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Changes in the Morphological Characteristics of Potato Plants Attributed to Seasonal Variability

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Abstract: The development of a potato crop differs according to the environmental conditions and growing season of an area. Periods of high temperatures and drought have been frequent in recent years, and this has affected crops worldwide. The effect of meteorological factors on the plant morphology of potato cultivars growing in A Limia was analyzed for three consecutive years. The crop cycle with the highest temperatures and least accumulated rainfall (2016) showed plants with a higher number of leaflets, which were shorter in length. The crop cycle (2014) with a lower temperature and more rainfall had the tallest plants, the highest degree of flowering, fewer pairs of leaflets and the highest length of the floral peduncle. Kennebec and Fontane were the varieties that showed the least variability in morphological characteristics during the seasons analyzed. Considering the meteorological and morphological data, a principal component analysis was carried out, which explained 80.1% of the variance of the data. Spearman rank correlations showed higher significant coefficients between the temperature and foliar characteristics. The leaf size of plants was estimated using a multiple linear regression analysis, which included the mean temperature, explaining 64% of the variability of the data.

Keywords: *Solanum tuberosum*; climatic elements; foliar characters; statistical multivariate analyses; temperature

1. Introduction

Climate change and climate variability will potentially influence the conditions for agriculture globally [1]. Forecasts of global warming and periods of high temperature and drought are frequent and encourage researchers to study the response of crops to changes in temperature [2–6]. Higher growing season temperatures can significantly affect agricultural productivity, farm incomes and food security [7]. In the coming years, the climate is expected to become gradually milder and more humid in Northern Europe, and hotter and drier in Southern Europe. Therefore, the productivity of crops is projected to increase in mid and high latitudes, extending northwards, especially for cereals and cool season seed crops [8,9]. Crops prevalent in Southern Europe, such as maize, sunflower and soya beans, could also become viable further north and at higher altitudes [1,9].

Potato (*Solanum tuberosum*) is one of the most important crops in the world. Since the expansion of the potato crop from the Andean highlands, more than 4500 cultivars have been adapted to different environments, with breeding programs originating from a very complex genetic pool [10]. This diversity of potato varieties depends on the geographical area, which is conditioned mainly by the climate. Several researchers indicated the influence of some environmental factors, such as the day length, solar radiation, temperature, rainfall or photoperiod in the development of potato plants [7,11–15]. Potato plants grow best in a cool climate during the frost-free season and do not perform well in heat [2,16]. The potato yield is highly dependent on temperature, and when droughts occur, providing irrigation is fundamental for successful growth. An increase in temperature shortens the life cycle of plant growth, resulting in smaller tubers and, consequently, a shorter reproductive phase duration and lower yield potential [17]. The optimal values for the growth of the aerial potato plant and the tubers are different [13]. The optimal growth temperature of the potato is considered to be between 16 and 25 °C, while the minimum temperature thresholds for tuber initiation and tuber bulking range from 4 to 18 °C, and at high temperatures, tuberization decreases [13,18].

The prediction and quantitative evaluation of phenological and morphological aspects play a pivotal role in assessments of the effects of climate change [6,14]. In this context, the lengthening of the growing seasons, mainly in the crops of Northern Europe, will cause a sowing and harvest time adjustment [2,7]. Consequently, the development of adaptation practices is necessary to mitigate the effect of climate change. Each modern agricultural practice contributes to the loss of potato diversity and influences production around the world. The adaptation of different plants to climate change will be a decisive factor in determining how agriculture will develop in future seasons [15,19].

An increase in the mean seasonal temperature can bring forward the harvest time of the current varieties of many crops and hence reduce the final yield, without adaptation to a longer growing season [1]. Undoubtedly, one of the most important challenges for modern agriculture is to develop strategies to deal with the possible negative impacts of climate change, with the objective of guaranteeing future food security. On the other hand, the botanical characterization of the leaf, stem and flower of potato cultivars has been poorly described [20–24]. In recent years, phenological descriptions and the influence of climate change with respect to the development stages of the potato crop were investigated in more detail [2,5,25,26]. However, the morphology of potato plants is the first step in the characterization of the potato cultivars. The study of the influence of meteorological factors on the development of potato plants is a useful tool for improving agricultural programs. The present paper evaluated the influence of the weather during three growing potato cycles on the plant morphology of sixteen potato cultivars produced in A Limia (Northwest Spain).

2. Material and Methods

2.1. Growing Potato Area

The research was conducted for three consecutive years (2014, 2015 and 2016) in A Limia (Northwest Spain) (Figure 1). The potato crop cycles in this area are between April and September, depending on the climatic conditions of each year. A Limia is the biggest production area for rainfed potato in the Iberian Peninsula. In this inland territory, the weather is characterized by a combination of Oceanic and Mediterranean features with a continental tendency. Rainfall and a mild temperature in winter, and high average temperatures and important drought intervals in summer are the climatic characteristics.

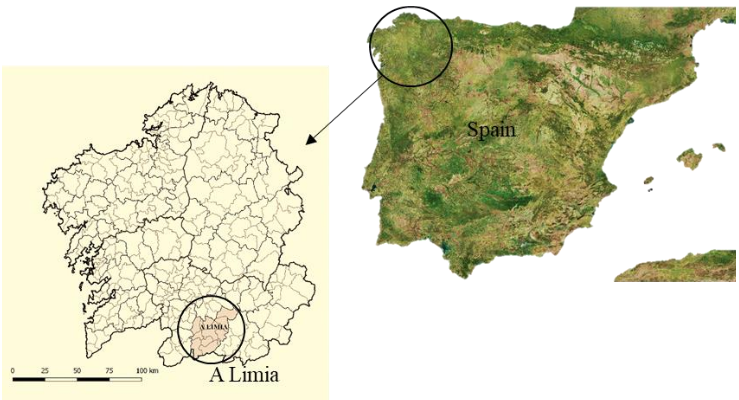
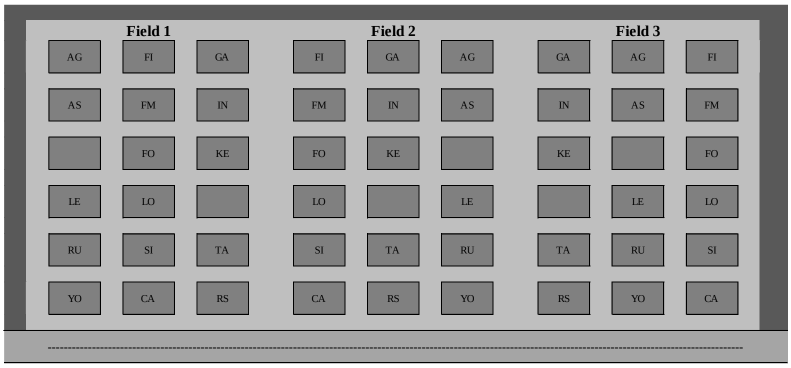


Figure 1. Location of the study area (A Limia).

2.2. Potato Cultivars

Sixteen potato cultivars were taken into account for this study, from cultivars with a cream color flesh (Cazona, Fina, Flamenco, Kennebec, Rudolph and Sifra), yellow flesh (Arsenal, Ganade, Innovator, Loane, Red Scarlett, Taurus and Yona), and dark yellow flesh (Agria, Fontane and Leonardo). Each potato cultivar was monitored in three plots, which were randomly distributed across experimental field trials, planted by the Agricultural Centre of INORDE in A Limia. Each test plot was distributed in six rows, in which each potato cultivar had approximately ninety potato plants by plot as the scheme (Figure 2).



(A)

(B)

Figure 2. Scheme of the distribution of the potato cultivars in test plots (**A**). Image of a part of the field test (Field 2) showing the distribution of the plots during the germination of the potato plants (**B**).

2.3. Monitoring of Meteorological Factors

Five weather parameters were used: the mean, minimum and maximum temperature (°C), relative humidity (%) and rainfall (L/m^2). The meteorological factors were recorded with a portable weather station, ONSET HOBO Pro Series H08-032-08 (ONSET, Bourne, USA), which was placed in the study field. The data per hour were extracted. The rainfall data were provided by the National Weather Service website, which has a weather station at a distance of approximately 500 m from the experimental field [27]. The analysis of meteorological data was carried out in consideration of the main phenological phases of the crop. The phenological observations in three phases were distributed: from sowing to emergence (phase 0), from emergence to flowering (phase 1), and from flowering until the onset of senescence (phase 2). The duration of the phases was calculated basing on the average days for each cultivar per crop year.

2.4. Description of the Morphological Characteristics of Potato Plants

The morphological study was carried out during the corresponding stages of the phenological development of the potato cycle. The samples to be analyzed were collected from two plants per plot for each potato cultivar. Therefore, the measures were performed with eighteen plants per variety (six for each year). A morphological description was made, following the methodology of Huamán [22], with some modifications. Some botanical characteristics were evaluated by codes, i.e., they do not contain a numerical measure (Table 1). General characteristics of the plants (such as the height of the plant, the degree of flowering and the presence of fruits) were observed within the three entire plots of each variety. The rest of the morphological characteristics, including the leaves and flowers, were measured in two plants per plot. The established phenological periods (phase 0, phase 1 and phase 2) were taken into account to analyze the relationships between the meteorological and morphological variables.

Table 1. Morphological characteristics evaluated and methodology used.

General Characteristics	Codification/Methodology
Height of plant *	Short (<0.75 m) (3), medium (0.75–1 m) (5), tall (>1 m) (7).
Degree of flowering *	Absent or very low (0), flower buds that fall (1), low (3), medium (5), profuse (7).
Leaf characteristics	
Number of primary lateral leaflet pairs	Counting the number of pairs.
Number of interjected leaflets	Counting the number of interjected leaflets.
Number of secondary lateral leaflet pairs	Counting the number of pairs.
Length of terminal leaflet	Measurement with metric ruler in cm.
Width of terminal leaflet	Measurement with metric ruler in cm.
Length of lateral leaflet	Measurement with metric ruler in cm.
Width of lateral leaflet	Measurement with metric ruler in cm.
Divergence angle	Divergence angle between leaf and stem.
Floral characteristics	
Length of peduncle	Measurement with metric ruler in cm.
Number of flowers per inflorescence	Counting flowers individually.
Flower size *	No flower (0), short (<30 mm) (1), intermediate (30–40 mm) (3), large (41–50 mm) (5), very large (>50 mm) (7).
Fruit *	Absence (0), presence (1).

* Codified characteristics according to Huamán [22].

2.5. Statistical Analyses

The meteorological and morphological data were statistically analyzed using SPSS 21.0 software (IBM, Armondk, USA) package for Windows and STATGRAPHICS Centurion XVI software (Statpoint Technologies, Inc., The Plains, USA). A variance analysis (ANOVA) using the Bonferroni test was performed ($p < 0.05$). The relationships between the described variables were analyzed a through a Spearman rank correlations and principal component analysis. Considering the significant meteorological variables, a multiple linear regression analysis was applied to evaluate which of the morphological characteristics described could be estimated.

3. Results

3.1. Growing Conditions of the Potato Crop Cycles

The main meteorological factors during the three phases of potato crop development (phase 0, phase 1 and phase 2) were analyzed. Significant differences in the weather factors between the analyzed crop cycles are shown in Table 2. The temperature (mean, minimum and maximum) was significantly higher in 2016, recording lower values (mean and maximum) in phase 0. The crop cycle of 2014 showed mean and maximum temperatures significantly lower during the three phases of phenological development than those of other cycles. The 2014 cycle showed significantly higher values in the mean accumulated rainfall than the other cycles, principally in phase 0. The mean relative humidity of the 2014 cycle was significantly higher than in the cycle of 2016, recording the higher values in this parameter in phase 1. In summary, temperature was the factor that showed the main differences during the development of the potato crop. There is a tendency toward a slight increase in temperature in the three years analyzed. The last crop cycle was the warmest, registering the highest average and maximum values in the three phases considered, with maximum average temperatures above 34 °C in the last two phases. Conversely, 2014 was the coldest year, registering the lowest mean temperatures (principally in phase 0).

Table 2. Mean data of the meteorological parameters according to the main phenological phases and potato crop cycle.

Meteorological Variables	2014	2015	2016
Mean temperature (°C)			
Phase 0	13.3 a	14.6 a	17.7 b
Phase 1	17.8 a	18.8 a	21.1 b
Phase 2	19.0 a	20.9 b	21.2 b
Complete cycle	16.8 a	18.7 b	20.3 c
Minimum temperature (°C)			
Phase 0	6.1 a	4.0 a	10.0 b
Phase 1	8.9	7.5 a	10.0 b
Phase 2	9.7	9.0	8.8
Complete cycle	8.3	7.4 a	9.5 b
Maximum temperature (°C)			
Phase 0	20.8 a	24.0	27.2 b
Phase 1	26.5 a	30.1 b	34.5 c
Phase 2	27.7 a	32.5 b	34.9 c
Complete cycle	25.2 a	29.7 b	32.8 c
Mean accumulated rainfall (L/m^2)			
Phase 0	1.4	0	1.1
Phase 1	0.9 a	0.2	0.1 b
Phase 2	0.8	0	0.2
Complete cycle	1.0 a	0.1 b	0.4 b
Mean relative humidity (%)			
Phase 0	74.8	75.1	76.4
Phase 1	76.0 a	70.7	66.3 b
Phase 2	71.5	68.4	67.6
Complete cycle	74.0 a	70.8	69.3 b

Different letters (a,b,c) indicate significant differences between the mean values of each meteorological parameter recorded by crop cycle.

3.2. Differences in the Morphological Characteristics by Crop Cycle

The effect of temperature, relative humidity and accumulated rainfall on the morphological characteristics of potato varieties cultivated in A Limia is shown in Table 3. Measurement of the foliar and floral morphology was conducted during growing phase 1, which is the vigor phase of the plants. The crop cycle of 2014 had the tallest plants and the highest degree of flowering. In general, there were differences in the leaf characteristics between the years. The plants of the 2014 cycle had the lowest number of primary lateral leaflet pairs. In addition, the size of the terminal and the primary lateral leaflets (both length and width) and the divergence angle were significantly different for the three crop cycles. The plants of the 2014 cycle had the significant highest mean values for both leaflets.

Conversely, the plants of 2016 presented the lowest mean value. The highest mean value of the angle of divergence was in 2014 and the lowest was in 2016. Regarding the floral characteristics, the longest peduncle and the lowest number of flowers per inflorescence were registered in 2014. The size of the flower was significantly lower in 2016 than in other cycles. Finally, in this crop season, plant fruits were not found.

Table 3. Mean data of the morphological characteristics of all plants by potato crop cycle.

	2014	2015	2016	Potato Variety
General characteristics				
Plant height *	4.3 a	3.4 b	3.0 c	AG, AS, FI, FM, FO, KE, RU, TA, YO
Degree of flowering *	5.4 a	4.6 b	3.2 c	AG, AS, CA, FI, FM, FO, GA, LE, LO, RS, RU, SI, TA
Leaf characteristics				
Number of primary lateral leaflet pairs	3.9 a	4.5 b	4.5 b	AG, AS, CA, FM, FO, GA, IN, LE, LO, SI, TA
Number of interjected leaflets	6.4	6.2	6.2	IN, LO
Number of secondary lateral leaflet pairs	0.3	0.3	0.3	
Length of terminal leaflet (cm)	8.5 a	7.4 b	5.8 c	AG, AS, CA, FI, FM, FO, GA, IN, KE, LE, LO, RS, RU, SI, TA, YO
Width of terminal leaflet (cm)	5.5 a	4.8 b	3.8 c	AG, AS, CA, FI, FM, FO, GA, IN, KE, LE, LO, RS, RU, SI, YO
Length of lateral leaflet (cm)	7.7 a	7.1 b	5.4 c	AG, AS, CA, FI, FM, GA, IN, KE, LE, LO, RS, RU, SI, TA, YO
Width of lateral leaflet (cm)	4.6 a	4.2 b	3.2 c	AG, AS, CA, FI, FM, GA, IN, KE, LE, LO, RS, RU, SI, YO
Divergence angle	48.9 a	40.8 b	34.6 c	AS, CA, FI, GA, IN, LE, LO, SI, TA, YO
Floral characteristics				
Length of peduncle (cm)	10.6 a	9.1 b	8.2 b	AS, FM, GA, LE, LO, RS, SI, YO
Number of flowers per inflorescence	14.9 a	18.8 b	19.6 b	AS, GA, IN, KE, LE, SI, YO
Flower size *	2.8 a	2.6 a	2.2 b	AG, AS, LE, SI, YO
Fruit *	0.4 a	0.5 a	0 b	AS, FM, FO, GA, IN, LE, RU, SI, TA, YO

The last column indicates the potato varieties that showed in each morphological characteristic significant differences between the studied seasons ($p < 0.05$). Different letters (a,b,c) indicate significant differences between the mean values. * Mean value of codified characteristics according to Huamán [22]. AG: Agria; AS: Arsenal; CA: Cazona; FI: Fina; FM: Flamenco; FO: Fontane; GA: Ganade; IN: Innovator; KE: Kennebec; LE: Leonardo; LO: Loane; RS: Red Scarlett; RU: Rudolph; SI: Sifra; TA: Taurus; YO: Yona.

Regarding the potato cultivars analyzed, the majority presented significant differences in the mean values between the years analyzed (Table 3). The same number of secondary lateral leaflets in the cultivars was found in each year. The potato varieties with the highest annual variability in morphological characteristics were Arsenal, Ganade, Leonardo, Sifra and Yona (presenting significant differences in more than 70% of the morphological characters studied). Furthermore, these varieties had in common that they were different in the measurements of the terminal and lateral leaflets, in the divergence angle, and in the length of the peduncle and flowers per inflorescence. On the other hand, lower variability was found in the Fontane and Kennebec varieties.

3.3. Relationships between the Meteorological Factors and the Morphological Characteristics

3.3.1. Spearman Rank Correlations

The influence of the main meteorological factors on the morphological characteristics was evaluated by a Spearman rank correlation analysis (Table 4). First, the set of meteorological and morphological data of the three growing crops were considered. The correlation coefficients reflected a strong dependence between these variables. The general characteristics of the plants had significant negative coefficients with the plant height and the flowering degree. At a higher mean temperature, lower plant height and lower degree of flowering were found. The mean and maximum temperatures were negatively correlated with the length of the peduncle of the inflorescences, the size of the corolla and the presence of fruits. The mean and maximum temperatures also had significant negative correlations with the length and width of the terminal leaflet and lateral leaflet, as well as the divergence angle. Conversely, the correlation coefficient was positive and significant between the mean and maximum temperatures and the number of primary lateral leaflet pairs. The mean relative humidity showed significant positive coefficients with the plant height and divergence angle, but it presented a negative coefficient with the number of primary lateral leaflet pairs. Rainfall had a significant negative coefficient with the number of primary lateral leaflets pairs, but the coefficients were positive and significant with the plant height. The degree of flowering, the length and the width of the terminal leaflet, the lateral leaflet, the divergence angle, the length of peduncle, the flower size and the presence of fruits had negative coefficients with rainfall.

Table 4. Spearman correlation coefficients between the meteorological and morphological variables.

	Mean Temperature	Minimum Temperature	Maximum Temperature	Mean Relative Humidity	Accumulated Rainfall
Plant height	−0.536 **	0.332*	−0.536 **	0.332 *	0.536 **
Degree of flowering	−0.423 **	0.148	−0.423 **	0.148	0.423 **
Number of primary lateral leaflet pairs	0.388 **	−0.424 **	0.388 **	−0.424 **	−0.388 **
Number of interjected leaflets	−0.036	−0.006	−0.036	−0.006	0.036
Number of secondary lateral leaflet pairs	−0.015	0.027	−0.015	0.027	0.015
Length of terminal leaflet	−0.743 **	0.227	−0.743 **	0.227	0.743 **
Width of terminal leaflet	−0.731 **	0.266	−0.731 **	0.266	0.731 **
Length of lateral leaflet	−0.823 **	0.232	−0.823 **	0.232	0.823 **
Width of lateral leaflet	−0.752 **	0.216	−0.752 **	0.216	0.752 **
Divergence angle	−0.713 **	0.307 *	−0.713 **	0.307 *	0.713 **
Length of peduncle	−0.317 *	0.178	−0.317 *	0.178	0.317 *
Number of flowers per inflorescence	0.135	−0.169	0.135	−0.169	−0.135
Flower size	−0.443 **	0.190	−0.443 **	0.190	0.443 **
Fruit	−0.385 **	−0.055	−0.385 **	−0.055	0.385 **

** $p < 0.01$; * $p < 0.05$.

Analyzing the hourly temperatures recorded during the day and night, we found that there was an important thermal amplitude, mainly in the 2015 cycle (Figure 3). These thermal differences determined the plant development of the crops, principally the diurnal temperature (Table 5), with significant correlation coefficients higher than −0.700 for the leaf characteristics. In general, high temperatures were negatively correlated ($p < 0.01$) with a lower height plant, lower degree of flowering, lower foliar area and smaller flower size. However, high temperatures were positively correlated with the number of primary lateral leaflet pairs ($p < 0.01$).

Table 5. Spearman correlation coefficients between the temperature (diurnal and nocturnal) and morphological characteristics of potato plants.

	Phase 0		Phase 1	
Temperature	Nocturnal	Diurnal	Nocturnal	Diurnal
Plant height	−0.191	−0.546 **	−0.215	−0.522 **
Degree of flowering	−0.264	−0.432 **	−0.284	−0.412 **
Number of primary lateral leaflet pairs	−0.031	0.383 **	−0.039	0.391 **
Length of terminal leaflet	−0.524 **	−0.731 **	−0.505 **	−0.750 **
Width of terminal leaflet	−0.474 **	−0.718 **	−0.453 **	−0.739 **
Length of lateral leaflet	−0.591 **	−0.819 **	−0.588 **	−0.822 **
Width of lateral leaflet	−0.541 **	−0.742 **	−0.527 **	−0.756 **
Divergence angle	−0.399 **	−0.716 **	−0.410 **	−0.705 **
Length of peduncle	−0.132	−0.322 *	−0.145	−0.309 *
Flower size	−0.247	−0.446 **	−0.257	−0.436 **
Fruit	−0.451 **	−0.372 **	−0.427 **	−0.396 **

** $p < 0.01$; * $p < 0.05$.

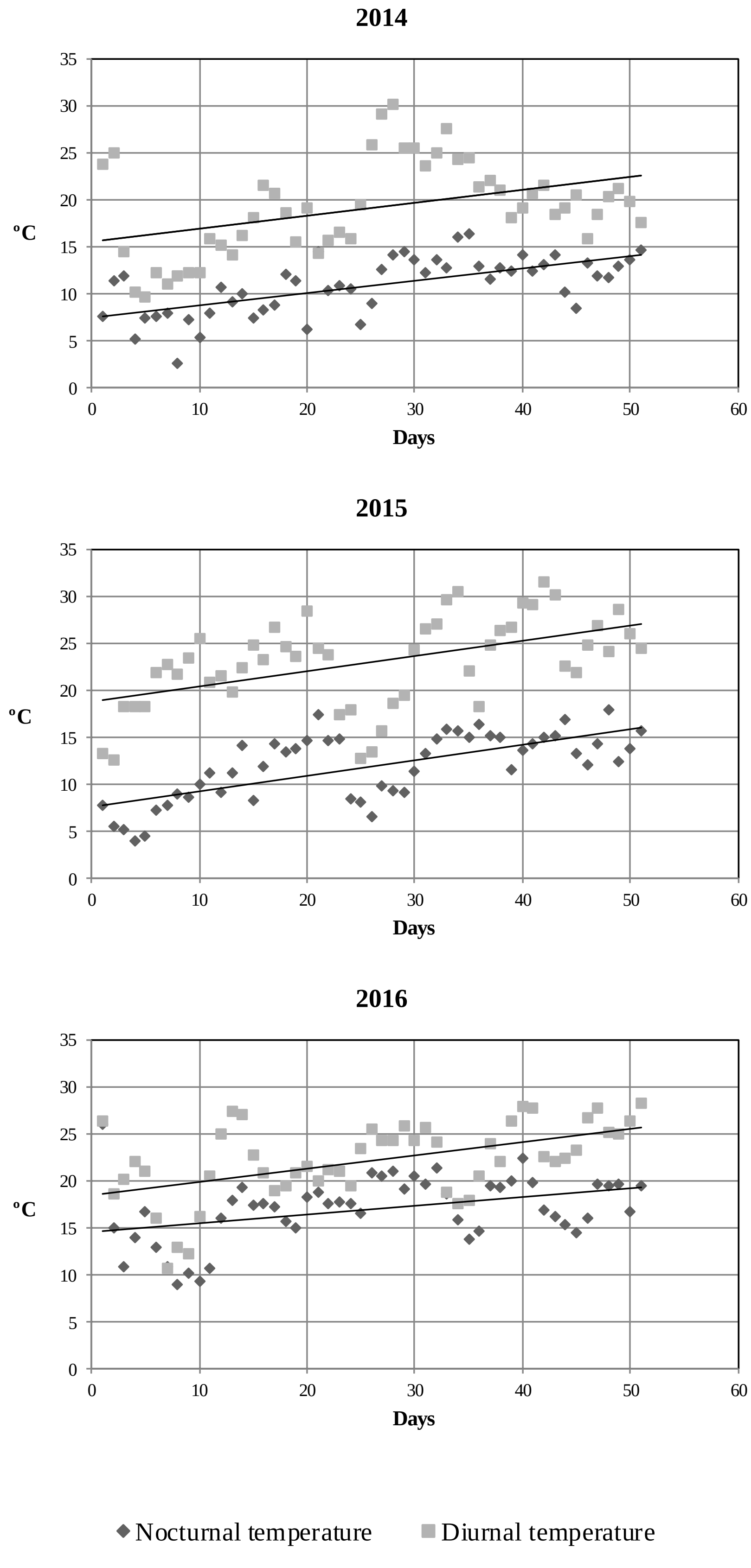


Figure 3. Oscillation of the diurnal and nocturnal temperatures during potato cultivation.

3.3.2. Principal Component Analysis

Principal component analysis was used to reduce the dimensionality and to explain the variance–covariance structure of the data. A total of five components were extracted, explaining 80.05% of the variance of the data. The first two components explained 52.15% (Table 6). The mean and maximum temperature, rain and most of the foliar characteristics had a greater influence on the data set, since they presented the coefficients of the highest weights in the first component (<0.30).

Table 6. Results of extracted components and scores of the coefficient variables performed by principal component analysis.

	Number of components				
	1	2	3	4	5
Eigenvalue	7.12	2.79	2.28	1.70	1.32
Variance (%)	37.49	14.66	11.99	8.94	6.96
Cumulative variance (%)	37.49	52.15	64.15	73.09	80.05
	Component weights				
	1	**2**	**3**	**4**	**5**
Minimum temperature	0.03	0.31	0.54	−0.10	0.06
Mean temperature	−0.36	0.04	−0.03	−0.13	0.03
Maximum temperature	−0.35	0.00	−0.10	−0.11	0.02
Mean relative humidity	0.04	0.31	0.54	−0.10	0.06
Rainfall	0.35	0.04	0.18	0.10	−0.01
Height plant	0.21	−0.10	0.21	−0.17	0.03
Degree of flowering	0.15	−0.36	0.20	−0.15	−0.22
Primary lateral leaflet pairs	−0.18	-0.25	−0.06	0.16	0.38
Number of interjected leaflets	−0.01	−0.16	0.21	0.55	−0.25
Secondary lateral leaflet pairs	−0.05	−0.11	0.15	0.54	0.38
Length of terminal leaflet	0.30	0.07	−0.19	−0.16	0.10
Width of terminal leaflet	0.31	0.11	−0.18	−0.02	0.03
Length of lateral leaflet	0.34	−0.02	−0.19	−0.05	0.05
Width of lateral leaflet	0.31	0.05	−0.19	0.15	−0.09
Divergence angle	0.25	0.15	0.01	0.32	0.24
Length of peduncle	0.16	−0.40	0.20	−0.28	0.10
Flowers per inflorescence	−0.07	−0.46	0.18	−0.12	0.21
Flower size	0.16	−0.14	−0.05	−0.14	0.54
Fruits	0.12	−0.37	0.04	0.13	−0.41

A graphical representation of the first two components is shown in Figure 4. The potato cultivars of 2014 were located in a quadrant consisting of the size of the leaflets, the angle of divergence between the leaf and the stem and the plant height, showing a close relationship between these variables. These potato varieties were produced during the coldest year and the one with the greatest accumulated rainfall. The potato samples grown in the warmest crop cycle (2016) were located on the opposite side. The number of primary leaflets was also highly related to the mean and maximum temperatures. Therefore, the 2014 cycle registered the lowest temperatures and accumulated more days of rainfall, favoring the size of the leaflets. On the contrary, the 2016 cycle registered the highest temperatures and less rain in the first stages of the phenological development, favoring a greater number of inflorescences and a greater number of primary leaflets.

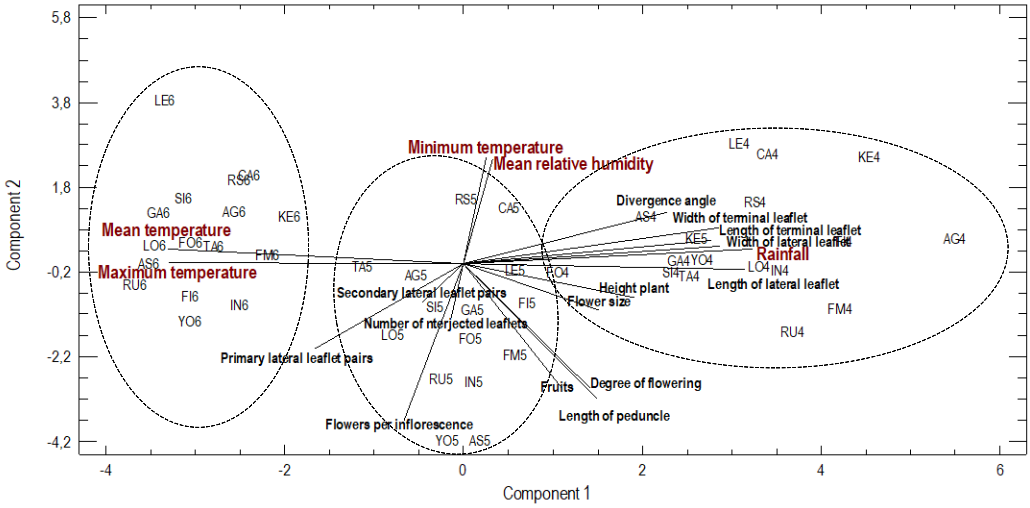


Figure 4. Principal component score plot based on the morphological variables of potato samples according to the crop year (2014: 4; 2015: 5; 2016: 6). AG: Agria; AS: Arsenal; CA: Cazona; FI: Fina; FM: Flamenco; FO: Fontane; GA: Ganade; IN: Innovator; KE: Kennebec; LE: Leonardo; LO: Loane; RS: Red Scarlett; RU: Rudolph; SI: Sifra; TA: Taurus; YO: Yona.

3.3.3. Linear Regression Analysis

The high correlation coefficients between the meteorological and morphological variables allowed for the estimation of the leaf size, although linear regression analysis obtained satisfactory results ($R = 0.80$; $F = 81.91$; $p < 0.001$). The best model, with $R^2 = 0.64$, included the mean temperature of phase 1, confirming the influence of the temperature during leaf development (Equation: Leaf size = 108.05 − 4.47 Mean temperature of phase 1).

4. Discussion

Potato cultivars are classified mainly by the physicochemical properties of the tubers [28–31], but the morphological characteristics of plants constitute the initial recognizable state of the variety grown in specific areas [24]. The influence of agronomic practices and the location of crop fields are conditioned by the climatic factors of the area. Current knowledge on the morphological characteristics of the plants provides information about their behavior in response to stress conditions, indicating that they may suffer during their development. Several factors limit potato plant growth, tuberization and tuber bulking [26]. A high temperature, drought, and nutrient stress adversely affect these factors [2,13,15]. It is important to take into account the growth stage, duration and intensity of each mentioned factor [14,26,32] which affects the tuber yield and quality [26].

A Limia has an oceanic climate with a continental tendency. The mild temperature and mean rainfall recorded in winter represent the oceanic features, while the drought periods, accompanied by a great thermal amplitude in summer correspond to the continental features of the area. In the last decade, the annual average temperature in the A Limia region (based on an analysis of data obtained from various meteorological stations in the area) has increased by approximately 1.6 °C [33,34]. This progressive increase in temperature could affects the development of potato crops. Multivariate statistical analyses explained the strong relation of the meteorological factors, mainly the temperature, with the morphological characteristics of potato plants cultivated in A Limia. The crop cycle of 2016 was the warmest, and plants had a higher number of leaflets, although they were shorter. Conversely, the coldest and rainiest crop cycle was 2014, and in this year, the plants were the highest and presented the highest degree of flowering, fewer pairs of leaflets and the highest peduncle length. Some researchers have found the effect of temperature on leaf development. At higher temperatures, potato plants had more leaves and leaflets, but their size was smaller, and consequently, the leaf area was reduced [18,35]. With the mean temperature of the three crop cycles, it was possible to estimate the leaf size of plants using a linear regression that explained 64% of the variability of the data. These results agree with the relationships found between the mean temperature and the leaf size of multiple species analyzed in other parts of the world [36]. At the driest sites, the leaf size weakly decreased, whereas across wetter sites, the leaf size increased. Undoubtedly, more years of sampling are necessary to improve the estimation of these morphological variables, as a consequence of the strong dependence on the climatic factors.

The decrease in the size of the terminal and lateral leaflets, accompanied by a higher number of lateral leaflets of plants cultivated in 2016, could be a consequence of a plant strategy to resist higher environmental temperatures and avoid dehydration, achieving the same photosynthetic efficiency. On the other hand, the number of inflorescences and the number of flowers per inflorescence depends on the temperature, photoperiod, plant density and fertilization (principally the nitrogen inputs) [24]. Some studies showed that flowering is more abundant when tuber formation is delayed, which occurs at higher temperatures in comparison with lower temperatures [18,35]. The results of this study likewise show that higher temperatures increase the number of flowers per inflorescence and reduce the length of the peduncle in potato plants.

Some researchers reported that warmer nights during potato flowering, the development of fruit and the mid-stage of tuber formation (with a minimum temperature higher than 10 °C) negatively influenced the potato tuber yield [5,17,25]. Global climate change in the form of extreme heat and drought poses a major challenge to sustainable crop production by negatively affecting plant performance and crop yield [26]. In conclusion, temperature is one of the most recognized climatic factors affecting agriculture, and it plays a decisive role in all aspects of morphological development and potato plant growth, especially during flowering.

The development of new cultivars with higher thermal time requirements and the implementation of sowing date changes for crops of rice and wheat [37–40]. However, there are few studies that have explained the influence of weather on the different types of potato cultivars and, more specifically, on their morphological characteristics. One of the first adaptations is the use of varieties more adapted to water scarcity [41]. Some researchers found that cultivars such as Krostar and Désirée reduced the number of green leaves and their length (by more than 20%) in moderate drought episodes during the season, but they responded similarly to water shortage in tuber yield and tuber number [42]. In the future, production in rainfed areas is likely to shift toward searching for cultivars that are able to survive early drought periods. This is the case of potato cultivars, such as Cara, King Edward, Markies, Russet Burbank and Rooster [41]. The Fontane and Kennebec cultivars analyzed in this study were less variable among the three seasons. Kennebec is the most cultivated variety in the northwest of Spain because it is the unique variety protected by the European Union, with the quality seal, *Protected Geographical Indication Patata* of Galicia. In the case of Fontane, it is a cultivar similar to Kennebec in terms of its general growth characteristics (growth habit, height and maturation) and foliar characteristics [24]. The planting of this variety is not common in the Galician territory. However, it could be an interesting option for the potato industry due to the interesting culinary qualities that it presents, such as potato chips. Therefore, the monitoring of the morphological characteristics of new potato varieties in areas where their crops are not habitual could be useful for actualizing their agronomic potential under the specific climatic conditions of the territory. At the same time, this study provides complementary information on the possible adaptation of potato cultivars in changing climate scenarios.

5. Conclusions

The effect of meteorological factors on the morphological characteristics of potato plants during the studied period in A Limia was evident. The height of the plant, the size of the terminal and lateral leaflets, the number of lateral leaflets and the degree of flowering were the parameters with the highest variation. Most of the potato cultivars showed variability in their morphological characteristics in function to the season, being Fontane and Kennebec, more commonly cultivated in the area, the most homogenous.

Statistical treatment showed the strong influence of the temperature on some foliar characteristics. Concretely, was possible to estimate the leaf size as dependent on the daily mean temperature of the period by linear regression. The monitoring of the morphological characteristics of new potato varieties in areas where their crops are not habitual could be useful for actualizing their agronomic potential under the specific climatic conditions of the territory. At the same time, this study provides complementary information on the possible adaptation of potato cultivars in changing climate scenarios.

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