damage was correlated to several fruit traits: Physical (weight, diameter, and firmness), chemical (SSC, pH, and TA), and biochemical (TPC) to potentially understand the host preferences of *C. pomonella*. Our study aimed to demonstrate possible differences between apple varieties in terms of *C. pomonella* infestation as mentioned for this insect among the walnut varieties [16] and some insects in other cultures, such as in the case of *Prays oleae* Bern. and *Bactrocera oleae* toward olive [35–37], *Ceratitidis capitata* on grapes [38], and *Bactrocera cucurbitae* on melon fruits [39]. Two regions and different varieties were considered in our investigations to highlight whether *C. pomonella* preferences could be attributed to similar fruit traits even under different climatic conditions.

Among the two apple collections, some varieties were highly attacked, while others were found to be less susceptible to the pest ($p < 0.001$). Moreover, the infestation levels varied according to the sampling dates and were correlated to some fruit traits: Some varieties were not/moderately/or severely infested in some surveys compared to other dates. Overall, the pest damage increased remarkably for all varieties during the last survey date. In Lannoceur station (the cold site), where twelve varieties were investigated, the codling moth preferred the varieties Golden Smoothee, Galaxy Gala, and Obro Gala. In Ain Taoujdate station (the warm site), Idared and Black Stayman varieties were the most preferred over the seven varieties inspected. Whereas the less susceptible varieties present in both sampling locations were Anna, Dorsett, and Stark Delicious.

Similar to our results, it has been reported that the infestation by *C. pomonella* varies notably among the apple varieties and some varieties are more heavily damaged than others (in the case of Golden Delicious compared to Granny Smith and Red Delicious) [18]. This preference can be explained by some volatile compounds emitted from the apple fruits. In both experimental stations, even in their different conditions, results showed that the medium and late maturing varieties had similar patterns in terms of pest damage compared to the early maturing ones (Anna, Dorsett, Vistabella, and Ein Shiemmer). An experiment conducted in the USA, exploring the susceptibility of 10 apple varieties to *C. pomonella* oviposition, reached similar results regarding codling moth preferences. It has been stated that late maturing varieties had higher vulnerability to pest infestations than the early maturing ones [40]. Moreover, a recent study performed in Norway reported that late maturing varieties are more susceptible to attacks compared to the early ones [41]. Our observations could be explained through the release of volatile compounds by apples

according to the variety and the maturity stage of fruits. In fact, some studies have shown that these volatiles vary greatly across varieties and increase as fruits mature [19,22]. These compounds could act as attractants and stimulate the moth's feeding and oviposition behavior, while others might have repellent properties and deter the moth from laying eggs and feeding on the fruit [21,23]. This aspect should be explored in further studies.

In addition to the importance of plant emissions in host selection, the susceptibility of apple varieties to codling moth could be influenced by a combination of other factors. Therefore, we analyzed the correlations between pest infestations and fruit traits in order to exhibit the parameters involved in these phenomena (Table 5). In both stations, especially in the August survey, our results showed that the damage rate was positively correlated with firmness. In fact, Galaxy Gala and Obro Gala being at Lannoceur station (the cold site) and Idared at Ain Taoujdade station (the warm site) were the firmest varieties and recorded the highest damage rates during this campaign. This result concords with the study of [25] attesting that *C. pomonella* larvae may prefer unripe and firm fruits for secured larval development before fruit-fall. A negative correlation established between infestations and fruit weight/diameter was observed only in one location (Ain Taoujdade), notably with Anna and Dorsett varieties recording less damage than the other varieties with small fruits. These correlations were not confirmed statistically at Lannoceur station in the August survey; however, it was observed in this site (considering all observation dates) that larger fruits were less susceptible to infestations compared to the small ones. In the same context, it was attested that fruit size could influence *C. pomonella* host selection among the walnut varieties [16].

Moreover, during the first survey, statistical analysis revealed that the pH was correlated to *C. pomonella* infestation (0.645 * and 0.682 * at Lannoceur and Ain Taoujdade stations, respectively). Comparable findings were uncovered assuming that the pH of melon fruits has a positive correlation with *Bactrocera cucurbitae* infestations [42,43]. It has also been reported that a low pH increases the attraction of *Drosophila suzukii* to berries [44]. Similarly, other relevant studies have stated that fruit acidity is one of the factors implicated in *Drosophila suzukii* host selection in addition to other parameters [45,46].

Finally, the concentrations of phenolic compounds varied substantially between the apple varieties and sampling dates in both experimental stations (Tables 3 and 4). The results showed that as the concentration of polyphenol content decreases, the damage caused by the pest increases (−0.679 * and −0.841 ** at Lannoceur and Ain Taoujdade stations, respectively) (Figures A2 and A3). These compounds are known to be associated with resistance to insects since they act as antifeedants, toxicants, mitochondrial oxidation inhibitors, and ovicides [47]. In both stations, it was observed that the moderately infested varieties, mainly Stark Delicious, Vistabella, and Red Chief, recorded the highest polyphenol content concentrations among the other varieties. These observations were supported by [48] attesting that resistant Chinese apple varieties to fruit fly *Carpomyia vesuviana* have more phenolic content than susceptible varieties. Similar results were found as well for the melon fruit fly *Bactrocera cucurbitae* [43].

5. Conclusions

The present work aimed to investigate the behavior of *C. pomonella* across apple varieties by examining various fruit characteristics and pest damage. Under two contrasted climatic conditions, *C. pomonella* displayed distinct preferences for different apple varieties and appeared to be influenced by similar fruit traits in specific periods. Firmness parameter seemed to be associated with codling moth at the end of the season in contrast to pH parameter, which is associated at the beginning of the campaign. Diameter and weight were correlated to pest damage only in one location; however, our observations tend to assume that large fruits are less preferred than small ones. Moreover, according to our observations, fruit firmness was the predominant factor influencing the insect's preference, even stronger than weight and diameter parameters. Overall, it could be concluded that regardless of the climatic conditions, the insect preferred medium and late maturing vari-

eties (Obro Gala, Galaxy Gala, Golden Smoothee, and Idared) rather than early maturing ones (especially Anna and Dorsett). Among the late maturing varieties, Stark Delicious was relatively less infested compared to the others. Finally, it could be inferred that the polyphenol content influences *C. pomonella* infestations as the damage increased at lower levels of this compound. Further studies are required to explore the role of other secondary metabolites (flavonoids and tannins) in restricting insect growth and tolerating the insect's presence. This investigation might contribute to the enhancement of our understanding of *C. pomonella* infestations pattern among the apple varieties and establishment of a susceptibility/preference pest index of varieties based on many parameters. These outputs could be considered valuable for planting new orchards and implementing a sustainable management program against *C. pomonella*.

Author Contributions: Conceptualization, S.E.I.E.H.; methodology, S.E.I.E.H. and D.A.; software, A.D.; validation, S.E.I.E.H. and D.A.; formal analysis, A.D. and D.A.; investigation, D.A. and A.B.; resources, R.B.; data curation, A.D.; writing—original draft preparation, S.E.I.E.H., D.A. and A.E.; writing—review and editing, S.E.I.E.H., D.A., K.H. and A.D.; visualization, A.E. and R.B.; supervision, S.E.I.E.H.; project administration, S.E.I.E.H. and D.A.; funding acquisition, A.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Acknowledgments: We thank Razouk Rachid for his contribution and revision of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Duncan's multiple range test for varieties classification according to pest damage at Lannoceur station.

Duncan Grouping			Mean	N	Variety
B	A		0.60703	18	Golden Smoothee
	A		0.56925	17	Obro Gala
	A	C	0.53931	17	Golden Delicious
	A	C	0.52616	19	Galaxy Gala
	A	C	0.52118	17	Early Red One
	A	C	0.50140	16	Washington Spur
		C	0.48605	19	Cherry Gala
		C	0.46880	18	Brookfield
	D	C	0.43761	18	Red Chief
	D		0.36494	15	Stark Delicious
E			0.16874	9	Dorsett
			0.20153	9	Anna

Table A2. Duncan's multiple range test for varieties classification according to pest damage at Ain Toujdate station.

Duncan Grouping			Mean	N	Variety
B	A		0.65010	3	Idared
	A		0.49802	9	Black Stayman
	A	C	0.48090	4	Stark Delicious
	D	C	0.31764	7	Ein Sheimmer
	D	C	0.30299	7	Vistabella
	D		0.24826	9	Dorsett
	E		0.00000	6	Anna

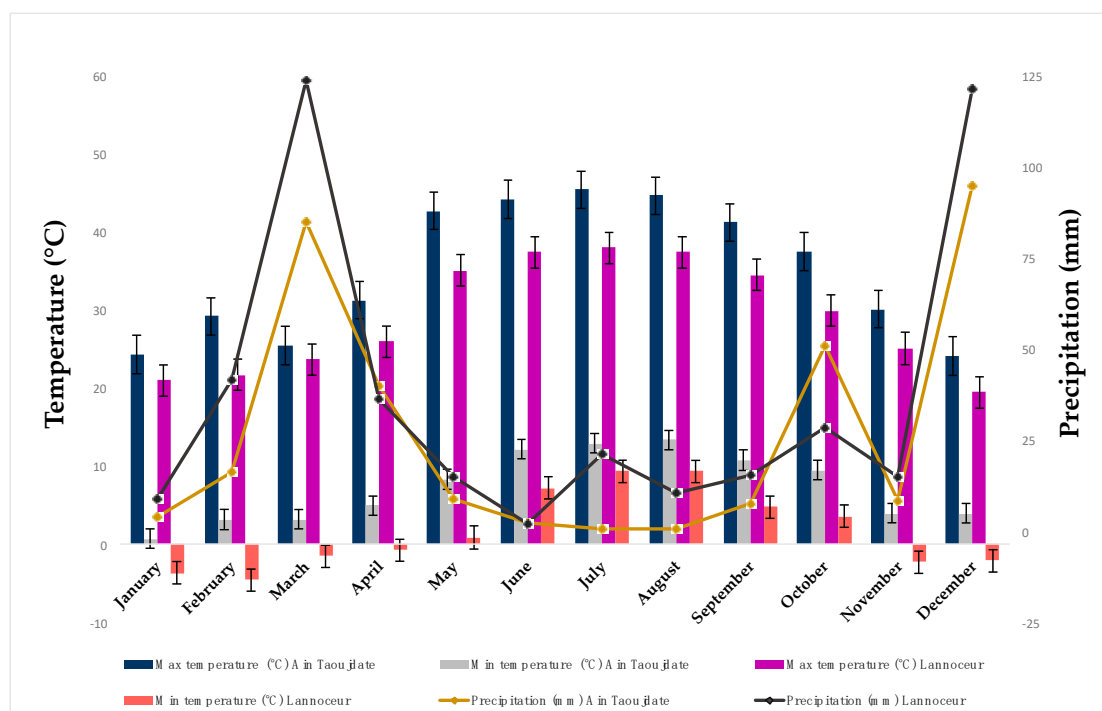


Figure A1. Climatic conditions of both experimental stations during the 2022 agricultural campaign.

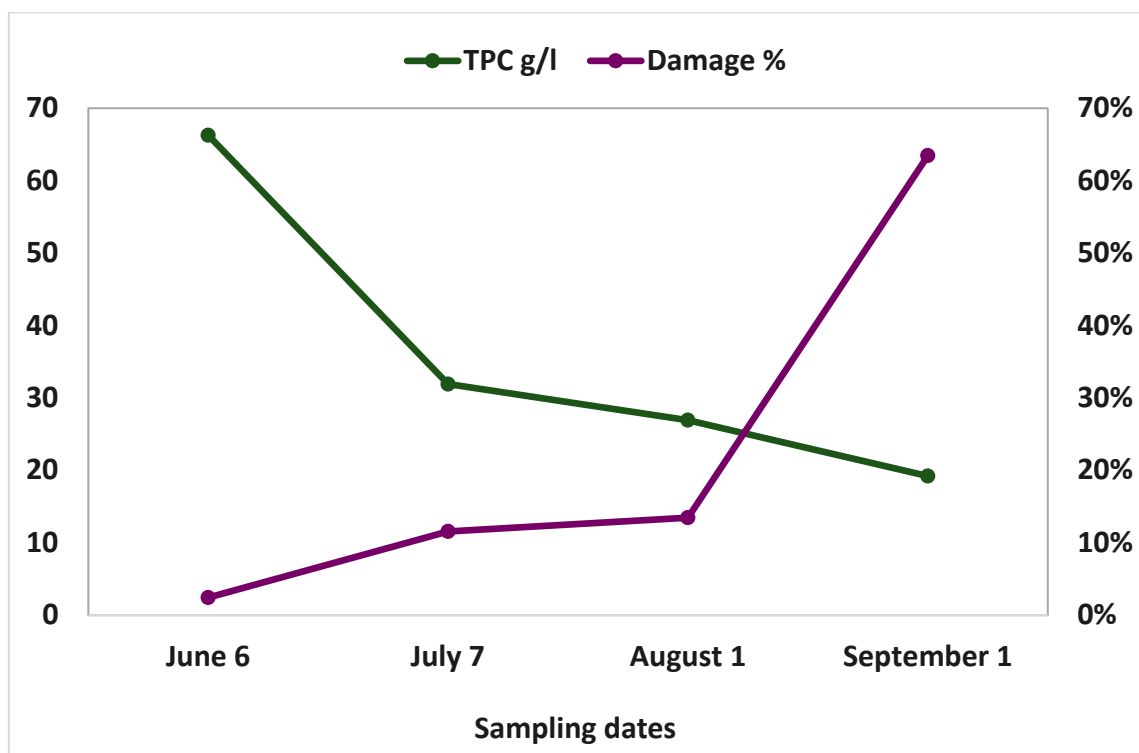


Figure A2. Damage interaction with phenolic content at Lannoceur station ($r = -0.679^*$). *: Significant, at the 5% level, correlation between the studied parameters and damage rate.

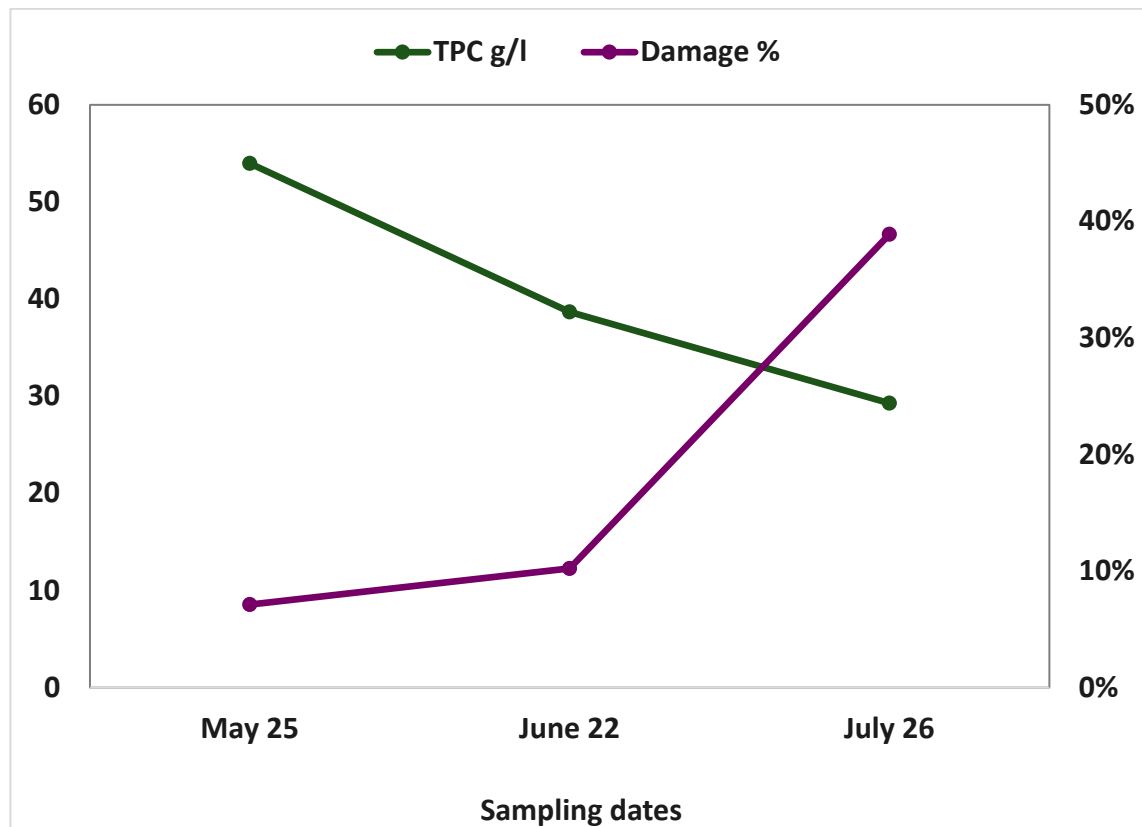


Figure A3. Damage interaction with phenolic content at Ain Taoujdate station ($r = -0.841^{**}$).
 ** : Highly significant, at the 1% level, correlation between the studied parameters and damage rate.

References

- Reyes, M.; Franck, P.; Charmillot, P.J.; Ioriatti, C.; Olivares, J.; Pasqualini, E.; Sauphanor, B. Diversity of insecticide resistance mechanisms and spectrum in European populations of the codling moth, *Cydia pomonella*. *Pest Manag. Sci.* **2007**, *63*, 890–902.
- Voudouris, C.C.; Sauphanor, B.; Franck, P.; Reyes, M.; Mamuris, Z.; Tsitsipis, J.A.; Vontas, J.; Margaritopoulos, J.T. Insecticide resistance status of the codling moth *Cydia pomonella* (Lepidoptera: Tortricidae) from Greece. *Pestic. Biochem. Physiol.* **2011**, *100*, 229–238. [\[CrossRef\]](#)
- Witzgall, P.; Stelinski, L.; Gut, L.; Thomson, D. Codling moth management and chemical ecology. *Annu. Rev. Entomol.* **2008**, *53*, 503–522. [\[CrossRef\]](#)
- Ju, D.; Mota-Sanchez, D.; Fuentes-Contreras, E.; Zhang, Y.L.; Wang, X.Q.; Yang, X.Q. Insecticide resistance in the *Cydia pomonella* (L.): Global status, mechanisms, and research directions. *Pestic. Biochem. Phys.* **2021**, *178*, 104925. [\[CrossRef\]](#)
- Sauphanor, B.; Brosse, V.; Bouvier, J.C.; Speich, P.; Micoud, A.; Martinet, C. Monitoring resistance to diflufenbureon and deltamethrin in French codling moth populations (*Cydia pomonella*). *Pest Manag. Sci.* **2000**, *56*, 74–82. [\[CrossRef\]](#)
- Boivin, T.; Chabert d'Hières, C.; Bouvier, J.C.; Beslay, D.; Sauphanor, B. Pleiotropy of insecticide resistance in the codling moth, *Cydia pomonella*. *Entomol. Exp. Appl.* **2001**, *99*, 381–386. [\[CrossRef\]](#)
- Bouvier, J.C.; Buès, R.; Boivin, T.; Boudinhon, L.; Beslay, D.; Sauphanor, B. Deltamethrin resistance in the codling moth (Lepidoptera: Tortricidae): Inheritance and number of genes involved. *J. Hered.* **2001**, *87*, 456–462.
- Brun-Barale, A.; Bouvier, J.C.; Pauron, D.; Berg'e, J.B.; Sauphanor, B. Involvement of a sodium channel mutation in pyrethroid resistance in *Cydia pomonella* L., and development of a diagnostic test. *Pest Manag. Sci.* **2005**, *61*, 549–554. [\[CrossRef\]](#)
- El Iraqui, S.; Hmimina, M. Assessment of control strategies against *Cydia pomonella* (L.) in Morocco. *JPPR* **2016**, *56*, 1. [\[CrossRef\]](#)
- Bosch, D.; Avilla, J.; Musleh, S.; Rodríguez, M.A. Target-site mutations (AChE and kdr), and PSMO activity in codling moth (*Cydia pomonella* (L.) (Lepidoptera: Tortricidae)) Populations from Spain. *Pestic. Biochem. Physiol.* **2018**, *146*, 52–62. [\[CrossRef\]](#)
- Hu, C.; Wei, Z.H.; Li, P.R.; Harwood, J.D.; Li, X.Y.; Yang, X.Q. Identification and functional characterization of a sigma glutathione S-transferase CpGSTs2 involved in λ -cyhalothrin resistance in the codling moth *Cydia pomonella*. *J. Agric. Food Chem.* **2020**, *68*, 12585–12594. [\[CrossRef\]](#)
- Stoeckli, S.; Hirschi, M.; Spirig, C.; Calanca, P.; Rotach, M.W.; Samietz, J. Impact of climate change on voltinism and prospective diapause induction of a global pest insect—*Cydia pomonella* (L.). *PLoS ONE* **2012**, *7*, 35723.
- Wearing, C.H. Distribution characteristics of eggs and neonate larvae of codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae). *Int. J. Insect Sci.* **2016**, *8*, IJIS-S38587. [\[CrossRef\]](#)

14. Light, D.M.; Knight, A.L.; Henrick, C.A.; Rajapaska, D.; Lingren, B.; Dickens, J.C.; Campbell, B.C. A pear-derived kairomone with pheromonal potency that attracts male and female codling moth, *Cydia pomonella* (L.). *Sci. Nat.* **2001**, *88*, 333–338. [\[CrossRef\]](#)
15. López, M.L.; Gómez, M.P.; Díaz, A.; Barud, F.J.; Camina, J.L.; Dambolena, J.S. Changes in the volatile profile of four varieties of quince (*Cydonia oblonga*) produced by codling moth (*Cydia pomonella*) infestation. *Phytochem. Lett.* **2022**, *49*, 187–191. [\[CrossRef\]](#)
16. Bezemer, T.M.; Mills, N.J. Host density responses of *Mastrusridibundus*, a parasitoid of the codling moth, *Cydia pomonella*. *Biol. Control.* **2001**, *22*, 169–175. [\[CrossRef\]](#)
17. Phillips, P.A.; Barnes, M.M. Host race formation among sympatric apple, walnut, and plum populations of the codling moth, *Laspeyresia pomonella*. *Ann. Entomol. Soc. Am.* **1975**, *68*, 1053–1060. [\[CrossRef\]](#)
18. Davis, T.S.; Garczynski, S.F.; Stevens Rumann, C.; Landolt, P.J. A test of fruit varieties on entry rate and development by neonate larvae of the codling moth, *Cydia pomonella*. *Entomol. Exp. Appl.* **2013**, *148*, 259–266. [\[CrossRef\]](#)
19. Sutherland, O.R.W.; Wearing, C.H.; Hutchins, R.F.N. Production of α farnesene, an attractant and oviposition stimulant for codling moth, by developing fruit of ten varieties of apple. *J. Chem. Ecol.* **1977**, *3*, 625–631.
20. Kovanci, O.B.; Kumral, N.A.; Larsen, T.E. High versus ultra-low volume spraying of a microencapsulated pheromone formulation for codling moth control in two apple varieties. *Int. J. Pest Manag.* **2010**, *56*, 1–7. [\[CrossRef\]](#)
21. Hern, A.; Dorn, S. A female-specific attractant for the codling moth, *Cydia pomonella*, from apple fruit volatiles. *Sci. Nat.* **2004**, *91*, 77–80. [\[CrossRef\]](#)
22. Wearing, C.H.; Hutchins, R.F.N. α -Farnesene, a naturally occurring oviposition stimulant for the codling moth, *Laspeyresia pomonella*. *J. Insect Physiol.* **1973**, *19*, 1251–1256. [\[CrossRef\]](#)
23. Hern, A.; Dorn, S. Sexual dimorphism in the olfactory orientation of adult *Cydia pomonella* in response to α -farnesene. *Entomol. Exp. Appl.* **1999**, *92*, 63–72. [\[CrossRef\]](#)
24. Vallat, A.; Dorn, S. Changes in volatile emissions from apple trees and associated response of adult female codling moths over the fruit-growing season. *J. Agric. Food Chem.* **2005**, *53*, 4083–4090. [\[CrossRef\]](#)
25. Stoeckli, S.; Mody, K.; Dorn, S.; Kellerhals, M. Association between herbivore resistance and fruit quality in apple. *HortScience* **2011**, *46*, 12–15. [\[CrossRef\]](#)
26. Gonçalves, M.F.; Malheiro, R.; Casal, S.; Torres, L.; Pereira, J.A. Influence of fruit traits on oviposition preference of the olive fly, *Bactrocera oleae* (Rossi) (Diptera: Tephritidae), on three Portuguese olive varieties (Cobrançosa, Madural and Verdeal Transmontana). *Sci. Hortic.* **2012**, *145*, 127–135. [\[CrossRef\]](#)
27. Simmonds, M.S.J. Flavonoid-insect interactions, recent advances in our knowledge. *Phytochem. Lett.* **2003**, *64*, 21–30. [\[CrossRef\]](#) [\[PubMed\]](#)
28. Barbehenn, R.V.; Peter Constabel, C. Tannins in plant herbivore interactions. *Phytochem. Lett.* **2011**, *72*, 1551–1565. [\[CrossRef\]](#)
29. Nath, P.; Panday, A.K.; Kumar, A.; Rai, A.B.; Palanivel, H. Biochemical resistance traits of bitter melon against fruit fly *Bactrocera cucurbitae* (Coquillett) infestation. *J. Agric. Sci.* **2017**, *9*, 217–225. [\[CrossRef\]](#)
30. Mayr, U.; Treutter, D.; Santos-Buelga, C.; Bauer, H.; Feucht, W. Developmental changes in the phenol concentrations of ‘Golden Delicious’ apple fruits and leaves. *Phytochem. Lett.* **1995**, *38*, 1151–1155. [\[CrossRef\]](#)
31. Schieber, A.; Keller, P.; Carle, R. Determination of phenolic acids and flavonoids of apple and pear by high-performance liquid chromatography. *J. Chromatogr. A.* **2001**, *910*, 265–273. [\[CrossRef\]](#)
32. Vinson, J.A.; Su, X.; Zubik, L.; Bose, P. Phenol antioxidant quantity and quality in foods: Fruits. *J. Agric. Food Chem.* **2001**, *49*, 5315–5321. [\[CrossRef\]](#)
33. AOAC. *Official Methods of Analysis*, 18th ed.; AOAC International: Gaithersburg, MD, USA, 2006; Volume 2000.
34. Singleton, V.L.; Orthofer, R.; Lamuela-Raventos, R.M. Analysis of total phenols and other antioxidant substrates and antioxidants by means of Folin–Ciocalteu reagent. *Meth. Enzymol.* **1999**, *299*, 152–178.
35. Petrakis, P.V. Larval performance in relation to oviposition site preference in olive kernel moth (*Prays oleae* Bern., Yponomeutidae, Praydina). *Agric. For. Entomol.* **2000**, *2*, 271–282. [\[CrossRef\]](#)
36. Burrack, J.H.; Zalom, F.G. Olive fruit fly (Diptera: Tephritidae) ovipositional preference and larval performance in several commercially important olive varieties in California. *J. Econ. Entomol.* **2008**, *101*, 750–758. [\[CrossRef\]](#)
37. Malheiro, R.; Casal, S.; Pinheiro, L.; Baptista, P.; Pereira, J.A. Olive cultivar and maturation process on the oviposition preference of *Bactrocera oleae* (Rossi) (Diptera: Tephritidae). *Bull. Entomol. Res.* **2019**, *109*, 43–53. [\[CrossRef\]](#) [\[PubMed\]](#)
38. Gómez, M.; Paranhos, B.A.; Silva, J.G.; De Lima, M.A.; Silva, M.A.; Macedo, A.T.; Walder, J.M. Oviposition preference of *Ceratitidis capitata* (Diptera: Tephritidae) at different times after pruning ‘Italia’ table grapes grown in Brazil. *J. Insect. Sci.* **2019**, *19*, 16. [\[CrossRef\]](#) [\[PubMed\]](#)
39. Dhillon, M.K.; Singh, R.; Naresh, J.S.; Sharma, N.K. Influence of physico-chemical traits of bitter melon, *Momordica charantia* L. on larval density and resistance to melon fruit fly, *Bactrocera cucurbitae* (Coquillett). *J. Appl. Entomol.* **2005**, *129*, 393–399. [\[CrossRef\]](#)
40. Joshi, N.K.; Rajotte, E.G.; Myers, C.T.; Krawczyk, G.; Hull, L.A. Development of a susceptibility index of apple varieties for codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) oviposition. *Front. Plant Sci.* **2015**, *6*, 992. [\[CrossRef\]](#)
41. Kaisoon, M. Susceptibility of Different Apple Varieties to Codling Moth (*Cydia pomonella*) and the Factors That Influence the Infestation Level. Master’s Thesis, Norwegian University of Life Sciences, Ås, Norway, 2021.
42. Haldhar, S.M.; Choudhary, B.R.; Bhargava, R.; Sharma, S.K. Screening of ridge gourd varieties/ genotypes (*Luffa acutangula*) for resistance fruit fly (*Bactrocera cucurbitae*) in hot arid region of Rajasthan. *Indian J. Hortic.* **2013**, *8*, 21–24.

43. Haldhar, S.M.; Choudhary, B.R.; Bhargava, R.; Gurjar, K. Host plant resistance (HPR) traits of ridge gourd (*Luffa acutangula* (Roxb.) L. against melon fruit fly, (*Bactrocera cucurbitae* (Coquillett)) in hot arid region of India. *Sci. Hortic.* **2015**, *194*, 168–174. [[CrossRef](#)]
44. Little, C.M.; Dixon, P.L.; Chapman, T.W.; Hillier, N.K. Role of fruit characters and colour on host selection of boreal fruits and berries by *Drosophila suzukii* (Diptera: Drosophilidae). *Can. Entomol.* **2020**, *152*, 546–562. [[CrossRef](#)]
45. Burrack, H.J.; Fernandez, G.E.; Spivey, T.; Kraus, D.A. Variation in selection and utilization of host crops in the field and laboratory by *Drosophila suzukii* Matsumara (Diptera: Drosophilidae), an invasive frugivore. *Pest Manag. Sci.* **2013**, *69*, 1173–1180. [[CrossRef](#)]
46. Pelton, E.; Gratton, C.; Guédot, C. Susceptibility of cold hardy grapes to *Drosophila suzukii* (Diptera: Drosophilidae). *J. Appl. Entomol.* **2017**, *141*, 644–652. [[CrossRef](#)]
47. Nishida, R. Sequestration of defensive substances from plants by Lepidoptera. *Annu. Rev. Entomol.* **2002**, *47*, 57–92. [[CrossRef](#)] [[PubMed](#)]
48. Haldhar, S.M.; Berwal, M.K.; Samadia, D.K.; Kumar, R.; Gora, J.S.; Choudhary, S. Biochemical basis of plant-insect interaction in arid horticulture crops: A scientific review. *J. Agric. Ecol.* **2018**, *6*, 1–16. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.