horticulturae

Article

Pistachio Phenology and Yield in a Cold-Winter Region of Spain: The Status of the Cultivation and Performance of Three Cultivars

Lidia Núñez [1], Hugo Martín [1], José Manuel Mirás-Avalos [2] and Sara Álvarez [1,*]

[1] Instituto Tecnológico Agrario de Castilla y León (ITACyL), Ctra. Burgos, 119, 47071 Valladolid, Spain; nunramli@itacyl.es (L.N.); marguthu@itacyl.es (H.M.)
[2] Misión Biológica de Galicia (MBG-CSIC), Sede Santiago, Avda. de Vigo s/n, Campus Vida, 15705 Santiago de Compostela, Spain; jmmiras@mbg.csic.es
* Correspondence: alvmarsa@itacyl.es

Abstract: In recent years, pistachio (*Pistacia vera* L.) cultivation is undergoing a great expansion in Spain, which is promising for regions where water and winter chilling are not limiting. Many areas of Castilla y León (Spain) provide suitable conditions for pistachio production, but heat requirement could be a limiting factor. The aims of this study were (i) to investigate the status of pistachios in Castilla y León and the relationships between phenology and agroclimatic conditions and (ii) to assess the performance of three pistachio cultivars ('Kerman', 'Lost Hills', and 'Golden Hills') in a plantation within this region. This work describes the phenological and productive behavior of three pistachio varieties in seven orchards over three years. The chilling requirements were exceeded, and heat accumulation was sufficient to complete the cycle in all seasons. Bloom and harvest occurred later in 'Kerman' than in 'Golden Hills' and 'Lost Hills'. In general, 'Kerman' had higher nut yield than the other two cultivars but also had more non-split and blank nuts, aspects that should be considered for future plantations. Despite the interannual variability in yield, a trend to increase the production with water received was observed, but this also affected the quality and modified the splitting percentage.

Keywords: flowering; heat accumulation; nut size; nut yield; *Pistacia vera* L.; shell splitting; winter chill

Citation: Núñez, L.; Martín, H.; Mirás-Avalos, J.M.; Álvarez, S. Pistachio Phenology and Yield in a Cold-Winter Region of Spain: The Status of the Cultivation and Performance of Three Cultivars. *Horticulturae* **2024**, *10*, 1235. https://doi.org/10.3390/horticulturae10121235

Academic Editor: Alejandro López-Martínez

Received: 29 October 2024
Revised: 18 November 2024
Accepted: 19 November 2024
Published: 21 November 2024

1. Introduction

The pistachio (*Pistacia vera* L.) is a dioecious species widely grown in the Mediterranean, where it is considered vulnerable to temperature increases caused by global warming [1]. In this sense, winter chill accumulation is a decisive factor in flowering and fruit set [2], hence affecting yield. Moreover, pistachio trees are considered drought tolerant and able to survive in areas with less than 100 mm of rainfall, but nut yield and/or quality improve markedly with irrigation [3], even with small amounts [4]. These features, along with the relatively high revenues for growers, the increasing marketing demand, and the fact that pistachio is an easy machinable crop [5], have expanded the acreage of this crop in several countries.

In Spain, the surface devoted to pistachios is steadily increasing despite the challenges in terms of climate conditions [6]. Nowadays, pistachios occupy 78,000 ha in Spain, approximately, although only 23% of this surface is under production and 70% of the total area cultivated in Spain is under rain-fed conditions [7]. In Castilla y León, where no winter-chill or water restrictions for pistachio growth are expected, the surface devoted to the crop is expanding [8], but this is a relatively novel crop, as the first plantations were established in the early 2000s. Nevertheless, growers are increasingly interested in this nut species due to the high revenues obtained. In 2022, the area devoted to pistachios in Castilla y León was 2835 ha, most of them under rain-fed conditions. Despite its low area compared to other regions in Spain, the pistachio is a relevant crop for Castilla y León due to its positive impact fixing the population in rural areas. The success of these new plantations will be mainly related to the selection of an appropriate cultivar, although most of the cultivars multiplied in Spain are relatively novel, and their performance under commercial growing conditions is limited [9], with few experimental data from regions with larger pistachio acreage than in Castilla y León, where this type of information is lacking.

Expanding the production of pistachios into regions with different climates from those of the species' origin in Central Asia or in its traditional production regions may lead to a mismatch between tree physiology and climatic conditions [10]. Pistachios, like other woody crops, evolved as a species in cold-winter regions, where it falls dormant during the cold season to reduce exposure of sensitive growing tissues to unfavorable conditions [11]. To break out of their dormant state, pistachios need to fulfil a chilling requirement to resume growth, produce leaves, and, eventually, bloom and develop fruits as the environment warms [12]. The timing of each developmental stage depends on heat requirements that are specific to each stage and vary across cultivars [1]. In Castilla y León, chilling requirements for pistachios are not compromised because of the long and cold winters experienced by the region, but heat requirements could not be attained in some years due to the short summer length, although this is subject to alterations because of the impacts of climate change [6].

Among pistachio cultivars, 'Kerman' is the most commonly planted in Castilla y León, occupying more than 70% of the surface devoted to this crop. 'Kerman' is a late bloom cultivar that has a relatively short entry in production. However, it has high heat accumulation requirements, which may be difficult to meet in Castilla y León, and shows a trend of alternating bearing between years [5,13]. Other pistachio cultivars, such as 'Golden Hills' and 'Lost Hills', have gained relevance in recent years, as for instance, in California, 90% of new plantations opted for these cultivars [14]. In Castilla y León, their surface is limited despite their interesting characteristics that make them appropriate for cultivation in regions with short summers and prone to spring frosts, namely medium cycle, lower cold, and heat requirements when compared to 'Kerman'. These cultivars are reported to be more productive than 'Kerman' and with a shorter cycle, which allows for earlier harvests, thus optimizing resources in regions where late cultivars are already planted. In addition, nuts from these cultivars are bigger than those from 'Kerman', and the percentage of split nuts is also higher [15,16].

Therefore, the choice of pistachio cultivars is a strategic decision with direct implications on both yield and nut quality as well as on the profitability of the plantations. However, this information is lacking in regions such as Castilla y León, where this crop is novel and soil and climate factors differ from those in areas where the pistachio is a major crop. In this context, the aim of the current study is two-fold: (i) to investigate the status of pistachio plantations in Castilla y León and the relationships between phenology and agroclimatic conditions and (ii) to assess the performance of three pistachio cultivars ('Kerman', 'Lost Hills', and 'Golden Hills') over 6 years in a plantation located in the province of Valladolid and the relationships with agroclimatic conditions and irrigation amounts.

2. Materials and Methods

2.1. Description of the Study Areas

During the 2018 to 2020 growing seasons, seven pistachio orchards located within four provinces of the Castilla y León region (Spain) were monitored for phenology and yield. Table 1 shows the main characteristics of the surveyed orchards.

Table 1. The location and main characteristics of the pistachio plantations surveyed in this study.

Plot	Province	Geographical Coordinates	Year of Plantation	Cultivar	Tree Spacings (m)	Nearest Weather Station [1]
P1—Perales	Palencia	42°10′ N, 4°35′ W	2002	'Kerman'	7 × 7	P04-Villoldo
P2—Toro	Zamora	41°31′ N, 5°22′ W	2004	'Kerman'	6 × 7	ZA08-Toro
P3—Pozal de Gallinas	Valladolid	41°20′ N, 4°50′ W	2008	'Kerman'	6 × 7	VA102-Medina del Campo
P4—Carpio	Valladolid	41°12′ N, 5°5′ W	2012	'Kerman', 'Golden Hills', 'Lost Hills'	5 × 6	VA02-Torrecilla de la Orden
P5—Fombellida	Valladolid	41°46′ N, 4°11′ W	2011	'Golden Hills', 'Lost Hills'	6 × 7	VA05-Encinas del Esgueva
P6—Madrigal Altas Torres	Ávila	41°6′ N, 5°6′ W	2015	'Lost Hills'	6 × 7	AV01-Nava Arévalo
P7—Villafuerte	Valladolid	41°44′ N, 4°19′ W	2014	'Kerman', 'Lost Hills'	6 × 7	VA05-Encinas del Esgueva

[1] It refers to the weather observatory managed by InfoRiego (https://www.inforiego.org/opencms/opencms) (accessed on 15 October 2024) and which is nearest to the surveyed plot.

These plantations were located in four different provinces of Castilla y León (Spain) and differed in year of establishment (from 2002 to 2015) in order to capture the great variability of conditions present in the region (Figure 1). Most of the sites were planted with cv. 'Kerman', whereas cvs. 'Golden Hills' and 'Lost Hills' were present in two and four plots, respectively. Tree spacings varied from 5 m × 6 m to 7 m × 7 m, although they were mainly 6 m × 7 m (Table 1).

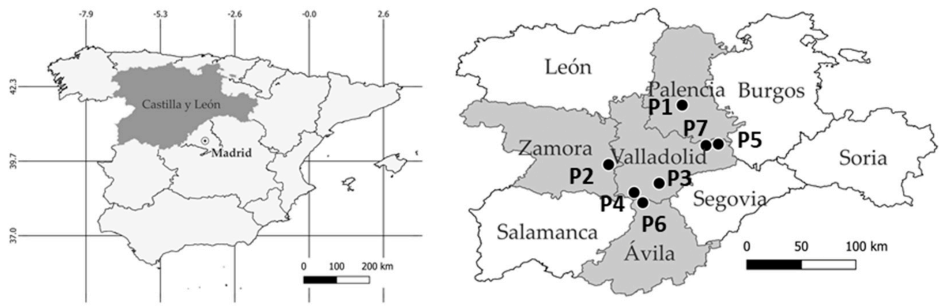

Figure 1. The location of the pistachio orchards in 'Castilla y León' region, Spain. P1–P7 represent the surveyed sites: P1 = Perales, P2 = Toro, P3 = Pozal de Gallinas, P4 = Carpio, P5 = Fombellida, P6 = Madrigal de las Altas Torres, and P7 = Villafuerte.

As a specific case study, the experimental orchard located in Carpio (P4), Valladolid (41°12′ N, 5°5′ W, 759 m elevation) was used to assess the performance of three pistachio cultivars: 'Golden Hills', 'Lost Hills', and 'Kerman' (Figures A1 and A2). Trees were planted in 2012 at 5 m × 6 m spacings (333 trees ha^{-1}). Additionally, this orchard had two masculine/pollinizing cultivars (11% of the total number of trees): 'Peter' and 'Randy'. Trees were grafted on the University of California at Berkeley I (UCB1) rootstock and received the same amount of water (both in volume and in frequency of events) through an automated irrigation system. Table 2 shows the amounts of water received each season during the study period (2016–2022).

Table 2. Seasonal (March to October) water amounts received by pistachio trees over the experimental period (2016–2022) in the Carpio orchard.

Water Received (m^3 ha^{-1})	2016	2017	2018	2019	2020	2021	2022
Irrigation	390	655	1520	2050	1745	1250	2466
Irrigation + Rainfall	1580	1655	2140	3230	5314	3390	3247

2.2. Weather Data and Bioclimatic Indices

Daily records of weather variables (including maximum and minimum temperature, relative humidity, rainfall and reference evapotranspiration—ETo–, among others) were collected from the agrometeorological stations nearest to the surveyed sites (Table 1) and managed by the InfoRiego service of the Castilla y León Government. From these records, the following bioclimatic indices were calculated according to Kallsen [17]: chill hours (temperatures between 0 and 7 °C) accumulated from November to March, growing degree days (GDDs) accumulated between April and October, using 7.2 °C as base temperature.

During the 2019 and 2020 seasons, from March to October, a sensor (MX2301, HOBO, Onset Computer Corporation, Bourne, MA, USA) was deployed in six of the surveyed plots to assess the reliability and accuracy of using temperature collected in the nearest station for the calculation of GDDs.

2.3. Soil Sampling and Determinations

Three composite soil samples per orchard were collected at 0–50 cm depth. Each of these samples consisted of four sub-samples, which were bulked to obtain the aforementioned three soil samples per plantation. These samples were considered sufficient to cover the orchard internal variability.

Samples were air-dried and sieved to 2 mm. Soil physical and chemical properties were determined using standard protocols [18]. Particle size analysis (contents of sand, silt, and clay) was carried out after organic matter destruction with H_2O_2, elimination of Fe and Al oxyhydroxides with HCl, and dispersion with hexametaphosphate and sodium carbonate. Particles < 50 mm were separated through the pipette method. Soil pH was determined in water (soil/solution 1:2.5). Organic matter content was determined using the loss on ignition method. Available phosphorus was determined using the Olsen method [19].

2.4. Pistachio Phenology and Yield

Pistachio tree phenology was observed from 2018 to 2020. In each plot, the general phenological stage for a given pistachio cultivar was recorded once a week according to pistachio flower opening stages defined by Guerrero Villaseñor et al. [20]. We considered that a given phenological stage was reached when it was evident in more than 50% of the shoots.

Yield components were determined from 2018 to 2020 in adult plantations (P1 to P5 in Table 1), except for the P4, in which yield data were recorded since 2016 until 2022. At harvest (usually in October), yield was recorded in three representative pistachio trees per cultivar and orchard. Trees were chosen on the basis of their size and general aspect, selecting those that represent the average tree size observed in the orchard (Figure A1). The yield components measured were fresh and dry weight of fruits per tree and number of pistachio nuts in an ounce (28.35 g). On a sample of 100 fruits per tree, percentage of split, non-split, and blank nuts were estimated. The weight per tree of each of these categories of nuts was calculated.

2.5. Statistical Analysis

Differences in soil characteristics and weather variables among sites were assessed with the Kruskal–Wallis test because they did not meet the assumptions of normality and homoscedasticity. Mean separation was performed with Dunn's test. Differences were considered significant at the 0.05 level.

Daily records of mean temperature collected at the weather stations were compared with those recorded by the on-site sensors by means of linear regression and the following statistical indicators: mean bias error (ME), root-mean squared error (RMSE), normalized RMSE (nRMSE), and index of agreement. These indices were computed according to Yang et al. [21], and the reference used was the records from the on-site sensors. The ME shows positive or negative deviations between values of the on-site sensors and the weather stations, whereas RMSE indicates the mean difference between values from different sources. The nRMSE represents the relative size of the mean differences as an unbounded percentage. The index of agreement varies between 0 and 1, and the closer it is to 1, the better agreement between data sources.

Linear regression was used to assess the relationship between the water received by the trees (rainfall + irrigation) and other weather-related indicators (GDDs, chill hours) with yield. The strength of these relationships was assessed by means of the Spearman's rank correlation test, and the Spearman's correlation coefficient (rho) was reported [22]. Principal component analysis (PCA) was used to separate pistachio nut yield according to bioclimatic indices, orchard, and year.

In the case study of P4, differences among pistachio cultivars in yield components were determined with one-way ANOVA, and means were separated using Duncan's multiple range test at the 0.05 significance level.

Statistical analyses were conducted in the R environment, version 4.3.2 [23].

3. Results

3.1. Effect of Site on Weather Variables and Bioclimatic Indices

Significant differences among weather stations were detected for the general climatic indicators over the growing season (April to October), calculated for the 2007 to 2023 period (Table 3). The mean temperature ranged from 15.3 °C to 17.6 °C depending on the weather station and was significantly higher in Toro, Medina del Campo, and Torrecilla de la Orden than in the remaining three weather stations (Table 3). In addition, the station in Medina del Campo recorded a lower amount of rainfall over the growing season (around 150 mm) than Villoldo and Encinas del Esgueva (Table 3). Moreover, ETo over the growing season was higher in Medina del Campo (where it reached 1024 mm on average for the 2007–2023 period), Torrecilla de la Orden, and Nava de Arévalo, while it was lower in Encinas del Esgueva (Table 3). Relative humidity over the growing season was lower in Medina del Campo and higher in Villoldo and Encinas del Esgueva (Table 3). Finally, sunlight duration over the growing season was lower in Encinas del Esgueva than in the rest of the stations (Table 3).

Table 3. The mean values ± standard deviation for mean temperature, rainfall, reference evapotranspiration (ETo), relative humidity (RH), and sunlight duration over the growing season, April to October, in the six weather stations considered (2007–2023 period).

Weather Station	Plot	Mean Temperature (°C)	Rainfall (mm)	ETo (mm)	RH (%)	Sunlight (h)
P04-Villoldo	P1	15.3 ± 0.6 b	229.7 ± 66.6 a	901.4 ± 51.9 b	67.0 ± 3.4 a	2429.9 ± 85.9 ab
ZA08-Toro	P2	17.3 ± 0.6 a	190.2 ± 71.8 ab	917.5 ± 36.7 b	59.7 ± 3.2 b	2431.6 ± 75.1 ab
VA102-Medina del Campo	P3	17.6 ± 0.7 a	154.1 ± 71.7 b	1023.9 ± 69.0 a	55.9 ± 4.0 c	2354.2 ± 60.5 b
VA02-Torrecilla de la Orden	P4	17.0 ± 0.9 a	192.2 ± 64.6 ab	999.9 ± 47.2 a	57.5 ± 3.8 bc	2448.2 ± 96.7 ab
VA05-Encinas del Esgueva	P5, P7	15.7 ± 0.7 b	223.7 ± 71.7 a	833.3 ± 42.3 c	63.8 ± 4.2 a	2166.1 ± 99.1 c
AV01-Nava de Arévalo	P6	16.0 ± 1.0 b	199.1 ± 67.9 ab	978.1 ± 105.0 a	61.5 ± 4.6 ab	2486.0 ± 149.5 a

Different letters in the column indicate significant differences among weather stations according to Dunn's test ($p < 0.05$).

Significant differences in the magnitude of bioclimatic indices related to pistachio crop were detected among weather stations. Cumulated GDDs over the growing season were significantly higher in Medina del Campo, Toro, and Torrecilla de la Orden, sites in which they surpassed 2200 °C day, while in Encinas del Esgueva, Nava de Arévalo and Villoldo did not reach 2000 °C day (Figure 2). Nevertheless, a high year-to-year variability was observed in all the weather stations considered.

Those indicators related to chill hours differed among weather stations (Table 4). The number of hours with temperatures lower than 7 °C between November and March was higher in Villoldo and Encinas del Esgueva and lower in Toro (Table 4). The number of hours with temperatures lower than 0 °C was lower in Toro and higher in Encinas del Esgueva (Table 4). Combining these two indicators, the number of hours between 0 °C and 7 °C was higher in Villoldo, significantly greater than the values recorded in Encinas del Esgueva, Medina del Campo, Nava de Arévalo, and Toro (Table 4). However, due to the high interannual variability in the data, no significant differences among weather stations were detected for the number of hours with temperatures higher than 24 °C in April (Table 4).

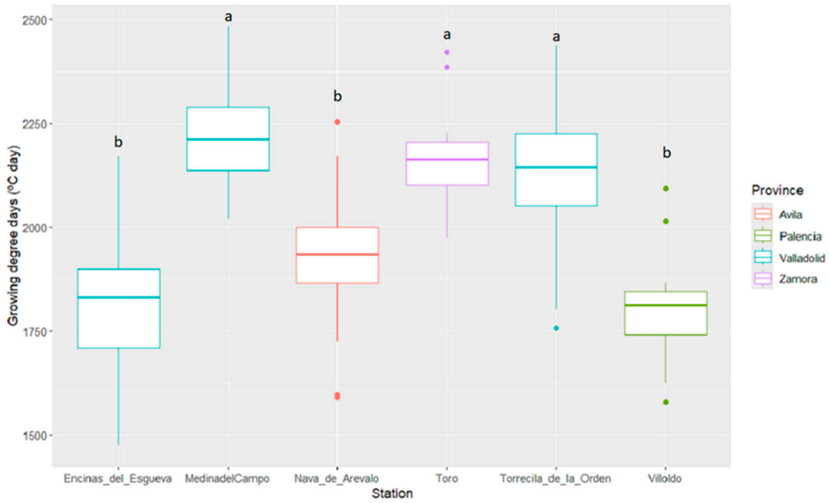

Figure 2. The boxplot for the cumulated growing degree days (GDDs, base temperature = 7.2 °C) between April and September in the six weather stations considered (2007–2023 period). Different letters on the boxes indicate significant differences between weather stations according to Duncan's test ($p < 0.05$).

Table 4. The mean values ± standard deviation for the number of hours below 7 °C and 0 °C between November and March and the number of hours over 24 °C in April in the six weather stations considered (2007–2023 period).

Weather Station	Plot	November—March			April
		Hours < 7 °C	Hours < 0 °C	Hours Between 0 °C and 7 °C	Hours > 24 °C
P04-Villoldo	P1	2438.0 ± 168.2 a	624.7 ± 147.5 ab	1813.4 ± 121.0 a	2.2 ± 4.0
ZA08-Toro	P2	2058.6 ± 166.7 c	500.6 ± 136.5 c	1558.0 ± 132.7 c	11.0 ± 14.6
VA102-Medina del Campo	P3	2113.3 ± 188.8 bc	528.5 ± 130.7 bc	1584.8 ± 163.6 bc	16.6 ± 23.5
VA02-Torrecilla de la Orden	P4	2237.3 ± 233.3 bc	511.9 ± 159.0 c	1725.4 ± 151.4 ab	8.8 ± 13.3
VA05-Encinas del Esgueva	P5, P7	2347.3 ± 171.6 a	727.1 ± 113.7 a	1620.2 ± 151.5 bc	7.0 ± 9.3
AV01-Nava de Arévalo	P6	2263.4 ± 189.2 ab	642.9 ± 163.6 ab	1620.5 ± 152.5 bc	7.0 ± 10.6

Different letters in the column indicate significant differences among weather stations according to Dunn's test ($p < 0.05$).

3.2. Comparison Between On-Site Temperature Records and Weather Stations

Temperature records from the weather stations tended to be lower than those from the sensors deployed on-site, as indicated by the slopes of the linear regressions (Table 5). However, data from both sources were strongly related according to the regression coefficients, never lower than 0.85. The magnitude of ME ranged from −0.24 to −1.51 °C, while RMSE varied from 0.54 to 1.99 °C (Table 5). The nRMSE values were lower than 10, except for two data series. The index of agreement was high, almost 1 in all cases (Table 5).

Table 5. The statistical indicators of the relationships between temperature data collected on-site with those recorded at the nearest weather station.

Plot	Year	n	Statistical Indicators					
			Slope	R^2	ME	RMSE	nRMSE	Index of Agreement
P1—Perales	2019	174	0.9309	0.984	−1.296	1.391	7.776	0.998
	2020	203	0.9298	0.987	−1.175	1.349	8.038	0.998
P2—Toro	2019	189	0.9353	0.979	−1.229	1.441	7.508	0.990
	2020	208	0.9478	0.985	−0.876	1.182	6.435	0.994
P3—Pozal de Gallinas	2019	174	0.9864	0.947	−0.241	1.125	5.862	0.999
	2020	207	0.9924	0.991	−0.154	0.539	3.043	1.000
P4—Carpio	2019	184	0.9800	0.983	−0.397	0.728	3.876	0.994
	2020	214	0.9751	0.876	−0.409	1.987	11.315	0.966
P5—Fombellida	2019	181	0.9240	0.964	−1.406	1.686	9.283	0.998
	2020	173	0.9235	0.967	−1.400	1.675	9.124	0.998
P7—Villafuerte	2019	176	0.9364	0.966	−1.134	1.461	8.075	0.998
	2020	206	0.9103	0.957	−1.508	1.940	11.237	0.997

When computing GDDs from temperature data from both sources, it was evidenced that using records from the weather stations produced lower accumulations of GDDs over the growing season, this difference ranging from 32 °C to 307 °C depending on the site. In summary, this underestimation of GDDs when using temperature data from the weather stations ranged from 1.4% to 14.5% (Table 6).

Table 6. The growing degree days (GDDs) in each plot and year as calculated from the records made by the on-site sensors and the nearest weather station. The difference between both sources is shown in percentage.

Plot	Year	GDD On-Site (°C Day)	GDD Weather Station (°C Day)	Difference (%)
P1—Perales	2019	1899.35	1676.08	11.76
	2020	1989.43	1754.51	11.81
P2—Toro	2019	2305.31	2073.24	10.07
	2020	2350.44	2174.63	7.48
P3—Pozal de Gallinas	2019	2120.16	2078.65	1.96
	2020	2222.10	2190.24	1.43
P4—Carpio	2019	2119.14	2050.33	3.25
	2020	2226.52	2149.25	3.47
P5—Fombellida	2019	2020.36	1766.99	12.54
	2020	1965.53	1724.19	12.28
P7—Villafuerte	2019	1922.71	1725.91	10.24
	2020	2117.93	1810.64	14.51

3.3. Soil Properties in the Pistachio Orchards Surveyed

Soil properties differed among orchards (Table 7). Basic pH (greater than 8) was observed in four locations, whereas the three remaining orchards had a soil pH ranging from 6.7 to 7.4 (Table 7). Soil electrical conductivity was low in all orchards; nevertheless, the orchards located in Carpio and Fombellida showed EC values significantly higher than those from the remaining locations (Table 7). In addition, there were large differences in soil texture among orchards, Madrigal being of sandy texture (>80% sand), while Fombellida and Villafuerte were clayey (>40% clay). Soil organic matter content was low in all plots, only surpassing 1% in Fombellida and Villafuerte (Table 7). Carbonates and active limestone contents were high in Fombellida and Villafuerte but not detectable in the rest of the orchards (Table 7). Phosphorus levels were lower than 30 mg kg^{-1}, except for Madrigal, while potassium levels showed high variability among orchards, ranging from 141 mg kg^{-1} in Perales to 340 mg kg^{-1} in Fombellida (Table 7).

Table 7. Mean values ± standard deviations (n = 3) of the main soil properties in the studied orchards (ND = not detected; EC = Electrical conductivity; OM = Organic matter).

Plot	pH	EC (dS m^{-1})	Sand (%)	Silt (%)	Clay (%)	OM (%)	Carbonates (gCaCO$_3$ 100 g^{-1})	Active Limestone (g 100 g^{-1})	Phosphorous (mg kg^{-1})	Potassium (mg kg^{-1})
P1—Perales	6.74 ± 0.38 c	0.10 ± 0.04 b	66.95 ± 2.75 b	11.76 ± 1.16 ab	21.29 ± 3.88 bc	0.74 ± 0.12 ab	ND b	ND b	9.12 ± 3.52 c	141.25 ± 17.59 c
P2—Toro	7.34 ± 0.36 bc	0.16 ± 0.02 ab	67.16 ± 0.28 b	6.35 ± 0.39 c	26.48 ± 0.11 ab	0.67 ± 0.17 ab	ND b	ND b	15.52 ± 5.90 abc	145.50 ± 32.90 c
P3—Pozal de Gallinas	8.11 ± 0.12 ab	0.10 ± 0.01 b	59.73 ± 10.32 bc	17.26 ± 10.10 ab	23.00 ± 0.92 bc	0.60 ± 0.02 ab	ND b	ND b	23.61 ± 3.31 ab	155.75 ± 20.48 bc
P4—Carpio	8.70 ± 0.10 a	0.26 ± 0.06 a	66.16 ± 2.15 b	9.97 ± 2.15 bc	24.93 ± 0.65 bc	0.45 ± 0.17 b	0.91 ± 1.71 b	0.36 ± 0.61 b	24.12 ± 16.72 abc	220.32 ± 19.24 ab
P5—Fombellida	8.55 ± 0.13 ab	0.31 ± 0.10 a	33.09 ± 4.64 c	19.92 ± 4.64 a	46.99 ± 6.65 a	1.34 ± 0.20 a	62.04 ± 8.33 a	21.61 ± 10.61 a	27.21 ± 5.03 ab	339.92 ± 74.75 a
P6—Madrigal Altas Torres	6.70 ± 0.06 c	0.07 ± 0.04 b	80.95 ± 0.11 a	8.20 ± 2.00 bc	10.86 ± 2.11 c	0.27 ± 0.02 b	ND b	ND b	43.48 ± 26.20 a	148.50 ± 55.86 bc
P7—Villafuerte	8.47 ± 0.05 ab	0.18 ± 0.01 ab	42.07 ± 3.86 c	14.87 ± 0.69 ab	43.06 ± 4.27 a	1.28 ± 0.38 a	44.67 ± 6.12 a	13.26 ± 1.78 a	9.82 ± 3.69 c	228.58 ± 51.72 ab

Different letters in the column indicate significant differences among weather stations according to Dunn's test ($p < 0.05$).

3.4. Effect of Weather Variables on Pistachio Phenology and Yield in Castilla y León

On average for the three surveyed years (2018–2020), 'Kerman' initiated pollen reception (stage C) between 11th and 16th April, depending on the site. The end of the blooming stage (F0) occurred between 3rd and 16th May, while harvest was performed in the second or third week of October depending on the location. In the case of 'Lost Hills', stage C occurred on mid-April in the three plots that included this cultivar, stage F0 occurred on mid-May, and harvest took place in the first week of October. Finally, the phenological cycle of the 'Golden Hills' cultivar coincided with that of 'Lost Hills'.

In terms of GDD accumulation, for 'Kerman', stages C, F0, and harvest occurred at 42.2, 186.7, and 2010.8 °C day, respectively, although there were slight variations among years and locations. In the case of 'Lost Hills' and 'Golden Hills', GDD accumulations of 30.8, 179.4, and 1912.9 °C day marked the occurrence of stages C, F0, and harvest, respectively. As an example, Figure 3 shows the occurrence of several phenological stages of 'Kerman' and 'Lost Hills' cultivars in the Carpio orchard during the 2019 growing season.

In 2018, budbreak for 'Kerman' occurred later in Perales and Villafuerte than in the rest of the sites. The flowering stage lasted longer in Perales, while the harvest date was similar in all sites for the 'Kerman' cultivar. The growing cycle for 'Golden Hills' and 'Lost Hills' was between 9 and 20 days shorter than that of 'Kerman'. In 2019, there was more variability among sites, but the phenological stages behaved in a similar way as they did in 2018. In 2020, there were less differences among sites. Overall, no significant correlations were detected between the dates in which the different phenological stages occurred and the temperature-based indices, except for F0 and GDDs (rho = −0.901, n = 7, *p*-value = 0.006).

A PCA was used to assess how sites would separate according to weather variables and the nut yield of 'Kerman' pistachio. The first two components (PC) of the PCA explained 74.3% of the total variability in the dataset (Figure 4). PC1 accounted for 44% of the total variability and related to temperature-based variables (GDDs, chill hours, and ETo), while PC2 explained 30.3% of the total variability and related to rainfall and nut yield. PC1 separated the Perales orchard from the remaining sites due to its higher number of chill hours (Figure 4). There is a clear separation of samples from 2020 in PC2 due to the higher rainfall and yields observed that year. Finally, the rest of the samples from 2018 and 2019 are not clearly separated (Figure 4).

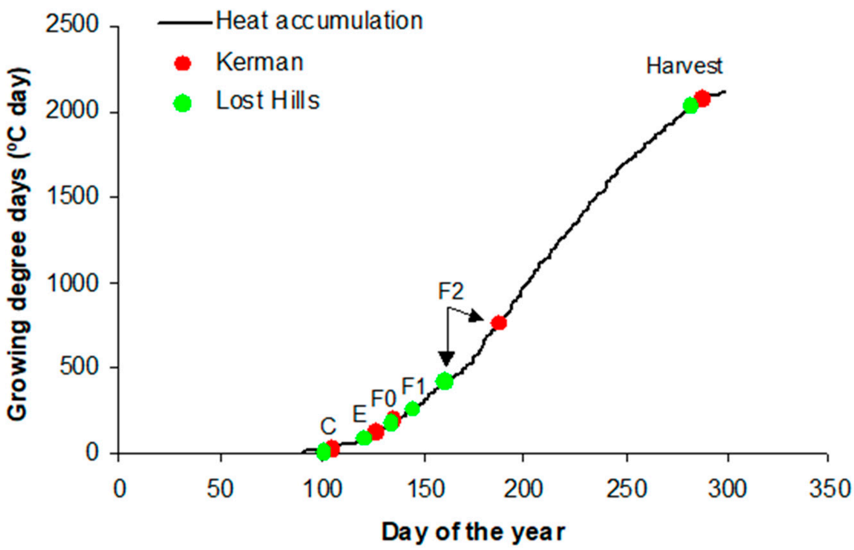

Figure 3. Occurrence of different phenological stages over the growing season of pistachio 'Kerman' and 'Lost Hills' cultivars in Carpio during 2019. C = beginning of pollination reception; E = separated clusters; F0 = end of blooming; F1 = beginning of mesocarp yellowing; F2 = yellow mesocarp.

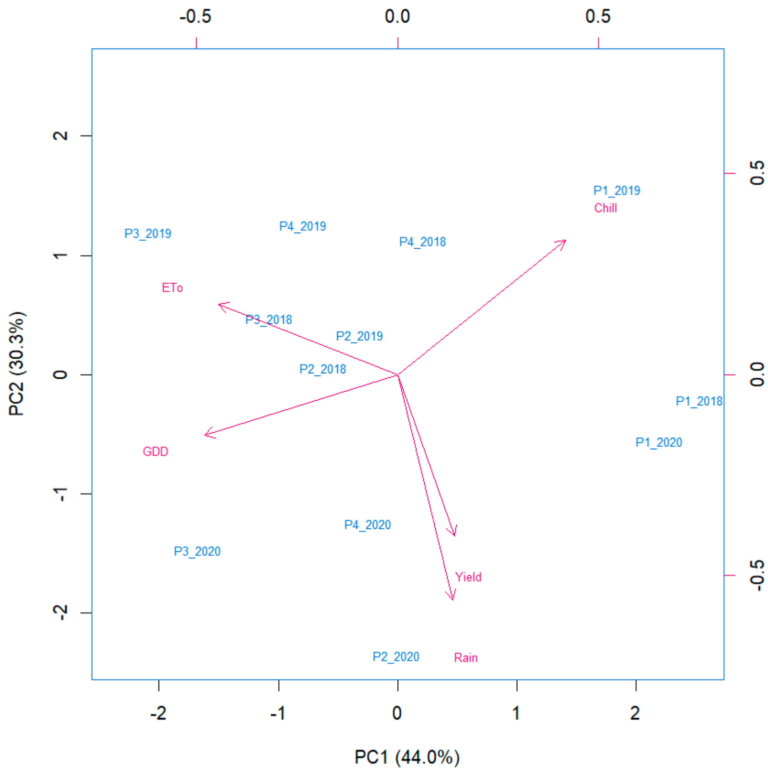

Figure 4. The principal component analysis (PCA) of 'Kerman' pistachio yield: the biplot for the first two components (PC) for bioclimatic variables and yield. P1–P4 represent the surveyed sites: P1 = Perales, P2 = Toro, P3 = Pozal, P4 = Carpio.

Yield was extremely variable depending on the year, the location, and the cultivar (Table 8). Plots 6 and 7 corresponded to young orchards and did not reach the production stage during the study period, so no yield could be obtained from these two plots. Nut yield in dry weight ranged from 6.8 to 10.8 kg per tree in 'Kerman', from 1.3 to 5.7 kg per tree in 'Lost Hills', and from 0.8 to 4.4 kg per tree in 'Golden Hills'. The percentages of non-split and blank nuts were relatively high, ranging from 4.1% to 41.1% and from 16.3% to 33.3%, respectively, depending on the cultivar and location (Table 8). Despite differences in location, no significant relationships of yield and soil properties could be detected.

Table 8. The average (±standard error) yield per tree and percentages of split, non-split, and blank nuts for the 'Kerman', 'Lost Hills' and 'Golden Hills' pistachio cultivars for the seasons 2018–2020 in the orchards surveyed.

Plot	Yield (Dry Weight) (kg tree^{-1})	Nut Classification (%)		
		Split	Non-Split	Blank
'Kerman'				
P1—Perales	10.8 ± 6.8	58.7 ± 16.0	25.0 ± 14.1	16.3 ± 4.4
P2—Toro	9.7 ± 3.2	40.5 ± 13.8	31.5 ± 14.0	28.4 ± 5.5
P3—Pozal de Gallinas	7.7 ± 4.7	31.9 ± 12.6	41.1 ± 18.0	27.0 ± 6.6
P4—Carpio	6.8 ± 1.6	58.7 ± 16.0	25.0 ± 14.1	16.3 ± 4.4
'Lost Hills'				
P4—Carpio	5.7 ± 1.4	49.1 ± 18.8	28.0 ± 11.7	22.8 ± 7.3
P5—Fombellida	1.3 ± 0.2	54.2 ± 7.4	22.8 ± 6.3	23.0 ± 6.1
'Golden Hills'				
P4—Carpio	4.4 ± 2.0	83.4 ± 2.8	4.1 ± 0.3	33.3 ± 14.9
P5—Fombellida	0.8 ± 0.5	43.3 ± 13.1	12.5 ± 2.5	23.4 ± 1.8

3.5. Case Study: Performance of Three Pistachio Cultivars in Castilla y León

Figure 5 shows the nut yield of the studied pistachio cultivars in the Carpio plot over 7 years, from 2016 to 2022. In 2016, all cultivars reached their first commercial production (4–5 years after plantation), and yield per tree showed an increasing trend with successive harvests. However, no yield was recorded in 2017 for any of the cultivars, and a low yield was recorded in 2021 due to damages caused by spring frosts. In general, the highest nut yield was observed in 'Kerman', while the lowest yields were obtained in 'Golden Hills' (Figure 5). In 2021, 'Lost Hills' was the most productive cultivar (Figure 5).

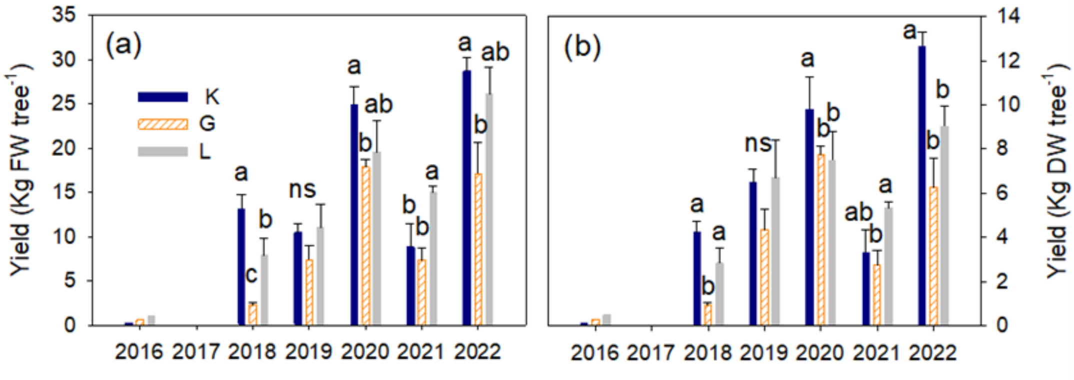

Figure 5. The evolution of the fresh (FW) (**a**) and dry (DW) weight of fruits per tree (**b**) in three pistachio cultivars (K = 'Kerman', G = 'Golden Hills', L = 'Lost Hills') in the Carpio orchard during the experimental period (2016–2022). Different letters indicate significant differences among cultivars according to Duncan's test ($p < 0.05$).

Regarding nut size, 'Lost Hills' fruits were larger (lowest number of nuts per ounce) compared to those of 'Kerman', which produced the smallest nuts, but not significantly different from those of 'Golden Hills' (Figure 6).

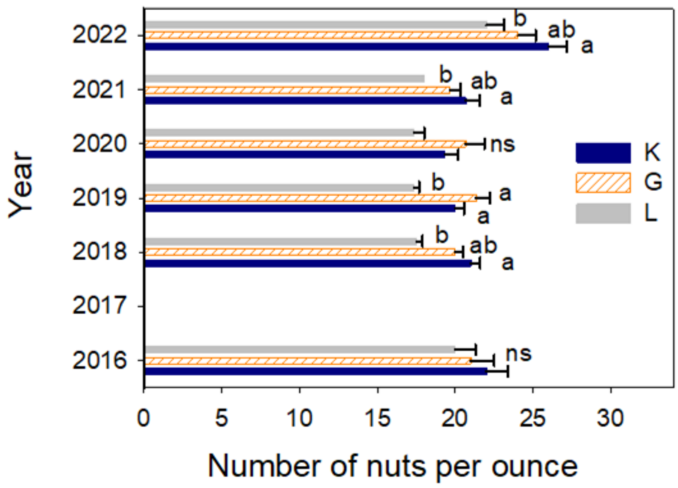

Figure 6. The pistachio sizes (the number of nuts per ounce) in three pistachio cultivars (K = 'Kerman', G = 'Golden Hills', L = 'Lost Hills') grown in the Carpio orchard during the experimental period (2016–2022). Different letters indicate significant differences among cultivars according to Duncan's test ($p < 0.05$), ns = not significant. No nuts were harvested in 2017 due to spring frost damage.

Among the cultivars, 'Kerman' showed the lowest percentage of split nuts and the highest percentage of blank nuts (Figure 7). On average for the studied period, the percentages of split and blank nuts in 'Kerman' were 32.8% and 32.9%, respectively. Contrarily, 'Golden Hills' produced the highest percentage of split (72% on average) and the lowest percentage of non-split and blank (10.8% on average) nuts, except in 2022. In general, the percentage of non-split and blank nuts was relatively high for all cultivars. This is particularly the case of 'Kerman', a variety in which the percentage of non-split nuts ranged between 13 and 48% and that of blank nuts ranged between 15 and 53%, depending on the year (Figure 7).

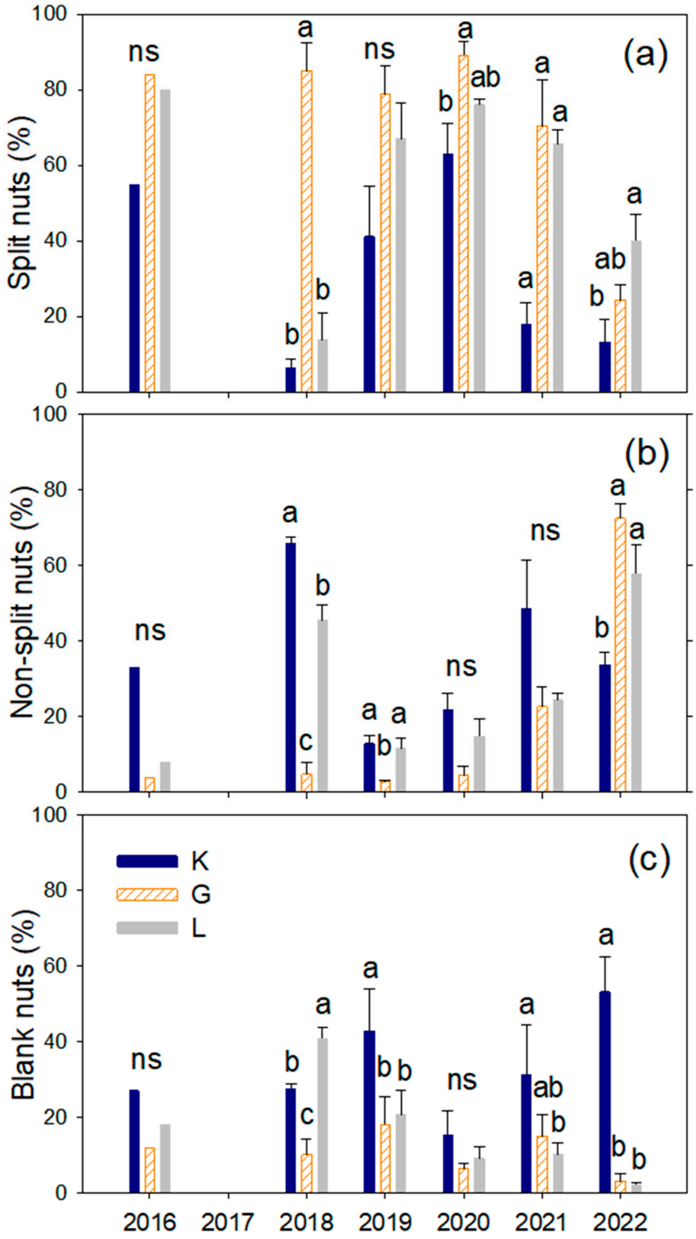

Figure 7. The evolution of the percentage of split (**a**), non-split (**b**), and blank nuts (**c**) in three pistachio cultivars (K = 'Kerman', G = 'Golden Hills', L = 'Lost Hills') grown in the Carpio orchard during the experimental period (2016–2022). Different letters indicate significant differences among cultivars according to Duncan's test ($p < 0.05$), ns = not significant. No nuts were harvested in 2017 due to spring frost damage.

The accumulated yield during the experimental period (2016–2022) is shown in Figure 8. 'Kerman' had the highest cumulated production (dehulled dried pistachios), while 'Golden Hills' had the lowest values (Figure 8a). However, 'Kerman' presented the lowest production of accumulated split nuts during these years (Figure 8b). Moreover, 'Kerman' produced the greatest amount of non-split and blank nuts, while 'Golden Hills' produced the lowest amount of non-split nuts (Figure 8c,d). 'Lost Hills' trees had a greater accumulated production of split nuts (5933 kg ha^{-1}) when compared to 'Golden Hills' (4930 kg ha^{-1}) and 'Kerman' (3785 kg ha^{-1}).

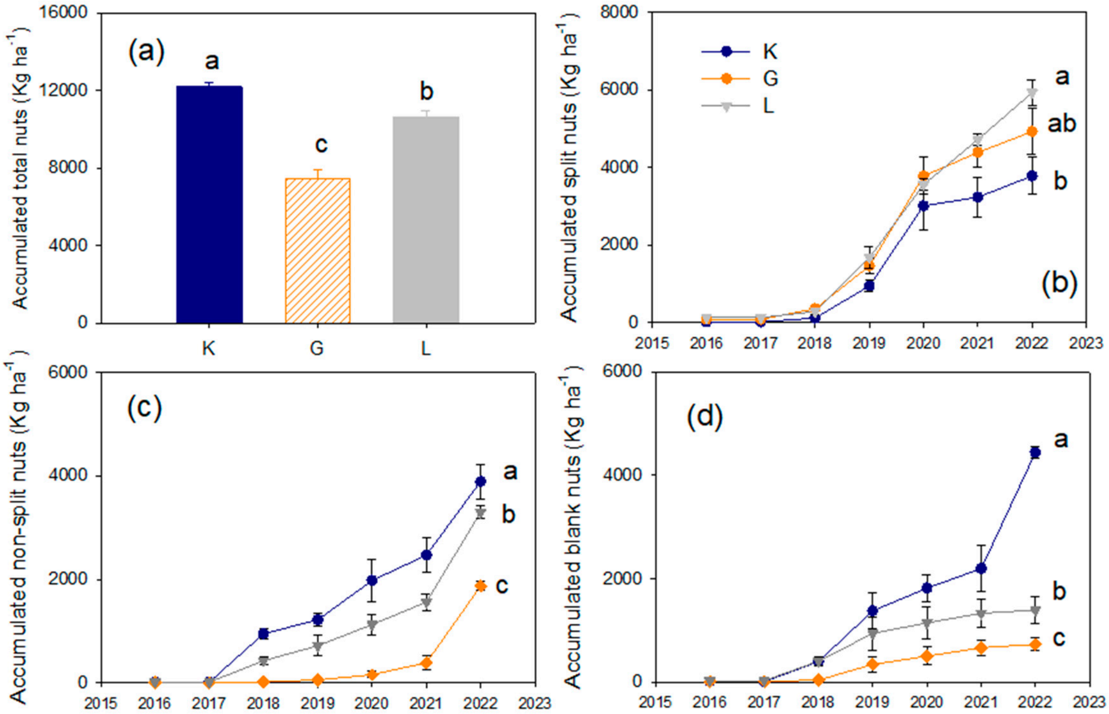

Figure 8. The accumulated yield (**a**) and dry weight of split (**b**), non-split (**c**), and blank nuts (**d**) in three pistachio cultivars (K = 'Kerman', G = 'Golden Hills', L = 'Lost Hills') grown in the Carpio orchard during the experimental period (2016–2022). Different letters indicate significant differences among cultivars according to Duncan's test ($p < 0.05$).

Concerning the relationships between yield and water received (Figure 9a), comparing two years in which the production was not altered by unfavorable weather conditions (2020 and 2022), the yield in fresh weight was similar between years, and the amount of water supplied in 2022 was much lower than that applied in 2020 (Figure 9a). In 2022, the percentage of split nuts was much lower in all cultivars (26 vs. 76%) (Figure 7a). This decrease was more pronounced in 'Golden Hills' and 'Kerman' than in 'Lost Hills'. Similarly, the percentage of non-split nuts sharply increased in 'Golden Hills', while 'Kerman' had a higher percentage of blank nuts in 2022 compared to 2020. However, the differences in total yield between varieties that had been described above remained.

Despite the interannual variability in pistachio yield, a trend to increase the production with the amount of water received can be observed (Figure 9b). The regression coefficient (R^2) obtained suggests that the water received by the trees is the most important factor in explaining the production obtained, although the influence of other factors (frost damage, age of the plantation, etc.) should not be discarded. In fact, the relationship is positive but marginally significant (rho = 0.829, n = 6, p-value = 0.058). The linear model fitted to the averaged data from the three cultivars (Figure 9b) is significant ($F(1,5) = 39.77$, p-value = 0.0015).

A significant relationship between the yield and the calculated bioclimatic indices has not been observed due to these interannual variations in production. However, the average production of the plot tends to increase with increasing GDDs, although the slope of the regression depends on the cultivar (Figure 10a). On average, the relationship is positive and relatively strong but not significant (rho = 0.657, n = 6, p-value = 0.175) (Figure 10b).

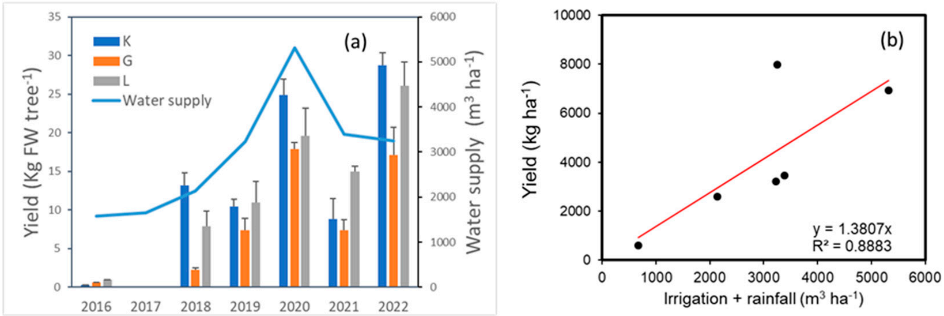

Figure 9. The evolution of fresh weight yield in three pistachio cultivars (K = 'Kerman', G = 'Golden Hills', L = 'Lost Hills') grown in the Carpio orchard and water supply (irrigation + rainfall) (**a**) during the experimental period (2016–2022) and the relationship between average yield of the three cultivars and water supply (**b**).

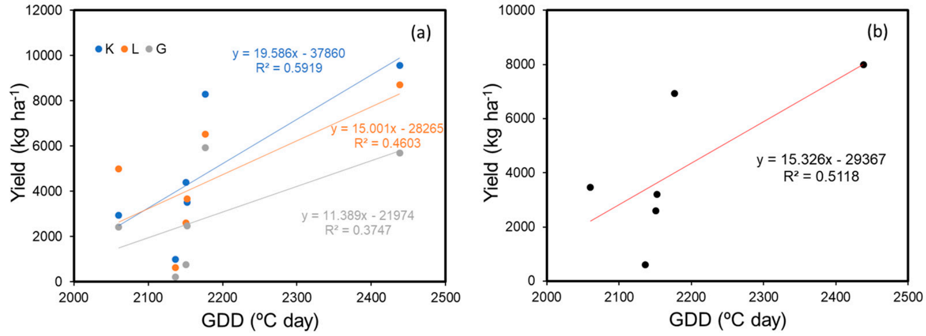

Figure 10. The relationship between growing degree days using the base temperature of 7.2 °C (GDDs) and yield in three pistachio cultivars (K = 'Kerman', G = 'Golden Hills', L = 'Lost Hills') grown in the Carpio orchard (**a**) and relationship between GDDs and the average yield of the three cultivars (**b**) during the experimental period (2016–2022).

4. Discussion

The current study constituted the first attempt to describe the effects of weather-related variables on pistachio performance in Castilla y León, a region in Spain in which this crop is steadily increasing its acreage. In this context, a survey was performed over three years in seven established pistachio orchards spread over a broad range of soil and weather conditions within the region. Moreover, a comparison of the performance of three pistachio cultivars over seven years was carried out in one of the plots, which is located in the area with more acreage of pistachio in this region.

In terms of chilling units, all the surveyed sites surpassed the minimum requirements for an adequate dormancy of pistachios, which are established between 800 and 1000 h with temperatures lower than 7.2 °C for 'Kerman' [24]. Nevertheless, previous reports have shown that when a threshold of chilling is surpassed, the nut yield is reduced, likely due to a mismatch between the blooming of male and female cultivars [10,17]. In the current work, the threshold of 1000 chill hours was surpassed in all sites and years. Conversely, negative temperatures over the month of April were registered in all sites, while in some years negative temperatures also occurred in May, suggesting that this region is prone to spring frost. Nevertheless, temperatures higher than 24 °C during April were also recorded in some years, especially in the provinces of Valladolid and Zamora, which might pose problems during the flowering stage that could negatively affect yield [17]. Therefore, Castilla y León is a region apt for pistachio cultivation in terms of climatic requirements; however, special consideration should be given to spring frosts, which are recurrent in this region.

In this study, the dates in which the different phenological stages of 'Kerman' occurred were slightly delayed from those reported by Armadoro et al. [6] and Guerrero Villaseñor et al. [20] in other Spanish regions, highlighting the relevance of understanding the behavior of pistachio cultivars under local growing conditions. In addition, 'Golden Hills' and 'Lost Hills' were earlier cultivars than 'Kerman' in the current study, being harvested between 9 and 20 days earlier, similarly to reports in California [15,16,25]. Moreover, these cultivars bloomed earlier than 'Kerman', suggesting that their chilling requirements are lower [15,16]; however, this fact makes them more susceptible to spring frost. Conversely, earlier harvests may be an advantage in those plantations with several cultivars because they could allow for an optimization of resources due to the longer time span for harvesting and for minimizing the risks associated with trees bearing fruits for a longer period, such as pest and disease incidence, extreme weather events, etc. [26]. Understanding the phenological cycle of pistachio trees of a given cultivar on a given region is of upmost relevance for optimizing management practices, such as irrigation, pest control, and harvesting operations [27]. The results from the current study serve as a basis for estimating several phenological stages of pistachio tree cv. 'Kerman', 'Golden Hills', and 'Lost Hills' in the center of Spain despite being preliminary. In the future, the database initiated with this study will be completed to generate a model for fruit and kernel development as a function of heat, similar to that reported for California [28].

In a study carried out in California by Kallsen [17], a clear influence of the accumulation of cold hours on the production of pistachio of the 'Kerman' variety was detected. However, this effect has not been observed in the present work since the variety's requirement threshold of around 1000 h of cold [24] has always been exceeded. Likewise, Kallsen [17] pointed out the influence of the yield obtained in the previous year on the production of the current year, an effect that can be sensed in the results of this work. Moreover, no relationships between nut yield and soil properties were detected in the studied orchards, but a trend to slightly higher yields for the 'Kerman' cultivar was observed in orchards with soil organic matter contents greater than 0.65% and pH lower than 8. However, these results are dependent on tree age, management practices, and the inherent year-to-year variability in yield.

In the particular case of the Carpio orchard, the amount of pistachio yield increased from 2016 to 2022 as the trees grow older. In our study, the first harvest occurred in the fourth year after plantation in all cultivars. Kaska [29] and Goldhamer and Beede [3] reported that pistachio trees reach the budding stage and begin to produce from the fifth year after planting, while maximum production can take up to 15 years. Pistachio crop yields in different years are not only affected by cultivar and bearing cycles (genetic factor) but also by the environmental conditions (such as the lack of meeting the chilling requirements, drought, frost, . . .) and orchard management practices, such as irrigation, nutrition, pest control, or orchard pruning operations [30]. In this regard, no nuts were harvested in 2017 due to damage caused by spring frosts. In addition, the nut yields corresponding to 2019 and 2021 were partially reduced by spring frosts.

In the current study, 'Kerman' trees were the most productive, while the lower yields were obtained from 'Golden Hills' in terms of accumulated total nut yield. In addition, our study showed that 'Lost Hills' had a lower number of nuts per ounce than 'Kerman'. The number of nuts per ounce is a marketing index that shows the size and weight of pistachio nuts: the lower the number of nuts per ounce, the larger the nut size [26]. These results agree with those described by Parfitt et al. [16], who demonstrated that the 'Lost Hills' variety has larger fruits than 'Kerman'. The market is demanding large-sized pistachios for snacks and green kernelled pistachio for the food processing industry [29]. In this context, 'Lost Hills' seems a promising cultivar for the studied region since its yield was comparable to that of 'Kerman' but with larger nuts and a lower proportion of blank and non-split nuts when compared to the other two cultivars ('Kerman' and 'Golden Hills').

Moreover, the comparison of the three pistachio cultivars in terms of total yield indicated that 'Kerman' cultivar was superior to the other two cultivars but also had higher percentage of non-split and blank nuts, in line with previous reports [15,16]. Nevertheless, the present study showed that the percentages of non-split and blank nuts were quite high in all cultivars and years, especially in 'Kerman', and could lead to poor marketable quality nuts [29,31,32]. The degree of shell splitting is a determining quality factor in pistachio, as most pistachios are marketed in the shell [26], and the split nuts represent more economic value than the rest of the harvest [33]. Moreover, blank nut production makes an inefficient use of energy, nutrition, and water during the growing season, so the understanding of this issue is important [34,35]. In this sense, our results provide information for guiding cultivar choice before plantation in the region of Castilla y León (Spain) and others with similar weather conditions.

In this study, the harvest was performed manually, collecting all the fruits present on each tree, which must be considered because after a mechanical harvesting, the fruits that usually remain on the tree are blank nuts [35]. The fact that 'Kerman' produced an excessive number of blank nuts compared to the other varieties could have been caused by excessively high temperatures during flowering or insufficient pollination [17] since the chilling requirements have been exceeded in all campaigns of this study.

When comparing yield values from 2022 with respect to 2020, the two years with similar production in the current study, the increase in the percentage of non-split nuts was more marked in 'Golden Hills' while that of blank nuts in 'Kerman'. In the present study, the amount of water supplied (irrigation + rainfall) affected the quality of pistachio nuts and modified the percentage of splitting, as previously reported by Gijón et al. [36] and Martínez-Peña et al. [37]. Besides irrigation conditions, nut quality can be also affected by other factors, such as branch crop load or kernel growth [38], but these have not been considered in the current study. According to Kaska [29], the 'Kerman' cultivar may have more than 85% naturally split nuts. In contrast, Zhang and Ranford [35] proposed that blank nuts usually represent about 25% of the total nut production based on nut counts. In contrast, 'Kerman' reached values of blank nuts above 50% in our study, much higher than the percentages mentioned in previous research [29,35].

As for the effects of irrigation management, from among the three pistachio cultivars, 'Lost Hills' was less affected by low water availability than 'Kerman' and 'Golden Hills' in terms of the degree of shell splitting.

In conclusion, the current study provides useful information for supporting decisions when planning a new pistachio plantation in a cold-winter region, with climate factors different from those in areas where the pistachio is a major crop. Pistachios could become an alternative to some traditional crops in cold-winter regions of Spain, particularly in Castilla y León. Pistachio has a significant potential to develop in this region because of its capacity to obtain profitable yields even under cold conditions, where heat accumulation is limiting. However, the results of this study suggest that in the case of Castilla y León, there are a number of additional factors that need to be consider (including water restrictions, irrigation, spring frost, and inadequate heat units) to ensure the sustainability and profitability over time of pistachio orchards.

Author Contributions: Conceptualization, S.Á., H.M. and J.M.M.-A.; methodology, L.N. and H.M.; validation, J.M.M.-A.; formal analysis, L.N., J.M.M.-A. and S.Á.; data curation, J.M.M.-A. and S.Á.; writing—original draft preparation, J.M.M.-A. and S.Á.; writing—review and editing, J.M.M.-A. and S.Á.; funding acquisition, S.Á. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by MCIN/AEI/10.13039/501100011033 and European Union «NextGenerationEU»//PRTR, grant number RYC2021-033890, and by MCIN/AEI/10.13039/501100011033 and FSE+, grant number PRE2021-098641. Co-financed by FEADER funds and Junta de Castilla y León (Spain).

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: We express our deepest gratitude to the owners of the pistachio orchards for allowing us to perform this study in their exploitations.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A

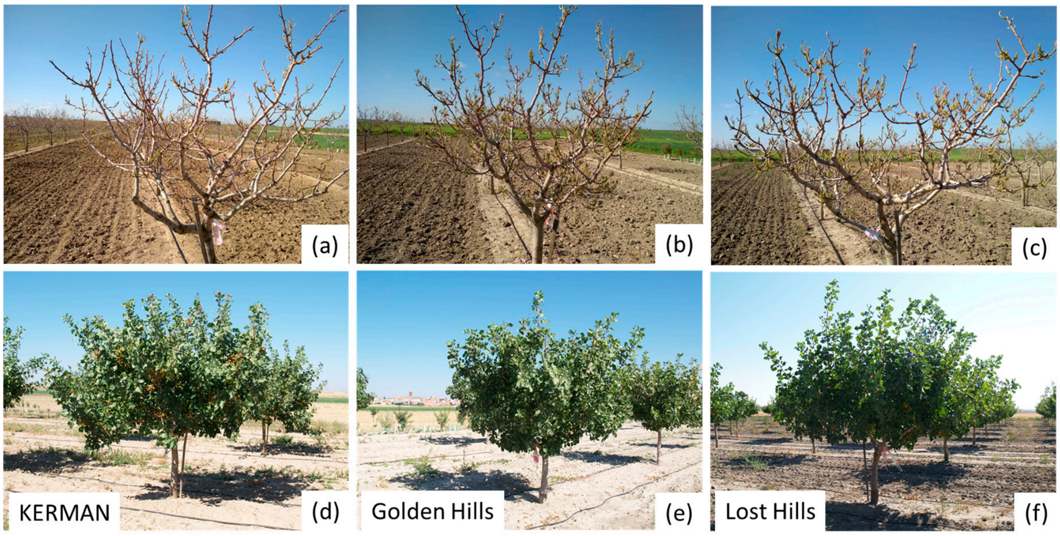

Figure A1. The general aspect of the selected trees from three pistachio cultivars ('Kerman', 'Golden Hills' and 'Lost Hills') grown in the Carpio orchard during the experimental period. In the beginning of the vegetative period, May 2018 (**a**–**c**) and in August 2018 (**d**–**f**).

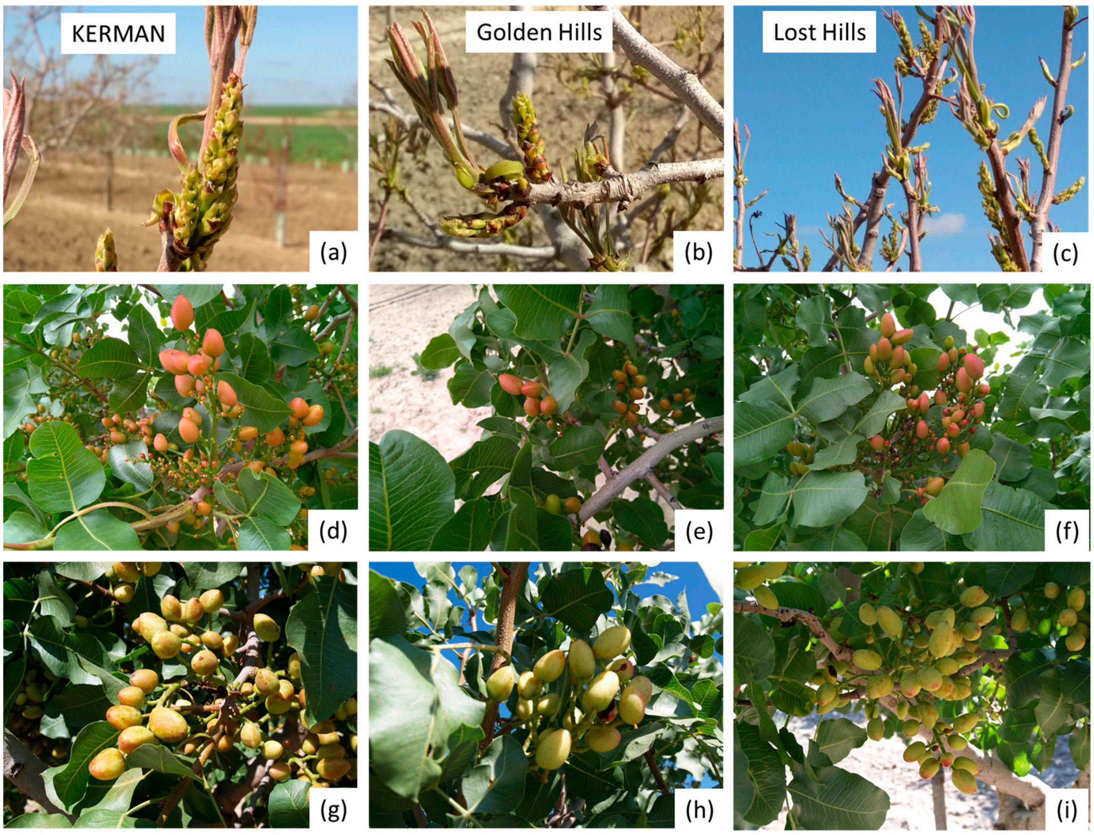

Figure A2. The detail of the flowers, leaves, and fruits in three pistachio cultivars ('Kerman', 'Golden Hills', and 'Lost Hills') grown in the Carpio orchard during the experimental period: at the beginning of the vegetative period, May 2018 (**a**–**c**), June 2018 (**d**–**f**), and in August 2018 (**g**–**i**).

References

1. Luedeling, E. Climate change impacts on winter chill for temperate fruit and nut production: A review. *Sci. Hortic.* **2012**, *144*, 218–229. [CrossRef]
2. Elloumi, O.; Ghrab, M.; Kessentini, H.; Ben Mimoun, M. Chilling accumulation effects on performance of pistachio trees cv. Mateur in dry and warm area climate. *Sci. Hortic.* **2013**, *159*, 80–87. [CrossRef]
3. Goldhamer, D.A.; Beede, R.H. Regulated deficit irrigation effects on yield, nut quality and water-use efficiency of mature pistachio trees. *J. Hortic. Sci. Biotechnol.* **2004**, *79*, 538–545. [CrossRef]
4. Monastra, F.; Avanzato, D.; Martelli, S.; Dascanio, R. Pistachio trial under different volumes of irrigation in Italy. *Acta Hortic.* **1995**, *419*, 249–252. [CrossRef]
5. García-Tejero, I.F.; Hernández-Cotán, A.; Muriel-Fernández, J.L.; García-Valverde, F.; Durán-Zuazo, V.H. Towards sustainable water management for pistachio (*Pistacia vera* L.) production under drought conditions: A review. In *Advances in Environmental Research*; Daniels, J.A., Ed.; Nova Science Publishers, Inc.: Hauppauge, NY, USA, 2017; Volume 55, pp. 127–157.
6. Armadoro, S.; Rodrigo-Gómez, S.; Armadoro, L.; Guerrero, J. Estudio preliminar de la respuesta fenológica de los principales cultivares de *Pistacia vera* L. en España frente al cambio climático. *Rev. Cien. Agric.* **2023**, *46*, 107–116.
7. MAPA. *Anuario de Estadística 2022*; Ministerio de Agricultura, Pesca y Alimentación, Gobierno de España: Madrid, Spain, 2023.
8. Barajas, E.; Álvarez, S.; Fernández, E.; Vélez, S.; Rubio, J.A.; Martín, H. Sentinel-2 satellite imagery for agronomic and quality variability assessment of pistachio (*Pistacia vera* L.). *Sustainability* **2020**, *12*, 8437. [CrossRef]
9. Marino, G.; Lima, P.; Maskey, M.L.; Rojo, F.; Snyder, R.L.; Shapiro, K.; Suvocarev, K.; Sanden, B.; Zaccaria, D. Maximum daily trunk shrinkage sensitivity to water use of pistachio under saline conditions. *Acta Hortic.* **2021**, *1314*, 47–52. [CrossRef]
10. Benmoussa, H.; Luedeling, E.; Ghrab, M.; Ben Yahmed, J.; Ben Mimoun, M. Performance of pistachio (*Pistacia vera* L.) in warming Medi-terranean orchards. *Environ. Exp. Bot.* **2017**, *140*, 76–85. [CrossRef]
11. Campoy, J.A.; Ruiz, D.; Egea, J. Dormancy in temperate fruit trees in a global warming context: A review. *Sci. Hortic.* **2011**, *130*, 357–372. [CrossRef]
12. Jones, H.G.; Gordon, S.L.; Brennan, R.M. Chilling requirement of Ribes cultivars. *Front. Plant Sci.* **2015**, *5*, 0767. [CrossRef]
13. Kallsen, C.E.; Parfitt, D.E.; Maranto, J.; Holtz, B.A. New pistachio varieties show promise for California cultivation. *Calif. Agric.* **2009**, *63*, 18–23. [CrossRef]
14. Kallsen, C.E.; Parfitt, D.E.; Maranto, J. UC pistachio cultivars show improved nut quality and are ready for harvest earlier than ‘Kerman’. *Calif. Agric.* **2020**, *74*, 86–93. [CrossRef]
15. Parfitt, D.E.; Kallsen, C.; Maranto, J.; Holtz, B. ‘Golden Hills’ pistachio. *HortScience* **2007**, *42*, 694–696. [CrossRef]
16. Parfitt, D.E.; Kallsen, C.E.; Holtz, B.; Maranto, J. ‘Lost Hills’: A new pistachio cultivar. *HortScience* **2008**, *43*, 247–249. [CrossRef]
17. Kallsen, C.E. Temperature-related variables associated with yield of ‘Kerman’ pistachio in the San Joaquin Valley of California. *HortScience* **2017**, *52*, 598–605. [CrossRef]
18. Carter, M.R.; Gregorich, E.G. (Eds.) *Soil Sampling Methods of Analysis*; Canadian Society of Soil Science: Pinawa, MB, Canada; CRC Press: Boca Raton, FL, USA, 2008; p. 1224.
19. Olsen, S.R.; Sommers, L.E. Phosphorus. In *Methods of Soil Analysis Part 2 Chemical and Microbiological Properties*; Page, A.L., Ed.; American Society of Agronomy: Madison, WI, USA, 1982; pp. 403–430.
20. Guerrero Villaseñor, J.; Gijón López, M.C.; Moriana Elvira, A.; Rivero Rincón, A.; Couceiro López, J.F. El pistachero en Castilla La Mancha. Primeros resultados (y 2). El cultivo en secano. *Frutic. Prof.* **2008**, *173*, 36–45.
21. Yang, J.M.; Yang, J.Y.; Liu, S.; Hoogenboom, G. An evaluation of the statistical methods for testing the performance of crop models with observed data. *Agric. Syst.* **2014**, *127*, 81–89. [CrossRef]
22. Spearman, C. The proof and measurement of association between two things. *Amer. J. Psycol.* **1904**, *15*, 72–101. [CrossRef]
23. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2023; Available online: https://www.R-project.org/ (accessed on 25 January 2024).
24. Crane, J.C.; Takeda, F. The unique response of the pistachio tree to inadequate winter chilling. *HortScience* **1979**, *12*, 135–137. [CrossRef]
25. Adaskaveg, J.A.; Wei, Y.; Wang, S.; Marino, G.; Blanco-Ulate, B. Characterizing varietal differences of pistachio development and nut quality at harvest. *Acta Hortic.* **2024**, *1406*, 91–95. [CrossRef]
26. Panahi, B.; Khezri, M. Effect of harvesting time on nut quality of pistachio (*Pistacia vera* L.). *cultivars. Sci. Hortic.* **2011**, *129*, 730–734. [CrossRef]
27. Zhang, L.; Ferguson, L.; Ying, L.; Lyons, A.; Laca, E.; Ampatzidis, Y. Developing a web-based pistachio nut growth prediction system for orchard management. *HortTechnology* **2024**, *34*, 1–7. [CrossRef]
28. Zhang, L.; Laca, E.; Allan, C.J.; Mahvelati, N.M.; Ferguson, L. Nonlinear model selection for fruit and kernel development as a function of heat in pistachio. *HortScience* **2021**, *56*, 769–779. [CrossRef]
29. Kaska, N. Pistachio nut growing in the Mediterranean basin. *Acta Hortic.* **2002**, *591*, 443–455. [CrossRef]
30. Abdolahi-Ezzatabadi, M.; Esmaeilpour, A.; Sedaghat, R.; Panahi, B. The factors affecting time series fluctuations of pistachio yield. *Pist. Health J.* **2021**, *4*, 30–50. [CrossRef]
31. Crane, J.C.; Iwakiri, B.T. Pistachio yield and quality as affected by rootstock. *HortScience* **1986**, *21*, 1139–1140. [CrossRef]
32. Martínez-Peña, R.; Castillo-Gironés, S.; Álvarez, S.; Vélez, S. Tracing pistachio nuts’ origin and irrigation practices through hyperspectral imaging. *Curr. Res. Food Sci.* **2024**, *9*, 100835. [CrossRef]

33. Memmi, H.; Gijón, M.C.; Couceiro, J.F.; Pérez-López, D. Water stress thresholds for regulated deficit irrigation in pistachio trees: Rootstock influence and effects on yield quality. *Agric. Water Manag.* **2015**, *164*, 58–72. [CrossRef]
34. Pourahmadi, E.; Mohamadkhani, A.; Roshandel, P.; Rohi, V.; Khademi, O. Amelioration of physiological disorders in pistachio nuts by organic manure and gypsum. *Sci. Hortic.* **2019**, *248*, 225–230. [CrossRef]
35. Zhang, J.; Ranford, T. Identification of Key Periods of Temperature Influence on 'Sirora' Pistachio Nut Quality. *HortTechnology* **2021**, *31*, 266–273. [CrossRef]
36. Gijón, M.C.; Guerrero, J.; Couceiro, J.F.; Moriana, A. Deficit irrigation without reducing yield or nut splitting in pistachio (*Pistacia vera* cv Kerman on *Pistacia terenbinthus* L.). *Agric. Water Manag.* **2009**, *96*, 12–22. [CrossRef]
37. Martínez-Peña, R.; Vélez, S.; Vacas, R.; Martín, H.; Álvarez, S. Remote Sensing for Sustainable Pistachio Cultivation and Improved Quality Traits Evaluation through Thermal and Non-Thermal UAV Vegetation Indices. *Appl. Sci.* **2023**, *13*, 7716. [CrossRef]
38. Marino, G.; Guzmán-Delgado, P.; Santos, E.; Blanco, B.; Adaskaveg, J.A.; Caruso, T.; Ferguson, L.; Marchese, A.; Marra, F.P. Effect of branch crop load on assimilation rates and nut growth of fully irrigated pistachio. *Acta Hortic.* **2024**, *1406*, 165–168. [CrossRef]